ARMY RESEARCH LABORATORY

Underlying Technologies for Military Logistics Prediction and Preemption Capability

by Romeo D. del Rosario, Kwok F. Tom, Gregory Mitchell,
Brian G. Ruth, Peter J. Grazaitis, Tom Ferryman, David E. Scharett, and
Charles J. Toomey, Jr.

ARL-SR-0166 February 2009

Approved for public release distribution unlimited.

NOTICES

Disclaimers

Army Research Laboratory
Adelphi, MD 20783-1197

ARL-SR-0166 **February 2009**

Underlying Technologies for Military Logistics Prediction and Preemption Capability

Romeo D. del Rosario, Kwok F. Tom, Gregory Mitchell,
Brian G. Ruth, and Peter J. Grazaitis
Sensors and Electron Devices Directorate, ARL

Tom Ferryman, David E. Scharett, and Charles J. Toomey, Jr.
Pacific Northwest National Laboratory

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)* February 2009	**2. REPORT TYPE**	**3. DATES COVERED (From - To)**

4. TITLE AND SUBTITLE Underlying Technologies for Military Logistics Prediction and Preemption Capability	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Romeo D. del Rosario, Kwok F. Tom, Gregory Mitchell, Brian G. Ruth, Peter J. Grazaitis, Tom Ferryman, David E. Scharett, and Charles J. Toomey, Jr.	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: AMSRD-ARL-SE-RE 2800 Powder Mill Road Adelphi, MD 20783-1197	**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-SR-0166
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report captures the results of a comprehensive assessment of technical requirements associated with achieving a logistics predictive and preemptive capability, or LPPC. It represents Phase II in a three-phased approach spanning operationally- and technically-focused assessment. Phase I, conducted from September to December 2006, documented the compelling case for predictive capabilities, tying it to guidance and concept development at the OSD, Joint, and Army levels. Phase II, the subject of this report, has as its objective the forecasting of technologies expected to be available through the year 2030 and their potential to provide predictive planning and analysis capabilities. The Phase II report thus becomes the catalyst for, and enabler of, Phase III – an assessment of the potential operational and resource benefits of predictive and preemptive capabilities, to include the development of actionable recommendations to senior logistics leaders on the steps necessary to achieve the envisioned end-state.

15. SUBJECT TERMS

Prediction preemption technology collection fusion exploitation

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	UU	430	Gregory Mitchell
U	U	U			**19b. TELEPHONE NUMBER** *(Include area code)* 301-394-2322

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

List of Tables

Foreword

R. del Rosario

Although this paper and the technologies and concepts contained therein are broken into four distinct sections, the most important facet to keep in mind is that the advent of new, enabling technologies makes them closely related in a much more quantifiable way than has been so in the past. The engineering and scientific constraints that the prediction and preemption technical community work within to develop new technologies will be a function of all of these areas with the overarching functions being cost and speed of deployment.

Assumptions

The Phase II white paper makes use of the assumptions for the Army's baseline capabilities in the year 2020 as illustrated in the Logistics Prediction and Preemption Experiment Phase I-Overview[1] with some minor qualifications (italicized below).

"…This experiment forecasts the technology required to achieve the capabilities envisioned for the logistics prediction and preemption end-state…[and assumes] the attainment of the 2020 baseline capabilities described below. [The project] will assess the risk, cost-benefit and feasibility of the capabilities, processes and concepts that the envisioned technologies would enable as they are inserted in the logistics enterprise throughout the decade up to its close in 2030."

1. The Army will retain its global presence responding to regional actions, urban unrest, and nation building primarily as a component of a Joint Force.
2. The Army will continue development of a single, integrated logistics enterprise that is fed by automated data from a variety of platform and non-platform sources to provide the ability to see, assess, decide, and deliver support to the force.
3. The DOD will continue to implement and will have a fully functional common operating picture connected to the Global Information Grid (GIG) providing for a net-centric capability.
4. The Army will fully implement assured communications allowing for near real-time situational awareness.
5. The Army will continue to investigate, support, develop, acquire, and invest *in cognizance* of information technology. The Global Technology revolution will accelerate providing advanced technology to all levels of the Army.

6. The Army will have on-board prognostics on all major systems, but not on every system, such as generators. Systems with prognostics will provide on-board sensor data directly into the network.

7. There will be a *small number* of net-centric operational, intelligence, logistics and administrative system connecting all domains.

8. Total asset visibility (TAV) and in-transit visibility (ITV) for mission needs will provide for timely and accurate information on the location, movement, status, and identity of units, personnel, equipment, supplies, medical support, host nation support, and cross-service availability.

9. There will be autonomous sensor and sentinel capabilities.

10. Computer capabilities and storage media will rapidly increase to the extent that Soldiers will possess lightweight, miniature, networked computers capable of full service computing with high speed, reliable transmissions. Transmission of data will easily flow across airborne up-link sources offering both secure and unsecured nodes.

11. The Army modular force transformation will be complete, but the force will remain a hybrid mix of Heavy, Stryker, and Future Combat System (FCS) equipped units.

12. The Army will field an operational logistics command and control (C2) capability that is joint interoperable and unifies logistics C2 across the Joint operations area (JOA).

13. Advances in RFID devices will be such that unmanned aircraft systems (UAS) and other platforms will be able to sense the data *either directly or indirectly* and support real-time global accounting of logistics assets.

14. The development of telepresence enablers will significantly advance in the use of sensors, communications, remote actions, and granularity resulting in the ability of logistics personnel to remotely project their presence via devices deployed to remote sites around the world.

15. There will be *substantially higher energy-density sources available for multiple levels of platform or component use. These sources will comprise a tradespace capable of being optimized* to support the massive computing requirements for data gathering, transmission, fusion, analysis, and exploitation.

The LPPC has its foundation in collecting data, information, and knowledge from disparate sources. Frequently, these reside in disparate formats not only in hard copy but electronically as well. In order to ensure that all echelons of command within the Logistics Enterprise are using common information, these disparities need to be overcome by converting them to standardized formats and languages that are compatible with the analytical Fusion & Analysis tools at all echelons. These analytical tools will extract echelon appropriate knowledge but using the same information across levels (figure 1). Several aspects of this commonality, particularly with regard to metadata, are being pursued within the USALIA Common Logistics Operating Environment (CLOE) and Army Integrated Logistics Architecture (AILA) efforts.

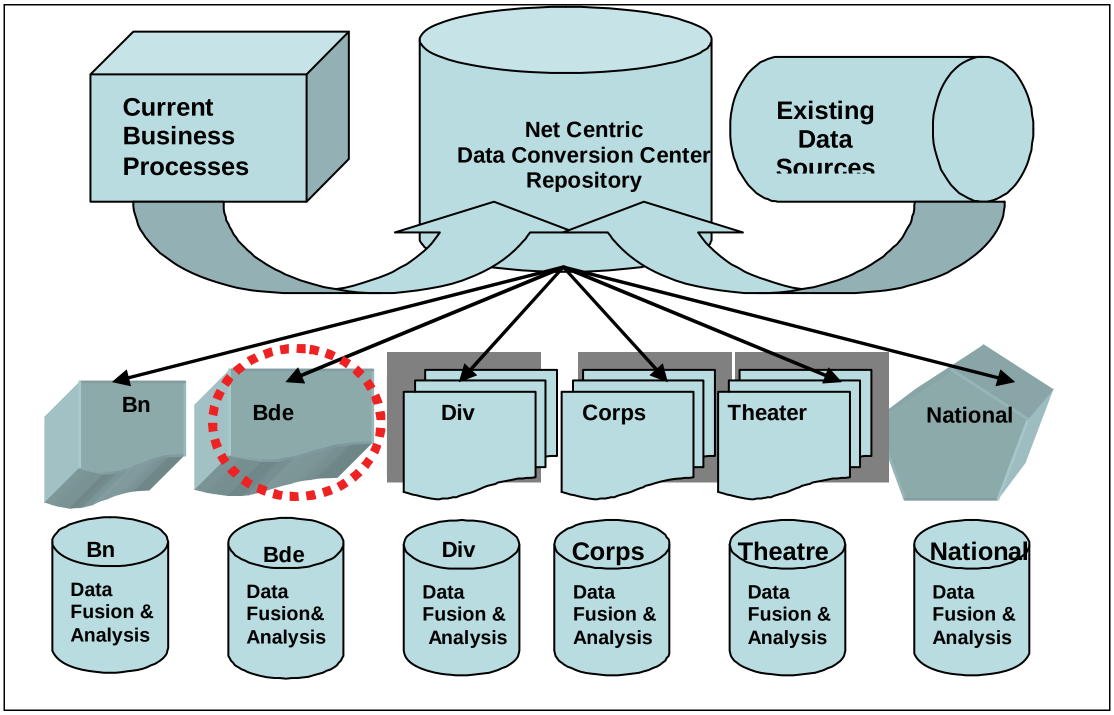


Figure 1. Net-Centric Data Conversion Center, compensates for disparate Existing Data Sources' language.[1] By the 2020 timeframe, information compatibility problems will be substantially reduced, due in large part to the evolution to XML type extensibility. Our current advancement efforts will enable fusion and analysis to take place in this distributed manner, increasing effectiveness and efficiency.

As described in figure 1, it is important to note that each echelon, from battalion and brigade through the national level, has very different responsibilities and tasks. The analytical tools[2], while common across the force, will present different functionality at the various echelons. (With regards to filtering, battalion (Bn)/brigade (bde) level will not have the same processing capability as the national level). Likewise, in an ideal LPPC, each echelon has its own read-write permissions. The brigade can input changes to the LPPC that affect the brigade, but those informational changes cannot be entered at the National level. Likewise, the brigade can see the national level data if it chooses to and/or it is a portion of the mission planning required by a brigade.

[1]Adaptive Logistics, Effects-Based Approach to Logistics (EBAL), Conditioned-Based Maintenance (CBM)+ connections.
[2]From here on referred to as decision support tools.

How to use this book:

The Phase II white paper consists of an introductory chapter and four specific chapters 2 through 5 dealing with Data Collection, Data Transmission, Fusion & Analysis, and Exploitation & Assessment. Chapter 1 serves as an overview as well as a technical summary of the most promising technologies within their respective area ("best in class"). The conclusion and associated graphics in each chapter will articulate three characteristics:

- Probability of Maturation – i.e., reciprocal of technical risk
- Cost of Development
- Benefit to Logistics Prediction and Preemption Capability

Chapter 6 revisits the overall set of technologies with a specific focus on the subset that has the most cross-cutting potential. It highlights those technologies that affect more than just one of the four aspects of LPPC. Each of the technical chapters starts with an overview leading into a technical primer and subsequently to the future technologies of interest.

Who it's for

In taking the above approach, this document aims to provide actionable technical advice to the Prediction Project Phase III team and to forecast advances in pertinent technology areas for senior-level decision makers with a vested interest in advancing logistics capabilities. While not explicitly noted, the undercurrent of merging C2 and logistics space in a virtual sense, as well as the underpinning technologies of both, make the subject matter and content appropriate for those outside the logistics community.

Executive Summary

This report captures the results of a comprehensive assessment of technical requirements associated with achieving a logistics predictive and preemptive capability, or LPPC. It represents Phase II in a three-phased approach spanning operationally- and technically-focused assessment.[1,2,3] Phase I, conducted from September to December 2006, documented the compelling case for predictive capabilities, tying it to guidance and concept development at the OSD, Joint, and Army levels. Phase II, the subject of this report, has as its objective the forecasting of technologies expected to be available through the year 2030 and their potential to provide predictive planning and analysis capabilities. The Phase II report thus becomes the catalyst for, and enabler of, Phase III – an assessment of the potential operational and resource benefits of predictive and preemptive capabilities, to include the development of actionable recommendations to senior logistics leaders on the steps necessary to achieve the envisioned end-state.

Organization of this report

The foundation for achieving predictive and preemptive logistics capabilities rests upon collecting data, information, and knowledge from disparate sources. Thus, four pivotal "building blocks" are required, and it is around these building blocks that the report is structured.

- *Data Collection*, the means by which raw facts are gathered for transmission, interpretation, fusion, processing, exploitation, and assessment;
- *Data Transmission*, the transfer of raw facts between functional elements over or through a medium according to a protocol;
- *Data Fusion & Analysis*, the combination of raw facts gathered from multiple sources. Once the data are fused, they must be analyzed using qualitative and quantitative measures to yield actionable knowledge; and,
- *Exploitation & Assessment*, the implementation of knowledge-generated courses of action to preempt the adverse effects of situations that would otherwise occur without predictive and preemptive intervention.

Chapter 2, *Data Collection*, focuses on the aspects at the initial ("front end") collection level for data, information, and knowledge. Based upon current development paths, there are four major attributes that will enable advanced data collection: automation, intelligence, embedding, and affordability. To achieve actionable knowledge entails the substantial leveraging of these attributes as they pertain to the base technologies for data collection: microelectronics, nanoelectronics (sensors), and ultra small form factor power supplies. The chapter details the current and future states of data collection and offers insights for the development of a highly integrated and advanced data collection system that could provide real-time data collection capabilities.

Chapter 3, *Data Transmission*, describes and evaluates current and future technologies that will lend themselves to the goal of rapid, secure, and accurate disbursement of information. Data transmission is unique because it is not a 'node' in the prediction and preemptive chain such as data collection, fusion & analysis, and exploitation & assessment. Instead, data transmission provides the necessary link to facilitate the progression from one stage in the prediction and preemptive process to another. The current and future states of data transmission are discussed, and the role of communication technologies as the essential element throughout the entire logistics enterprise and linkage to the LPPC is reviewed.

Chapter 4, *Data Fusion & Analysis*, presents a comprehensive review of the data fusion process. As described, data fusion is an information process that first samples data and information from single and multiple sources, then associates, correlates, and combines these data to estimate the identities and locations of all sensed entities. Once all perceived entities are identified and located, one highly desirable output that the fusion process produces could be a comprehensive Course of Action presentation. This process of data fusion is a natural extension of human cognition.

Chapter 5, *Exploitation & Assessment*, concentrates on the exploitation of prediction and forecasting technologies and the assessment of their relevance to military success. An LPPC will enable decision makers to assess the impact of future conditions, thereby allowing military commanders to make operational decisions knowing the risks associated with those decisions. The author assesses methodologies and advanced technologies required to develop an enterprise-class prediction and preemption capability. In doing so, he illustrates the complexity of synchronizing all of the prediction and preemption processes.

Chapter 6, *Integrating Cross-Cutting Technologies*, emphasizes the importance of examining technologies for LPPC from a holistic, integrated, and synergistic perspective.

Methodology

The process used to conduct this technical assessment centered on the evaluation of specific technologies that support each of the "building blocks" identified above. Technologies were examined, in both a quantitative and qualitative construct, from three perspectives:

- *Probability for maturation within the 2020-2030 timeframe*. Technological maturity is defined as being ready for introduction to the commercial marketplace.
- *Cost* to proliferate the technology to the number of users needed to enable a logistics end-to-end enterprise predictive and preemptive capability. The cost assessment entailed both development (e.g., further maturation of the technology to make it manufacturable) and reproduction, or the cost of actually manufacturing the technology.

- *Benefit* to predictive and preemptive logistics capability.

Findings

General:

- A logistics predict and preempt capability will require exponential increases in data collection and processing capabilities.
- Communications requirements to support envisioned future warfare will increase markedly. This increase will be manifested in the amount of data collected, stored, and transmitted, as well as the level of electronic processing required.
- Technology alone will not drive a comprehensive prediction and preemption capability. It must be supported by the requisite infrastructure improvements such as network transport and services capabilities.
- Data collection technologies will be most easily leveraged from the commercial sector. Fusion & analysis and exploitation & assessment capabilities will require moderate to high levels of investment.
- The most significant investments required for an LPPC capability will be needed in the fusion & analysis and exploitation & assessment areas; research and development activities in both areas are limited at present.
- Commercial sector, university, Department of Energy, and other Department of Defense laboratory research and development can be leveraged to achieve an LPPC capability. The most promising areas for such leveraging include: advanced computing, micro-electricalmechanical systems, nanoscience and nanomaterials, alternative energy sources (e.g., photovoltaics, advanced batteries, fuel cells, etc.). Partnerships, cooperative research and development activities, interagency agreements, and interagency technology transfer agreements may need to be established and exploited.

Specific:

- <u>Technology assessment</u>
  - *Data Collection.* Sensor technology, specifically solid state memory micro-electrical mechanical systems and nanotechnology, multi-core processors, and transducer electronic data sheets are key to the success of the LPPC. They provide not only capabilities to the complex data collectors, but also to the processing power that will be needed to fuse and analyze the data.
  - *Data Transmission.* Hybrid networks, free space optical communications, and multi-platform common data links have the potential for the greatest impact on an LPPC capability.

- *Data Fusion & Analysis*. Distributed blackboard fusion architecture enabling intelligent and adaptive sensor web and social network analysis, simulation-based COA analysis, simulation-based reflexive analysis, and Cyc-based virtual logistician technologies are key contributors to the essential data fusion and analysis elements of an LPPC.

- *Exploitation & Assessment*. Service-oriented architectures, web services, geospatial analysis, software agents, and business process integration will play critical roles in obtaining maximum use and benefit for any future information technology system.

- *Cross-cutting and integrating technologies*. Cross-cutting and integrating technologies will be crucial. A future logistics C2 strategy must be centered upon achieving a life-cycle driven end-to-end logistics enterprise that supports the application of integrated capabilities across the full spectrum of military operations. The most promising include:

  - Multi-core processors, which will present orders of magnitude improvements.

  - Memory (pre-positioned) which represents the most ubiquitous technology today, and which will grow as applications mature.

  - Transducer electronic data sheets are critical in enabling the intelligent sensor webs, which are critical to data fusion technologies.

  - Multi-platform common data links able to support an operationally mobile force and characterized by real-time information transfer.

  - Intelligent/autonomous sensor webs that fuse data in a decentralized manner and are capable of sensing, recognizing, and then reporting acquired entities and objects.

  - Business process integration, a logical first step that enables optimum placement of innovative and novel solutions that comprise the LPPC.

- <u>Cost</u>

  - Data collection technologies stand to leverage the most from the commercial sector. Any investment by the Army would focus primarily on maintaining technical cognizance and influencing the development of technical standards to facilitate insertion of the technologies into Army systems.

  - Data transmission will be an essential area for the LPPC's integration with the operational and intelligence domains. Group development would be most visible in the multi-platform common data link.

  - The underlying mathematics requirements associated with fusion & analysis and exploitation & assessment represent a significant challenge.

Recommendations

The following recommendations are suggested as follow-on actions that leverage the findings presented in this report.

1. *Determine what needs to be predicted and preempted.* This will require a methodology through which end-to-end logistics processes are decomposed and mapped to specific logistics tasks executed at the strategic, operational, and tactical levels.
2. *Assess the 'predict and preempt' capability from the perspective of an enterprise-wide service oriented architecture*. The focus would be on web technologies and business process integration. Key would be the relationships and task decomposition between nodes, activities, and information exchange requirements.
3. *Identify and assess the predictive analytics* associated with the business processes and operational and systems architectural views of those processes. This analysis would serve as a foundation for integration of LPPC technologies, facilitation of mission thread analysis, and refinement of requirements for subsequent DOTMLPF analysis.
4. *Conduct follow-on technology assessment*. Determine if existing technologies in the commercial sector and emerging technologies in the Army S&T community contribute to the development, testing, and validation of predictive analytics.
5. *Properly scope any predict and preempt demonstration.*
6. *Continue to engage the S&T community*. LIA staff that support the development of predict and preempt capabilities should continue to engage the OSD, Army, other services, Department of Energy, and commercial sector S&T communities.
7. *Conduct recurring evaluations on the state of technology advancement*. There are two simple explanations for this. First, the pace of technological change in those areas that have the potential for predict and preempt will only continue to increase. Second, as the Army implements and fields improved logistics capabilities across DOTMLPF made possible through execution of JCIDS and development of capabilities integration maps, new insights will be gained and new capability requirements for logistics will be validated, thus making for a continuous cycle of concept and solutions development, experimentation, and capability fielding.

---

[1]G. Dolinish, W. Koenig, LIA, T. Ferryman, R. McKay, J. Stevenson, Logistics Prediction and Preemption Experiment: Phase I – Overview, U.S. Army Logistics Innovation Agency, 18 December 2006.
[2]T. Ferryman, "Essential Elements of Prediction," <additional publication info>2006.
[3]IBM Corporation. U.S. Army Logistics Transformation 2032. Contract Deliverable. 11 Mar 05.

INTENTIONALLY LEFT BLANK.

Chapter 1. Technology Advances that Will Change the Face of Logistics

R. del Rosario, C. Toomey, D. Scharett

"You will not find it difficult to prove that battles, campaigns, and even wars have been won or lost primarily because of logistics."

- General Dwight D. Eisenhower

1.1 Introduction

In order to achieve a predict-and-preempt capability for the logistics enterprise, a series of fundamental issues and principles must be recognized and addressed. The very foundation for combat operations—whether they are local, regional, or global—is a logistics capability. This has been a fundamental principle throughout history. Long considered a materiel advance, the Welsh longbow fundamentally changed the nature of western warfare by yielding a distinct range advantage to English archers. Increases in manufacturing and training led to ranges of up to 275 meters with skilled archers capable of firing as many as 20 shots per minute. However, the "cloud of arrows" produced by thousands of archers at the Battle of Agincourt during the Hundred Years War was quietly enabled by the addition to the force of young men tasked solely with the job of re-supplying the volleys[4] of the medieval "machine gun."

Two of the greatest defeats in military history resulted from Russia's use of its expansive geography to exhaust the logistical capabilities of its enemies to the breaking point. Both Napoleon's forces during the War of 1812 (Figure 1.1) as well as the Third Reich's Sixth Army in World War II suffered from over-extended lines of communication in their marches to Moscow. Ammunition, food, and fuel were depleted and the long Russian winter, exacerbated by "General Mud" in the spring, reduced the enemy's ability to resupply combat forces and lowered their resistance to fight the advances of the Russian Uranus Operation forces. A more cohesive relationship between intelligence, operations, and logistics with respect to data/information sharing early in the formulation of combat operations could have enabled prediction of adequate combat materials to conduct sustained combat operations in adverse weather conditions over extended distances.

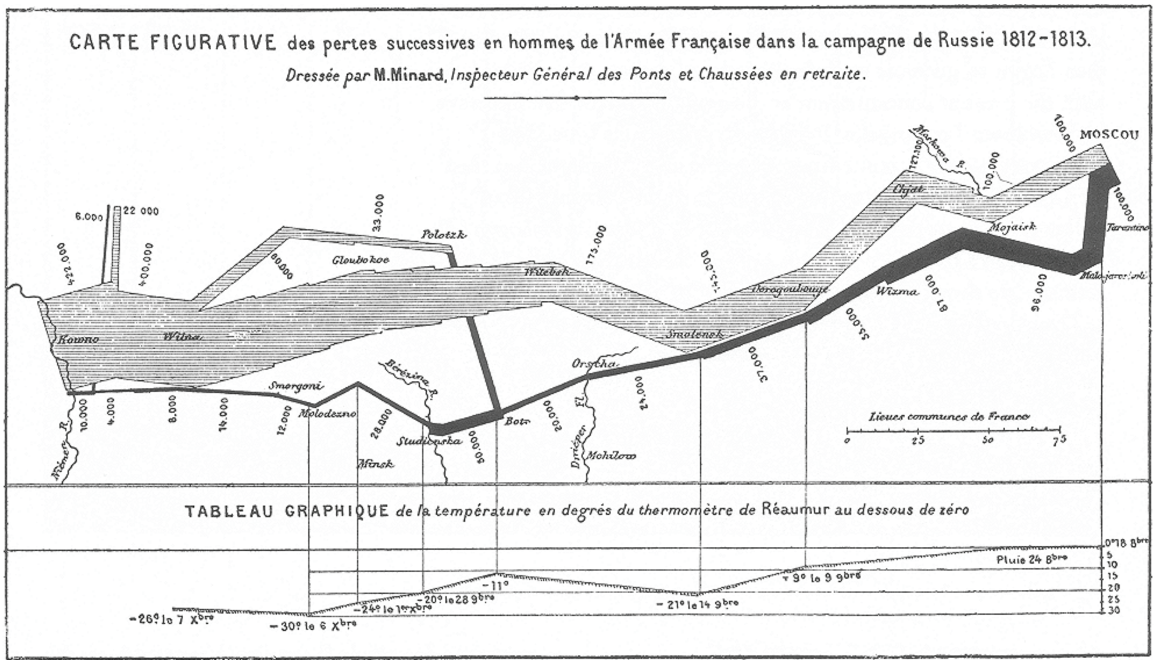


Figure 1.1. An early version of data fusion (albeit post facto for Napoleon). Logistical data and its impact upon military capability are shown in Minard's map of Napoleon's attempted invasion of Moscow. The approach is represented by the thick light gray line, the retreat by the black line, with temperature charted at the bottom. Widths of the gray and black lines correspond directly to the number of French troops remaining.

Timely data collection, fusion, and analysis of intelligence, operations, and logistics information are fundamental to successful combat operations. The Army has historically spent undisclosed amounts of funding in research, development, and fielding of data collection, fusion, and analysis in support of intelligence data gathering. It has similarly supported the operations community. However, even within the past decade it would be difficult to find any similar commitment to logistics – the foundation for sustained combat operations.

To provide the capacity for sustained combat operations, the logistics operations cycle must be conducted within the decision cycles of both the enemy and the U.S. combatant commander. Consequently, logisticians require essential information from intelligence and operations early and often during the planning and execution of sustainment for ongoing and future combat missions. This will contribute significantly in ensuring the successful and favorable outcomes of combat missions. Logisticians not only need to know the current status and location of combat and support equipment, they also need to know the location, quantities, and status of all classes of supply:

- Availability of transportation assets
- Location and ability to deliver supplies within the schedule of current and future combat operations

- Communications status, to affect dynamic redirection of shipments and cross-leveling of unit assets
- Nature, location, and predicted actions of enemy forces with regard to convoy or aerial delivery
- Current and forecasted weather conditions

In short we would desire visibility *and accessibility* of all in-theater stocks and all shipments en route in order to enable redirecting of mission essential commodities which emulate the dynamics of the modern operating environment and will favorably affect the outcome of ongoing missions.

The logistics end-to-end (E2E) enterprise[3] will require exponential increases in data collection and processing capabilities. Likewise, 24/7 communication requirements within and to all other components of a Joint or Coalition Force will increase markedly in order to provide a logistics capability to predict and preempt. These substantial increases will be manifest in the amount of data collected, stored and transmitted as well as the level of electronic processing required. Knowledge critical to ensuring successful sustained combat operations are currently contained in databases that cannot communicate with one another or with logistics systems. Similarly absent is the information regarding the current and future health status of deployed/employed combat and combat support equipment due to such things as lack of embedded platform prognostics (embedded sensors and requisite data fusion). While there is much written about asset visibility, the Army's current capability to dynamically track and redirect assets is limited at best.[4]

Designing a future force that contains combat equipment capable of traversing off-road conditions at two to four times the rate of combat service support equipment sub-optimizes the overall combat capability of the force and places the force at increased risk on the battlefield. This further emphasizes the need for intelligence, operations, and logistics collaboration early and often, thereby enabling the logisticians to take preemptive actions to minimize risks to the force and ensure successful combat missions.

1.2 Definitions

Prior to delving into more technical detail on the technologies that will shape the future logistics prediction and preemption capability (LPPC), it is important that we articulate the definitions we will use in this set of papers for the underpinning technology categories.

Data Collection: The means by which raw facts are gathered for transmission, interpretation, fusion, processing, exploitation and/or assessment.

[3]All of the inter-related business practices that comprise that enterprise

[4]Current thrusts such as ITV (In-transit Visibility) will help remediate this challenge

Data Transmission/Flow/Distribution/Exchange: The transfer of raw facts between functional elements over or through a medium according to a protocol.

Data Fusion and Analysis: The combination of raw facts gathered from multiple sources. Once the data are fused, they need to be analyzed using qualitative and quantitative measures to yield actionable knowledge. The resulting actionable knowledge is used to develop potential courses of action (COAs). Realistic quantified uncertainties must be provided.

Exploitation and Assessment: The implementation of knowledge-generated COAs to preempt the adverse effects of situations that would otherwise occur without predictive preemption intervention. As decisions are implemented and COAs are applied to missions and tasks supporting sustained combat operations, the assessment process identifies events that occurred but were not predicted, adverse affects that were preempted due to predictive preemption intervention, and COA successes and failures.

These definitions are placed graphically over time in a representative logistics prediction and preemption capability illustrative combat mission in Figure 1.2. Here the LPPC is illustrated within the context of a single mission where 24 hours are available before the start of the mission. N represents the current time along the horizontal axis. The mission needs and logistics status are entailed by the data inputs to be collected, transmitted to appropriate nodes, and fused & analyzed to determine optimum COAs. For $N+24$, the COAs are then in the process of being executed (exploited) with assessment occurring post mission.

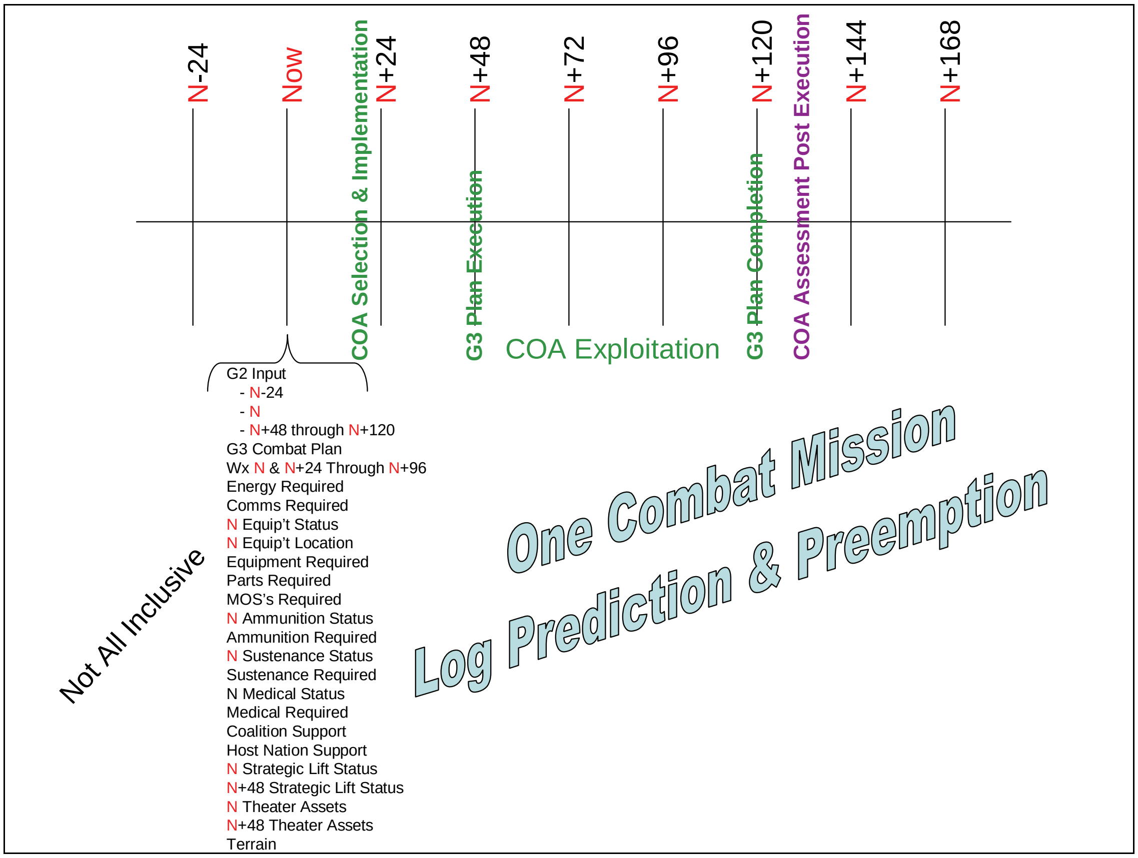
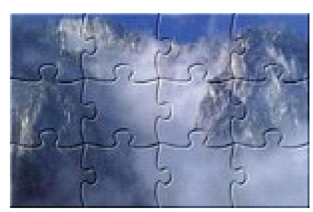


Figure 1.2. Combat mission with LPPC insertion timeline (24 hr).

1.3 LPPC and Its Benefits to Combat Operations

We have a very clear picture and understanding of those combat situations that the logistics component of combat operations needs to preempt. From preventing Soldiers from being killed to loss of a common operating picture, the capability of the logistics enterprise to predict and preempt these events from occurring is essential to the successful planning and conduct of combat missions. Prior to collecting, fusing, and analyzing these data, information and knowledge elements, our picture of what the mission looks like is akin to the hazy picture seen in the jigsaw puzzle at the right. Following the collection, fusion, and analysis, the clarity of the mission and all of its risks looks more like the picture seen in the jigsaw puzzle below. An Army LPPC will provide the foresight and clarity of the operating environment and status of global resources needed to ensure Army dominance on the battlefield now and in the future.



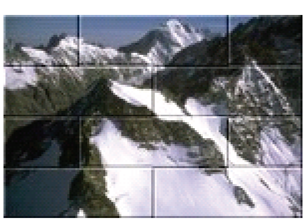


Figure 1.3 shows a high-level relationship between events/situations to be avoided (preempted) and pertinent LPPC technologies via command nodes and knowledge elements (contained in appendix B). Table 1.1 is a list of nineteen events that commanders want to preempt. Within the

context of a mission, these events shape the types of data elements needed as inputs to an LPPC. They are represented by the leftmost box in Figure 1.3.

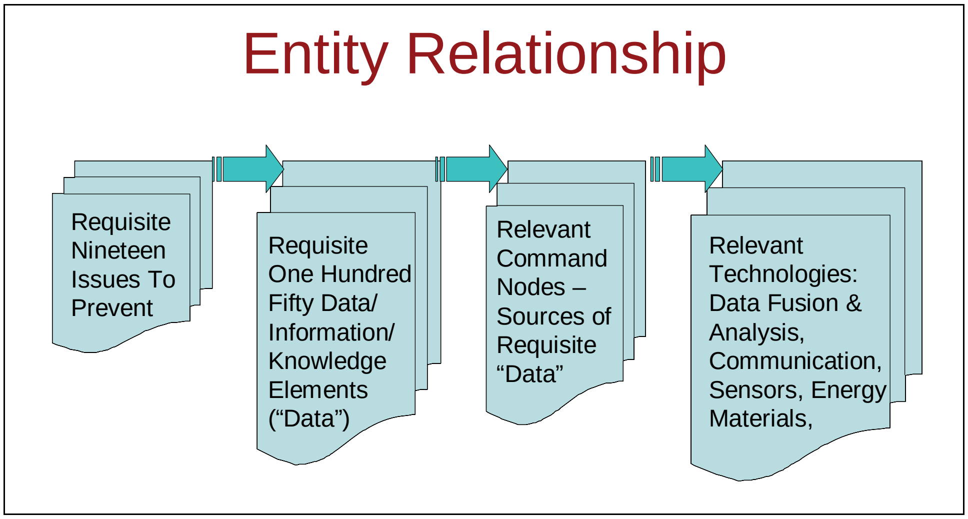


Figure 1.3. Qualitative relationship of undesirable events to pertinent technologies.

Table 1.1. Military critical events jeopardizing mission success.

Losing the engagement (mission) to the enemy
Soldiers dying or being wounded
Running out of Ammunition
Running out of Fuel
Running out of Medical Supplies
Running out of Water
Running out of Batteries/Fuel Cells
Breakdown of Equipment Not Due to Enemy Action
Encountering Bad Weather
Encountering Threat Forces
Loss of Strategic Lift Assets and Their Cargo
Loss of Theater Lift Assets and Their Cargo
Closure of APODs and SPODs
Closure of Sea Lanes
Loss of Lines of Communication
Encountering Inaccessible Terrain with Convoys
Untimely Delivery of Mission Critical/Essential Parts and Spare Parts
Loss of Communications w/ log, intelligence, and operations
Loss of Common Operating Picture (COP)

Given that we know what we want to prevent, success depends upon what data/information/ knowledge ("data") we collect, fuse, and analyze. Requisite data elements will include mission information such as: start time, duration, terrain; enemy information such as size, location, intent, tactic; weather information including forecasts and impedance to air and land convoys. In addition, data elements for supplies must be included from munitions, subsistence, fuel, medical, and portable energy. The specific data elements associated with each of the 19 situations that need to be preempted are detailed in appendix B. This appendix also spells out precisely who within the Joint/Coalition Force has these specific "data" elements. The task at hand then is to fuse and analyze these specific data elements to determine if one or more of the undesirable situations will occur unless actions are taken to preempt them from happening.

For illustrative purposes, the data elements (specific details of which are found in appendix B) are represented by the second box (from the left) in Figure 1.3 and the command nodes within the Joint/Coalition Force enterprise by the third box. The meshing of these specific data sources establish the framework to bound the determination of the technologies required to collect, fuse and analyze, such that it will produce predictions of impending occurrences of the 19 situations that need to be preempted. Once it is determined that one or more of the undesirable situations will occur if no intervening actions are taken, then appropriate focused courses of action can be formulated and implemented to preempt their occurrence. The Brigade Combat Team (BCT) is the basic building block within the modular force construct, and serves as the focus of LPPC application in Phase Two.

As such, the data, information, and knowledge that are collected, fused, and analyzed is in direct support of the BCT, the focal point of this Army combat capability. The elements identified in appendix B will be fused and analyzed at various echelons of command in order to formulate robust courses of action that will minimize vulnerabilities of combatant forces, maximize availability of combat ready equipment (A_o), while at the same time producing a proactive rather than reactive logistics enterprise that is more adept at meeting the challenges of today's and tomorrow's dynamic battlefield.

The remaining chapters will identify current and emerging technologies that offer more robust and integrated net-centric means to collect, transmit, fuse & analyze the requisite data/ information/knowledge, develop and implement courses of action, and assess the results of what was predicted prior to implementation of the mission.

1.4 Technology Evaluations: Description of the Quadrant Model

In all four technical chapters, we have used a modified version of the quadrant model in order to perform our evaluations of each area's technologies in terms of Probability of Maturation, Cost, and Benefit to LPPC. Figure 1.4 shows the end result of a notional quadrant chart.

The circles on the chart represent specific technologies. Their locations along the x-axis indicate relative benefit to a logistics prediction and preemption capability. A circle's position along the y-axis indicates the technology's *Probability of Reaching Maturity* within the 2020-2030 timeframe. In this report, *maturity* is defined as being ready for introduction to the commercial marketplace. This does not include the added cost for the additional product development required for military application and fielding.

The color of the circle represents its respective cost for research and development: green indicates that the activity is currently well researched by other vested communities with substantial leveraging potential for the logistics community; yellow indicates moderate investment; and red indicates substantially higher costs and frequently a shortfall in current research investments pertinent to the logistics community.

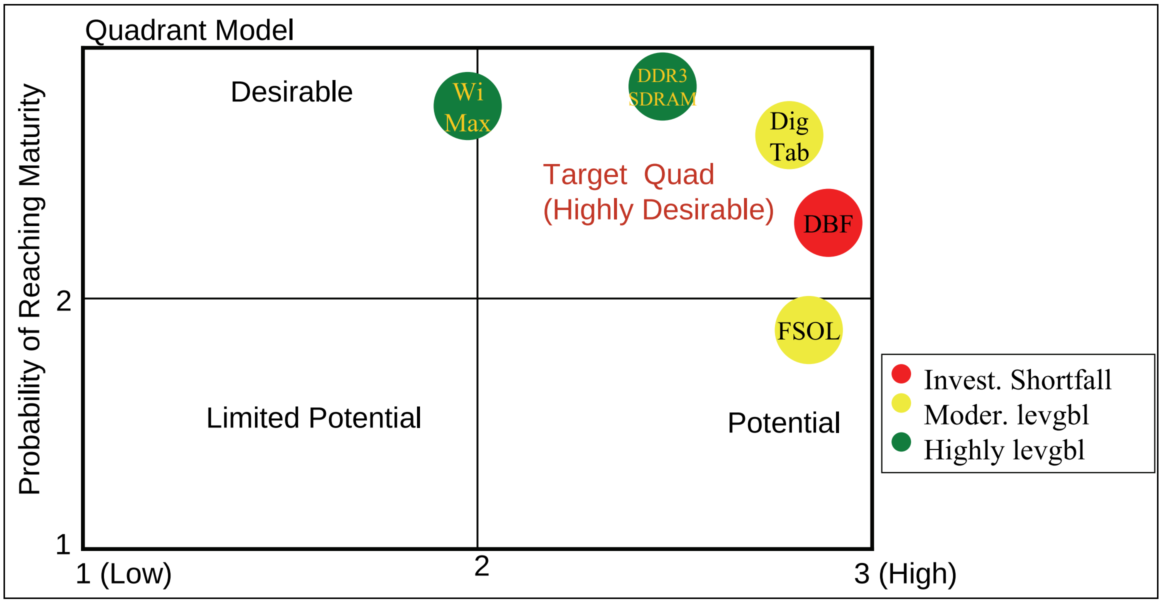


Figure 1.4. Modified quadrant model (notional technologies).

1.4.1 Underlying Scoring Methodology

This document's goal is to provide a technical assessment that allows each of the subject matter experts to be as detailed as their respective expertise allows, while keeping the results normalized for overall comparison, even across technology regimes:

For a given technology area (Data Collection, Data Transmission, Fusion & Analysis, and Exploitation & Assessment), if there are N technologies discussed in the chapter, the three figures of merit determined in our assessment and directly associated with the technology's position on the quadrant chart are:

1. Π_N - probability that technology N will reach maturation within the 2020-2030 timeframe on a scale of 1 (low chance of reaching maturity) to 3 (strong chance of reaching maturity)

2. C_N – relative cost to proliferate the technology to the number of users needed to enable an enterprise level P&P capability. This entails 2 primary factors: development and reproduction. Development includes costs to further mature the technology to make it manufacturable, whereas Π_N includes only costs necessary to bring a technology to a proof-of-principle demonstration. Reproduction is the cost of actually manufacturing the technology.

   Examples: For software, reproduction costs to proliferate are negligible, but development time is very extensive. For a MEMS micro-mirror array, development time is shorter, but manufacturing costs will be higher and the sub-factors will primarily address those issues.

3. L_N – Describes Benefit to Logistical Prediction & Preemption Capability. 1 indicates low benefit. A value of 3 indicates maximum *direct* benefit to LPPC.

Equations describing these three figures of merit are as follows:

$$\Pi_N = \sum_{i=1}^{n} W_i s_i \ , \quad where \quad W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{1.1}$$

$$C_N = \sum_{j=1}^{m} W_j s_j \ , \quad where \quad W_j = \frac{w_j}{\sum_{j=1}^{m} w_j} \tag{1.2}$$

$$L_N = \sum_{k=1}^{p} W_k s_k \ , \quad where \quad W_k = \frac{w_k}{\sum_{k=1}^{p} w_k} \tag{1.3}$$

The subscripts i, j, k represent the indexing for the pacing sub-technologies, sub-cost factors, and 19 events to be avoided, respectively.

Scoring for the three parameters was determined as follows:

With regard to Π_N, C_N, L_N, each technology was deconstructed in terms of its primary sub-technologies, cost drivers, and the 19 events to be avoided, respectively. Weights ranging from 1 (low importance/pertinence) to 10 (high importance/pertinence) were then assigned to the sub-technologies, sub-cost factors, and 19 events. (Note that although weighting values ranged from 1 to 10, the weights were normalized for a given technology such that $W_n = w_n / \Sigma w_n$. So, the number of subcategories does not penalize/benefit one technology vs. another).

The sub-technologies, sub-cost factors, and 19 events to be avoided were then scored by a low, medium, or high value (1,2,3) The scores were then multiplied by the normalized weights and summed to give the total scores for Π_N, C_N, and L_N.

With regard to the distinction between cost and maturation, the subcategories for costing are generally not the same as those used for technical risk. Rather, they reflect each subject matter expert's knowledge of the realistic cost-drivers with respect to each technology. For example, both MEMS (micro-electromechanical systems) and mainstream silicon (processors and memory) share similarities in the manufacturing process leading to low reproduction costs for both. However, integration costs for MEMS can be substantially higher because of the increased actuation voltages as compared to the purely electronic counterparts. Hence, the two might have the same technical score but very different cost scores. In the case of adaptive free space optical communications versus photon counting receivers, both have comparable probability of maturation (technical risk) scores. However, for application to LPPC, the former will be much more applicable. The cost score is indicated by the color of the circles on the quadrant charts:

- Those in the lower group, $1<C_N<1.66$, are green,
- Those in the middle group, $1.66<C_N<2.33$ are yellow, and
- Those in the highest group, $2.33<C_N<3.0$ are red.

Consistent with our discussion in section 1.3, in order to evaluate benefit to logistics prediction and preemption capability, the subcategories used were taken directly from the 19 items in table 1.1. Increased weighting again indicates increased importance in preventing a particular event item, while the score indicates how well the technology can *directly* obviate that event. For example, advanced Sensors will have a high direct, relevance to ensuring adequate inventory, so a weight of 10 is assigned. The types of technologies discussed will encompass a capability for ultra-small form factor and lower power draw such that only a small design "footprint" will be required. Since these implications mean that the proposed sensors would perform their job well in this regard, they would receive a score of 3 (high).

With regard to the scoring methodology, the rationale behind varying the amounts of sub-technologies was to maximize subject matter expertise. Depending on the particular technology, there are potentially many showstoppers at the fundamental level, e.g., devices, materials, or fabrication. Our adaptive approach allowed for a more detailed examination of these critical underlying sub-technologies. The weighting and normalization were used to ensure that we did not necessarily favor one technology over another simply because of familiarity on the part of the subject matter expert. This approach is also consistent with the development of critical paths necessary to advance the technologies. Cost realism scoring indicates authors' estimates of necessary investment based upon hardware, software, system–of-systems integration, and existence of plans and capability to accomplish technology transition (but not fielding).

1.5 What to Expect in Chapters 2 through 5

The following chapters present detailed discussions in the areas of Data Collection, Data Transmission, Fusion & Analysis, and Exploitation & Assessment. All follow the same general structure, starting with an introduction and description of the current state-of-the-art, general areas of technical criticality, followed by emerging technologies. In the context of this paper, standards as technologies has been added (see paragraph 1.5.5) and where warranted, we have added additional discussion about the basics of a technology area, such as the many different types of memory (appendix D).

1.5.1 Data Collection

Chapter 2 focuses on the aspects at the initial ("front end") collection level for data, information, and knowledge. Based upon current development paths, there are four major attributes that will enable advanced data collection: automation, intelligence, embedding, and affordability. To achieve actionable knowledge entails the substantial leveraging of these attributes as they pertain to the base technologies for data collection: microelectronics, nanoelectronics (sensors), and ultra small form factor power supplies. The author details the current and future states of data collection and offers insights for the development of a highly integrated and advanced data collection system that could provide real-time data collection. He concludes that sensor technology, specifically solid state memory (Mem) micro-electromechanical systems (MEMS) and nanotechnology, multicore processors, and transducer electronic data sheets (TEDS), are key to the success of the LPPC and that they provide not only capabilities to the complex data collectors, but also to the processing power that will be needed to fuse and analyze the data.

1.5.2 Data Transmission

Chapter 3 focuses on the discussion and evaluation of current and future technologies that will lend themselves to the goal of rapid, secure, and accurate disbursement of information. Data transmission is unique because it is not a node in the prediction and preemptive chain such as data collection, fusion & analysis, and exploitation & assessment. Instead, data transmission provides the necessary link to facilitate the progression from one stage in the prediction and preemptive process to another. The author details the current and future state of data transmission and clearly expresses communication technologies as the essential element throughout the entire logistics enterprise and its linkage to the LPPC. He concludes that hybrid networks, free space optical (FSO) communications, and multi-platform common data links (MP-CDL) have the potential for the greatest impact on a logistics prediction and preemption capability.

1.5.3 Data Fusion & Analysis

Chapter 4 presents a comprehensive review of the data fusion process. As described, data fusion is an information process that first samples data and information from single and multiple sources, then associates, correlates, and combines these data to estimate the identities and locations of all sensed entities. Once all perceived entities are identified and located, one highly desirable output that the fusion process produces could be a comprehensive Course of Action (COA) presentation. This process of data fusion is a natural extension of human cognition. The author provides a clear picture of the current and future states of data fusion. He concludes that distributed Blackboard Fusion Architecture enabling intelligent and adaptive sensor web (ISW/ASW) and Social Network Analysis, Simulation-Based COA Analysis, Simulation-Based Reflexive Analysis, and Cyc-Based Virtual Logistician technologies can be viewed as a key contributors to the essential data fusion & analysis elements of an LPPC.

1.5.4 Exploitation & Assessment

Chapter 5 concentrates on the exploitation and assessment of prediction and forecasting technologies and their relevance to military success and actionable logistics knowledge. An LPPC will enable decision makers to assess the impact of future conditions, thereby allowing military commanders to make operational decisions knowing the risks associated with those decisions. The author assesses methodologies and advanced technologies required to develop an enterprise-class prediction and preemption capability. In doing so, he illustrates the complexity of synchronizing all of the prediction and preemption processes. To achieve this collaboration, the author concludes that service-oriented architectures, web services, geospatial analysis, software agents, and business process integration would all play critical roles in obtaining maximum use and benefit for any future information technology system.

1.5.5 Standards as Technology

A note on *standards* as technology: In this report (particularly chapters 2 and 3), we include *standards* as technologies. By this we mean specific exemplars of a "well-defined interface," either from hardware-to-hardware, hardware-to-software, or software-to-software.

As a primary example refer to Transducer Electronic Data Sheets (TEDS, section 2.1.) The overarching concept of the technology is the inclusion of a sensor's characteristics in an electronic format on the sensor itself. The corresponding system will have the ability to "learn" that particular sensor's capabilities upon being connected to it. Although the concept of wireless technology has existed since the last century, contemporary standards such as Wi-Fi entail highly detailed specifications that have been designed to solve very specific problems. Thus, the scientist's and engineer's use of standards represent a clearly defined manifestation of more general concepts. Technologies become standards by two different approaches:

1) Market forces eliminate competition in emerging technology areas, leaving a small number of proprietary approaches as the de facto standards. Example: multiple personal computer architectures existed in the late 1970's and early 1980's; after the culling, the IBM PC architecture and Apple Macintosh remained. However, since the IBM patent reached its expiration, an enormous number of startups emerged using that architecture as a standard for PC "clones." As Apple held its IP closer, it lost substantial market share in large measure to Microsoft's infringement on Apple's user friendly displays (windows).

2) Multiple companies band together via standards groups (frequently assembled by professional societies such as the Society of Automotive Engineers or the Institute of Electrical & Electronic Engineers) in order to work out mutually beneficial specifications to hardware or software technology interfaces. Example: Wi-Fi, Bluetooth, and other wireless standards that have been adopted by numerous chipmakers and hardware manufacturers have enabled a proliferation of affordable, practical wireless extensions to cell phones, computers, etc.

The consensus is that the resulting interoperability lies in the best technical and financial interest of all entities involved and enables clear delineation of respective intellectual property. Hence, in using the term *standards*, we mean the specific technological manifestations, rather than the explicit documentation to which they are associated.

[4] J Barker, Agincourt: Henry V and the Battle That Made England (2006), ISBN 0-316-01503-2.

Chapter 2. Data Collection

K. Tom

"Science is facts; just as houses are made of stones, so is science made of facts; but a pile of stones is not a house and a collection of facts is not necessarily science."

- Henri Poincare

2.1 Overview

The data, information, and knowledge that are requisite to an enterprise LPPC will formulate robust courses of action, minimize vulnerabilities of combatant forces, maximize availability of combat ready equipment (A_o), and concurrently produce a proactive logistics enterprise. These heterogeneous data structures will reside in many formats and locations. This chapter focuses on the aspects at the "front end" collection level while the following chapters focus on the transmission, fusion & analysis, and exploitation & assessment aspects, respectively.

The data, information, and knowledge required relate directly to the nineteen events (see table 1.1: Events to be Preempted) that the Army logistics enterprise needs and wants to preempt from happening. It is paramount to note that in considering the development of an LPPC in a holistic sense, the technologies in each chapter are area are inexorably intertwined with the three others. Hence, the volume of data collected directly impacts the design constraints of the communication channel to be used. Likewise, although local processing capability will continue to advance, transfer of the data back to forward operating bases (FOBs) and higher levels will make it available to larger computing resources for fusion & analysis and appropriate decision-making for exploitation.

2.1.1 Data, Information, Knowledge Formats and Sources: Current and Emerging Approaches

2.1.1.1 Written Reports

Written or electronically prepared reports such as the daily Logistics Status Report (LOGSTAT) are critical documents forwarded to the next higher level of support. Typically forwarded electronically, it is not uncommon to use courier service or "snail mail" when units experience communication problems, lack sufficient bandwidth for the size of the report, or receive lower bandwidth priority by the G6 due to exigent circumstances on the battlefield. In the case of the Brigade Support Battalion, the report is forwarded to the supporting Sustainment Brigade that provides support on an area basis. LOGSTAT reports are collected, analyzed and supplies distributed based on the unit's requirements.

Of note is the concept of "pushed" versus "pulled" distribution. Class I (Subsistence) is referred to as a "pushed" commodity because there are a known number of Soldiers in each unit. Re-supply is not contingent on the receipt of a requisition from subordinate units before replenishing them. However, in the case of Class V (Ammunition), a "pulled" commodity, replenishment by type and quantity is based on a unit's requirements which are determined by its upcoming mission, priority, and the quantities available for distribution

2.1.1.2 Radio Reports

Radio reports are used in numerous situations. Although it is standing operating procedure to keep radio traffic to a minimum in order to reduce one's electronic signature on the battlefield, as well as to keep from providing sensitive information over a non-secure net, radio traffic reporting is often necessary when reporting on current events that need to be transmitted immediately. An example might be if a bulk fuel point is lost or destroyed due to enemy activity, contamination, or natural causes. Reporting must be immediate if the event puts the mission in jeopardy. Additionally, reporting via radio is often done when "on the move." Ground convoys transporting supplies over the battlefield are constantly reporting their positions to both parent and higher headquarters. Moreover, often the target of enemy ambushes, convoys must have the immediate means by which to report enemy activity and request support as necessary.

2.1.1.3 Raw Sensor Readings from Equipment

Raw or direct sensor readings are those readings taken directly off a piece of equipment, collected, analyzed, and acted upon. Conducting daily preventive maintenance checks and services (PMCS) is an example of a task requiring raw sensor readings. During PMCS, prior to operation, the Soldier is responsible for performing a series of user level tasks to ensure the equipment is safe and mission ready. Testing fluid levels, checking pressure gauges, ensuring head and tail-light operations for normal and black-out conditions, and conducting radio checks are only a handful of the types of readings taken during everyday PMCS. Once a complete PMCS has been conducted and all the data has been collected, certain faults found on the vehicle are determined operator level repairs where others may require a higher or direct support level of repair, in which case the paperwork is forwarded to the appropriate section for further analysis.

Another type sensor reading is one that requires additional processing. Such is the case under the Army Oil Analysis Program (AOAP). Select pieces of equipment are required to undergo close engine oil scrutiny to preempt vehicular malfunction or failure. All Army aviation assets are enrolled in the AOAP. On a scheduled basis, oil samples are collected and sent to the supporting AOAP lab where the oil is analyzed and checked for evidence of metal shavings, viscosity anomalies, and other indications that the equipment could be vulnerable to failure. If such indications are present, the equipment is immediately put in a deadline status for further data collection, analysis and repair.

2.1.1.4 Radio Frequency Identification (RFID)

Sustaining a military operation is arguably one of the most difficult tasks of any combat operation. Being able to provide the correct quantity of materiel to the right place at the right time is a logistician's "right of passage." Knowing where that equipment is at any given time is critical to proper supply chain management. The development and implementation of the RFID tag infrastructure by the Army G-4's, Logistics Innovation Agency (LIA) was a massive undertaking that proved to yield enormous dividends. Today, materiel release orders (MROs) are cut by item managers who receive requisitions from front line units. The MRO is filled at the depot and up to level 6 data is entered into the RFID tag affixed to the pallet. Interrogators along the distribution pipeline provide nodal, in-transit *snapshots* of the supplies en route to the theater of operation by collecting the time the pallet hit an interrogator node such as the depot gate, Aerial or Sea Port of Embarkation (APOE/SPOE), ports of debarkation (POD), and final destination at the supported unit's Supply Support Activity (SSA). Next Generation Wireless Communication (NGWC) is a technology under development at LIA whereby asset visibility is expected to increase demonstrably through the union of multiple wireless applications.

2.1.1.5 Smart Buttons/"Thumbdrives"

Another collection tool widely used in the aviation community and on select ground pieces of equipment are Smart or Memory Buttons. These thumb drive type devices are storage repositories for maintenance information. The Memory Button's purpose is much like that of a memory stick we plug into our computers to download, collect or store data. The button is simply an electronic log book for all maintenance conducted on a piece of equipment from cradle to grave. It is intended to replace the hard copy maintenance log books that often go missing but are required in all pieces of equipment during operation and stored in the unit motor pool when not in service. The smart button will become more widely accepted across the Army when next generation equipment is manufactured to allow easy access to smart button portals.

2.1.2 Tradespace at the Data Collection Level

Many of these sources of data, information, and knowledge require no further efforts to collect as they are currently collected at the appropriate echelons of command (where fusion & analysis needs to occur) as part of existing Army business practices.

As the LPPC grows and evolves, extensibility in the data collection portion of the enterprise, it will be imperative as additional sources of data continue to be added from places currently outside of existing business processes. The remainder of this chapter will present a primer of the key engineering tradespace issues for data collection, namely: (physical) type of data to be collected, timing and frequency of collection, and initial processing of the raw data at the local level.

As a starting point, the definition of data collection is the means by which raw facts are gathered for transmission, interpretation, fusion, processing, exploitation and/or assessment. In this chapter, the "raw facts" are the requisite data, information and knowledge. The word "data" will be used to denote these "raw facts".

Data Collection systems, data acquisition[5] systems and data loggers are basically the same concept. Although at high level the data collection system is the same for simple and complex systems, the hardware implementations will vary significantly. A data collection system is viewed as an embedded, standalone system that has appropriate sensors that measure the environmental and operational condition that the hardware is subjected to. These data are stored in some form onboard the embedded device with some ability to transfer the data for additional analysis and processing. Data will have to be tagged with some indexing for registration. Another name for tagging data is "metadata" or data about data, i.e., labels. Memory storage and energy consumption will come to play and be an issue for embedded systems.

The processing ability of the data collection system will depend on the complexity of the platform that it is attached to. For simple operations, where the life expectancy of the item is well understood from environmental conditions, the data collection system will be straightforward in implementation. For complex systems, there will be a significant investment in the storage of the data and relaying of the data off of the system for off-board processing.

The cost of the data collection system will depend on the asset being monitored. Return On Investment (ROI) will play a significant role in determining which hardware/platforms should be monitored. "The number of sensors used is an important factor in the cost equation in terms of time, money and effort and should be limited by the information gained." The determination of the optimal number of sensors that will be required is not a straight decision as "in most situations decisions are more reliably made when there are more rather than less sensors."[5] To promote data collection systems across many diverse platforms, the concepts of modularity and plug & play will have to be ingrained into the data collection system concept.

2.1.3 What is Data?

Empirical data will be necessary to develop predictive processes. There are many sources: field usage, combat damage and repair factors. Data collection will have to be automatic, autonomous for an embedded data collector. However, one must not limit input into the LPPC solely to the data that can be gathered by embedded data collectors. Collection of information needs to occur during the design and development stages. "Collected data throughout the testing phase are used to develop and mature diagnostic and prognostic algorithms." Information such as "historical data is used wherever possible to characterize the system in the environment for a typical intended mission of the system." Access to computer models/simulations that help guide and define the sensing modalities determines the construction of the data set. "Sensor selection and placement starts with the testability analysis/model. It is used to identify failure modes, failure

---

[5]The term "Data acquisition" is used in this chapter, and, within this context, is used interchangeably with "data collection." We note this syntax because in the scientific and engineering communities the former is used almost exclusively.

effect propagation time and gain. The figure of merit selection step focuses on maximizing detection and identification of the failure mode while minimizing the number of sensors. The optimization step takes all of these factors through a statistical analysis to provide the optimal number of sensors and their placement."[6]

2.1.4 What is Metadata?

The strict definition of metadata is dependant on the application. Given that many more data sources will be available, we will need to know more about the data itself. Spatial-temporal information registration will be an absolute requirement: "To get labeled and associated information, we need to place the data in both space and time".[7] Metadata can be viewed as surrounding data that provides the glue to hold the data together in some structure that will provide the essential understanding of relationships among the various sensor measurements.

> In short, metadata is data about data. What this means is that a small amount of descriptive data, say a zip code, can be used to specify/replace a larger amount of data, in this case district, county, city and state.

In order for us to translate data into actionable knowledge, we need to know which platform spawned that data, when it occurred, and under what conditions. The primary challenge with regard to metadata will be that logisticians at different echelons will require different levels of detail.

2.1.5 The Chicken or Egg Question

The notion of developing an LPPC capability presents an operative pair of questions:

1. How do you know what sensors you will need unless you have tried the algorithm for predicting something?
2. How do you develop the algorithms without having all the sensors that you need?

Theoretically, the 100% solution to achieving LPPC would entail full instrumentation on every asset, followed by field experiment to at least a theater level. This would provide what we call a "training set" for the data fusion portion. This would allow the fusion "brains" to learn in preparation for actual operations, in the same sense that humans drill to practice for real combat. The trade space for the number of data collectors, amount of data actually required, and computational complexity will then be better defined and navigated.

> A microcosm of this is observable in the development of electronics prognostics & diagnostics. How do you come up with a data collection system without initially collecting data on this system? A conclusion reached by the National Defense Industrial Association (NDIA) key workshop on System Engineering Division, Integrated Diagnostics Committee, Electronic Prognostics Technology, Ground Weapons Task Group, E-Prog II Workshop is very much applicable to the data collection issue for predictions. "While the data required to implement individual electronic system

prognostic approaches may vary some, the need to validate operating environment, operating time, historical test and maintenance data may be common to all approaches. Acquisition requirements to capture these data and integration of the process into the maintenance program are viewed as paramount in successful fielding of an (electronic) system prognostic capability." A vast and significant amount of data will need to be collected in the development of the prognostic algorithms.

In both the microscopic example of platform prognostics and the macroscopic view of prediction in theater, clearly a compromise between amount of data collected and our capability to analyze it will be required at any node. Reduction in raw data balances with use of the data fusion models and directly affects uncertainty.[8]

Non-technical factors will be used as guidance to solve the quandary of what comes first, all of the possible data, or the development of the complex analyses. These will be predicated on the users' needs. For example, "What are the mission essential systems for each type vehicle by type mission?" That is the primary question. The next question is, "What is the vehicle density, e.g., do we have 400,000 or 4,000?" If the vehicle density is high then you do not need embedded prognostics (on every single vehicle.) If, on the other hand, the vehicle density is low, and the vehicle is critical to prosecution of combat with no suitable substitute, then you need embedded prognostics on those systems that enable the fundamentals of combat: MOVE, SHOOT, and COMMUNICATE, e.g., power plant, drive train, fire control system, and essential communication systems.

2.1.6 What Do You Collect?

In addition to indexing, (e.g., bar code ID or RFID), the list of example raw physical attributes that can be measured includes temperature, humidity, vibration, shock, light levels, location, etc. (any sensors that can record physical phenomenology).

2.1.7 When and How Fast Do You Collect It?

The aerospace industry has implemented various configurations of data collection systems and embedded diagnostics. A review of the aerospace solutions will show that there is great variability depending on the required accuracy, resolution and cost. In developing these systems, several factors had to be weighted to establish the implementation of such a data collection system and its complexity.

Aircraft data monitoring systems have been implemented in either "Cardinal Point" (suppliers have to make calculated guess of the requirements/specifications) or provided detailed specifications that provides little flexibility in design, which in the end run provides for a "black box" that limits its application to specific aircrafts, expensive, high maintenance resulting in poor return on investment. Various data collection systems evolved over several decades for dynamic flight data acquisition in the aerospace community. The COTS world offers data collection, processing and data storage technologies. In conjunction with the technologies, the commercial world has developed standards for sensor/bus interfaces and data distribution. Recent digital data collection systems are being designed to reduce the drawbacks of closed system design.[9] "During the first generation of digital recording products, individual manufacturers developed proprietary solutions without any means for interoperability and data interchange. This lack of flexibility prevented users from taking advantage of advancements in technology and competition among vendors." A comparison of the capabilities of these various data collection systems and applications for the aviation community are as follows:

System	No. of Parameters	Data Rate	Data Storage	Data Processing
Flight Test	In the thousands	50 K/sec to 2 M/sec	Recorded on board with Critical data transmitted to Ground via real time link	Real Time and Post Flight
OLM	In the hundreds	1/sec to few hundred/sec	Recorded on board for post flight processing	Post Flight
ODR	In the hundreds	Tens of K/sec	Recorded on board for post flight processing	Post Flight
FDAU	In the tens	Tens of K/sec	Recorded on board for post flight processing	Post Flight
HUMS	In the tens	Few samples/minute to few tens/sec*	Recorded on board for later processing. On board processing reduces data to minimum (exceedances outside limits are recorded only)	On board and Post Flight

(*If raw vibration data are required this could rise to tens of K/sec for short durations)
OLM – Operational Loads Monitoring
ODR – Operational Data Recording
FDAU – Flight Data Acquisition Unit
HUMS – Health and Usage Monitoring Systems[10]

From this comparison of various data collectors in the aerospace community, one can see that the data collectors' functionality and operational capability is highly dependent on the final application. This clearly sets the stage for the modularity and adaptability that will be a design requisite for future collection systems[6].

2.1.8 What Do You Do With It?

Heuristically, in the future paradigm, data management, traditionally the concern of the analyst performing the fusion, will become necessary at the collection level because of the increased resolution and amounts of data. These increases will be met by improved local processing (on-platform) capability; hence it is appropriate to discuss some aspects of local analysis in this chapter. The primary issues have already transitioned from storage itself to the caching and distribution of the data.[11] Emerging capabilities that help standardize these data formats, e.g., Common Logistics Operating Environment (CLOE), will dramatically improve these aspects, such that by the 2020-2030 timeframe, management of peta-scale databases will be a commodity. This is a critical and credible need for a prediction & preemption capability.

[6] For aviation, addressing these tradeoffs entails substantially higher cost because of the need for air-worthiness certification.

Data fusion at higher echelons is the primary topic for chapter 4. However, the advances in collection technologies also include increased processing power at the local nodes (maintainer/transporter/operator). A very simple example would be that in the past, a vehicle had a simple analog fuel gauge. With vibration sensors (accelerometers) added to the vehicle, a *usage profile* can be determined on the fly. Rather than reporting an unqualified fuel level, it now becomes straightforward to predict actual number of miles left before refuel is required as a function of road quality, evasive maneuvers, ambient temperature and moisture. The same functionality is true for the relationship between tread wear depth and usable remaining miles on the tire. On the stock HMMWV, in CONUS, the ¼ inch of tread may mean another 25,000 miles, on the PA turnpike-perhaps 15,000, and so on. Some of these capabilities are currently observable in environments such as Formula One racing, NASA, and others and the advancement and proliferation of small form factor, distributed, interconnected and automated data collection will enable the same capabilities for Army logistics.

2.2 Ancient, Current, and Emerging Data Collection Technologies

2.2.1 Manual Data Collection

Manual data collection has existed since the beginning of recorded history. We are all participants in the U.S. census collection that occurs every decade. Some of the data are used for statistical purposes to obtain a clear picture of the health and welfare of the population. Similar data collection occurs in the deployment and distribution of military assets, and assessment of usage profiles and sustainment requirements. It is an evolutionary process whereby the content of the data information is being updated as necessary to provide a clearer picture of the situation. Since human beings are involved, data collected will contain human errors.

On the role of the state of Florida in Presidential Elections – the pitfalls of manual data collection: The data collection (and tabulation) issues pertaining to the results of the 2000 U.S. presidential election are widely known. What is not remembered by the general public are the contentious results of the 1876 Presidential election. In both cases, confusion over the data collection ("hanging chads" and misleadingly illustrated ballots, respectively) resulted in increased uncertainty. For the 1876 scenario, this resulted in the matter being taken up by entities external to the Electoral College and the final decision based upon political alignment rather than the objective results of the data collection.[12]

2.2.2 Logbooks

Historically, information useful for prediction was found in logbooks. They are generated to document the measurements on a subsystem level as the unit device is being manufactured and tested. Other applications of logbooks involve transactions of supplies and the operational usage/maintenance of high dollar machinery/vehicles. Important parameter values can be established from the previously recorded data.

The term "Logbook" is derived from the naval application of formally documenting the distance that a ship would have traveled in a given time interval. This was measured by an instrument called a "log" that estimated the speed of the ship. The application of logbooks proved so important and useful that the concept of documenting the process has evolved to the application today where logbooks are meant as a means of documentation.

In the past, most of these logbooks were recorded onto paper and bound. As the 20th century came to a close, the advent of electronics and computers resulted in semi-automated technologies to significantly speed things along. In either form, electronic or paper, the information can and does sometimes appear in forms that can be difficult to manage. The electronics age (loosely described here as the late 20th century) enabled semi-automated data collection in standardized formats (e.g., bar codes). The digital age (present) presents the ability to merge these resultant data streams, regardless of format. One of the best examples of this is in extensible markup language (XML), where regardless of the application software being used, as long as the originating data are in a digital format, it can be stored in a file that contains instructions for reassembling it.

This approach was not practical with earlier technologies because the memory requirements were too large. A 10 digit bar code for a jar of peanut butter would be 80 bits long. The grocery store computer "knows" it is peanut butter because it speaks one language, the universal price code (UPC). If they had tried to make an XML version of this information back in the 1970's, the label would have to contain the instructions for assembling the information:

- this is a bar code
- it is in English
- it refers to a grocery item
- that item is peanut butter
- the brand is…
- the size is 48 oz

Even in this simple example, we would now be up to about 1024 bits, so about half of the label on the jar would have been taken up by the bar codes to explain all of this.

As chapters 4 and 5 will explain, future technologies will enable us to complete the path from manual data collection to semi-automation via standards, to full automation (agnostic of standards) to the desired prediction end-state described in the project's Phase I paper.

2.2.3 Semi-Automated Data Collection: Bar Codes

Bar codes are ubiquitous to the modern society at the beginning of this century. The commonly encountered application of the barcode is found in the retail consumer stores. It helped the retail grocery market provide significant reduction in the checkout process with improved reliability and better tracking and inventory control. It is the merging of the modern computer and bar code technology that has provided infrastructure that we see today. Initially, the bar code was being developed to identify railroad cars, but the big momentum to its development was the retail grocery market. It has migrated from a stationary device for identification to a mobile application to tracking of packages for the major package delivery services such as UPS and FedEx.

The bar code is machine read data that usually provides an ID for the item that it is attached to. The bar code is a binary code (composed of ones and zeros) that is represented by a series of lines and spaces of varying thicknesses. A scanner reads the bar code by linearly sweeping past the bar code and converting the lines and spaces to a binary format that the computer can use. The information contained on the bar code is meaningless by itself. It is used as a lookup index to retrieve the pertinent data stored in a database. In essence, the bar code is only as good as the information structure designed around the bar code tag.

Since its inception, the bar code has evolved from its application as a Universal Product Code (UPC) for the retail market. Due to space limitations, many physical variants of this tag form have been spawned. There are different formats that specify the dimension of the lines and spaces in addition to the overall length of the bar code. Attempts to increase the storage capability of the bar code have resulted in the addition of another dimension. Instead of lines and spaces, a 2D bar code uses a series of stacked square cells to provide representation. As applications of the bar code have expanded, so have the specification and physical representation associated with it (Figure 2.1).

Figure 2.1. Bar code representations of "Wikipedia," the internet encyclopedia, using a both 1D and 2D (right) configurations

2.2.4 Semi-Automated Data Collection: PDAs

Personal Digital Assistants (PDAs) are basically handheld computers. Originally, the implementation started as personal organizers that electronically stored an address and appointment books in addition to some basic functions such as clock and calculator. As technology developed, additional features were integrated into the PDA design. The development of larger memory chips and wireless communication has also contributed to more advanced PDAs. Like the tablet PC, the LCD screen has a digitizer (tactile screen that functions as an input device as well as a display) where a stylus pen can be used to input data by touching the screen. The adaptability of the PDA has been expanded by the use of memory cards where the memory capacity size can be increased through insertion of these cards. The developments of wireless communication protocols have allowed designers to incorporate applications like Global Positioning System capabilities, mobile phones and interconnection to area networks.

Like the desktop PC, applications can be designed and programmed to operate on the PDA within the confines of its capabilities. This offers portability in a truly small size, but the disadvantage is the small display screen. Field medics are currently using the iPAQ as a point-of-care logbook for recording vital data on injured Soldiers. It is this type of data collection, in an electronic format from the start, which expedites the analysis of the data and translation to actionable information. In this case, the data can be immediately synchronized with ruggedized MC4 notebook computers that can then quickly transmit data on dozens of patients in a format that is non-lossy (e.g., copies of copies or unreadable faxes).[13] Figure 2.2 highlights the use of a PDA in the field for this application.

Figure 2.2. PDAs in use for medical semi-automated data collection. Although the data collection is being performed by Soldiers, having the initial input in a digital format substantially expedites its transfer to physicians for assessment and exploitation.

2.2.5 Automated Data Collection: RFID Tags

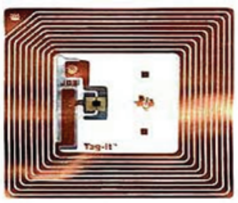
Automated data collection systems offer many advantages over manual data and semi-automated collection. These types of systems provide an accurate data recording mechanism. The biggest advantages provided in an automated data collection system are improved performance in eliminating errors due to oversight and transcription as well as collection speed.

Radio Frequency Identification (RFID) describes a system where tags are attached to items and through the use of radio waves communicate information about the item. This technology has two categories: passive and active systems. In a passive system, there is no active (on-board power supply not required) component on the tag. The tag responds by reflecting the signal from the reader source. In an active system, the tag has a transmitter and a power source so that it can send out information stored inside the tag. Operation of these units occurs at various frequencies depending on the make, model, and application. Depending on the desired application, the performance varies as a function of the operating frequency, signal path attenuation.

2.2.5.1 Passive Tags

Passive tags have no power supply or transmitter on the tags themselves. Rationale for this approach is both design simplicity and cost (relatively low cost, on the order of tens of cents). When properly implemented, these tags receive enough RF energy from the interrogating device (handheld or portal-based scanner) in order to supply the tag with sufficient power to respond to the reader with the information embedded in the tag. The information on the passive tag is limited to identification usage, making this functionally identical to automated barcode reader. To continue our grocery store example, the concept espoused by some retailers would be to eliminate the checkout stand all together and simply have RFID tag readers at the entrance to the store. One would simply gather the desired items and they would be scanned as you returned directly to your car.

There are various frequencies of operations and associated operating range as shown in Figure 2.3.



Type	Frequency Band	Range (feet)
Low Frequency	124, 125, or 135 KHz	1
High Frequency	13.56 MHz	3
Ultra-high Frequency	860 to 960 MHz	>10

Figure 2.3. Example of a passive tag: The spiral loop antenna gives a scale indicator in terms of the large percentage of area taken up by that one component.

The performance obtained by the passive tag is related to the particular frequency band of operation and desired range for reading of the tag. Low-frequency tags operate over a small range but offer some ability to penetrate beneath the surface of the item. Figure 2.3 shows an example of a passive tag. Although range is better with higher frequency tags, the tradeoff is that energy is not as easily directed so that other units may respond besides the desired unit, leading to confusion.

2.2.5.2 Active Tags

As their name implies, active tags have their own transmitters and an associated power sources. The benefit of an active tag over the passive tag is the increased effective range over the passive tag. Typical range may be on the order of 60 to 300 feet. Typical operating frequencies are 455 MHz, 2.45 GHz, or 5.8 GHz. The architecture of an active tag is complex in comparison to the passive tag, but offers additional capabilities over the passive tag that provides only identification. This active tag does come with a significantly higher cost than the passive tag. Depending on the complexity, the cost could range from tens to hundreds of dollars.

Active tags can track items over longer distances than passive tags. Due to the higher cost, these types of tag are typically used in smaller quantities to cover larger assets such as cargo containers and rail cars. There are two basic categories of the active tag: transponders and beacons. The transponder type is a semi-active device. Upon an activation signal from a reader, the tag will wake up and respond to the request with a unique ID. This type of system is implemented in the "EZPass" system for vehicular traffic through the nation's toll booth collection system. A beacon type tag is a continuous operating device where the tag is transmitting signals at a prescribed time interval in order to provide sufficient information to identify and track the item of interest. With this type of tag, additional sensors may be attached to the unit to provide environmental and operating conditions. A disadvantage with the active tag is the maintenance cost associated with replacing batteries. One gains in performance over the passive tag, but with a higher and continuous associated cost throughout the lifetime of the active tag.

2.2.6 Automated Digital Data Collectors

The next step beyond these active tags is to increase the capability to include sensors either on-board, hardwired, or via additional wireless connections. Rather than storing simply the identification of an asset, the overall data collection process is further expedited by taking additional data automatically e.g., operating parameters of the asset and ambient environmental conditions. Going beyond identifying the item, a digital data collector can be interrogated to determine the temperature, humidity, and barometric pressure conditions in which it has been stored. If the on-board sensor includes an artificial "nose," it could tell you that a food shipment has reached spoilage and has now become a liability rather than an asset for transport.

The final configuration for a digital data collector will be highly dependent on the asset that to which the collector is attached. This asset dependence yields a broad trade space for design of the digital data collectors with the typical factors being form factor, power requirements, cost effectiveness in relation to the asset and the primary source of degradation (environmental, storage, transportation and/or operational). Analogous tradeoffs will exist for the associated software. Even if the data collector hardware is a generic in its' physical form, the software/firmware necessary for proper operations will be dependent on the requirements of the end item. Frequently, sensor specificity and degradation mode are inversely related to software complexity.

There are some fundamental engineering questions that will need to be addressed in the implementation of a data collector. These are related to the identification of the sensing modalities that are applicable to degradation of the asset and defining the type and amount of local on-board processing versus the off-board processing (the domain of chapter 3) of the collected data. Even for a specific application there are myriad design and implementation issues to be resolved and defined. They include but are not necessarily limited to the following[14]:

1. Data Acquisition
   - Signal types (continuous versus discrete)
   - Signal sampling rates
   - Signal synchronization across suite of sensors
   - Signal conditioning/processing

2. Data Processing
- On-board processing
- Hardware capabilities/constraints
- Processing bandwidth
- Storage requirements
- Reporting/Fault annunciation
- Off-board processing (if any)
- Data communication infrastructure

2.2.6.1 Black Box versus Open Architecture

What is a "Black Box"? For the data collector, this is viewed as a closed system where the only knowledge of the system is just the type of sensors used for input and the availability of some form of processed data. There is no available knowledge about the hardware and software implementation, nor the algorithm used in processing of the data. It is in the best interest of the Army to avoid black boxes in data collection systems. The knowledge that is hidden or proprietary does not provide information necessary to advance the predictive process across many disparate asset/platform configurations.

One approach to avoiding unnecessary constraints from proprietary approaches is collaboration with industry, academia, and additional government entities for standards. In the case of digital data collection system, a good example is found in the effort toward an Open System Architecture (OSA) for Condition-Based Maintenance (CBM) where the primary focus is the definition of distributed software architecture for CBM. "Openness is a general concept that denotes free and unconstrained sharing of information. In its broadest interpretation, the term "open systems" applies to system of design approach that facilitates the integration and interchangeability of components from a variety of sources. For a particular system integration task, an open systems approach requires a set of public component interface standards and may also require a separate set of public specifications for the functional behavior of the components. The underlying standards of an open system may result from the activities of a standards organization, an industry consortium team, or may be the result of market domination by particular product (or product architecture)."[15]

The Tri-Service Open Systems Architecture Working Group defines the term as "a system that implements sufficient open specifications for interfaces, services, and supporting formats to enable properly engineered components to be used across a wide range of systems with minimal changes, to operate with other components on local and remote systems, and to interact with users in a style that facilitates portability. An open system is characterized by well defined, widely used, non-propriety interfaces/protocols, and uses standards bodies. An open system defines all aspects of system interfaces to facilitate new or additional systems capabilities for a wide range of applications, and provides explicit provisions for expansion or upgrading through the incorporation of additional or higher performance elements with minimal impact on the system."

One interpretation of this would be: "I do not have to pay you or ask your permission to interface my system to yours (and other competitive systems using the same hardware/software interface) to allow the user to gain full functionality of both."[16]

2.3 The Future of Data Collection

As evident by the current development paths, there are 4 major attributes that will enable advanced data collection: [Automation, Intelligence, Embedding, and Affordability]

1. Automation – to reduce the burden on the human factor and produce a manageable and realistic implementation as data collection processes extend down to the individual parts arena
2. Intelligence (processing on board) – at various levels of the chain, some amount of processing power must be organic to the individual parts. Computational requirements are not likely to be as challenging, however, power requirements will need to be met.
3. Embedding – In order to track the smallest spare parts, replacement equipment, etc. tracking hardware of some sort must be physically embedded exist on the items that are above the level of logistical significance.
4. Affordability – while not every asset will be tracked solely with a 10 cent RFID tag, in the same sense, not every piece of equipment will require a $300K digital data collector. Price point appropriate solutions already exist for many levels; the key challenge will be the interconnections.

The fundamental building blocks of the data collector are sensors, processors, memory devices, and power sources. To develop a highly integrated and advance data collection system, other factors will come into play such as standards, processing algorithms, and communication and display technologies.

2.3.1 Input: Transducer Electronic Data Sheets

The sensors will provide the data necessary for a predictive system. It can be envisioned there will be a requirement for several different types of sensors. The environmental parameters such as temperature and humidity are some of the fundamental items that will be need to be monitored. Shock and vibration monitoring will be necessary for degradation due to transportation and operational usage. As the data are stored, some form of metadata (such as time) will be used to tag the data for correlation. Other parameters will have to be sensed but they will likely depend on the value of the asset and the predictive algorithms that will be required. It is important that the fundamental characteristic of the sensors be matched to the proper conversion by the data collection system. The following parameters are important:

- Frequency response: the output response of a sensor to the input that varies in frequency
- Dynamic range: the range of values from the sensor from the smallest to the largest output

- Accuracy: the degree to which the sensor can measure the parameter in comparison to the true value
- Resolution: the smallest measurement unit that the system can produce. In most cases, if the sensor is an analog type device, the resolution will be determined by data acquisition system of the data collector
- Calibration: the relationship/transfer function between output response and the corresponding input values

The data collection process in an automated system starts at the sensor (or transducer). This is the device that does the actual sensing, e.g., the vibrating element in the microphone, the CCD (charge coupled device) in the camera, and so on. In the past, it was necessary to periodically calibrate the transducer in order to get accurate actionable information from it. As the sensors get "smarter," much of this information will be stored locally on the device itself. One can think of this as having the entire instruction manual for your new camcorder being stored right on the label.

Transducer Electronic Data Sheets (TEDS) as defined by IEEE 1451.4 will play a role in the use of smart sensors. The TEDS will provide information to help the implementation of plug and play connectivity among sensor measurements, as had been achieved with the USB devices and computer. Depending on the class of the sensor, digitally stored information on the sensor is stored with the sensor and can be easily connected to a data acquisition system since the interface has been defined. "Imagine, for example, the benefits to the shipping industry. A smart TEDS sensor could be installed to monitor the condition of contents in a refrigerated or pressurized package. Because of the standardized TEDS data structure and interface, a receiving dock could automatically detect the contents of the package and its conditions, regardless of its manufacturer and origin, saving time by simplifying the receiving process. It wouldn't matter if the information transfer from the package occurs over an analogue or digital wire, via a wireless protocol such as Zigbee, or by RFID. The significance of TEDS is the standardization of the structure of the self-identification mechanism."[17]

The architecture of the smart sensor is defined by the IEEE 1451.4 standard which consists of the TEDS and the sensor. TEDS provides the configuration, scaling and calibration information necessary to attach to the sensor. Implementation of a data collection system that uses this standard will provide the flexibility of connecting to multiple sensors. "Prognosis architectures must be developed given the current state of sensor technology readiness. Equally important is that these architectures are designed with a high degree of modularity so that new sensor technology can be integrated as the current state of the art expands."[18]

2.3.2 Sensors

Sensors form the fundamental inputs to a data collection system. A sensor is basically a transducer device that detects and converts some form of physical property into another. In this data collection system, the sensors provide the data in a digit form or can be converted in order to interface to a processor. Fundamentally, the sensors provide the capability to monitor the environmental or operational condition of the platform they are embedded on. The environmental sensors will primarily involve temperature, humidity, vibration and shock. Additional sensors will cover the primary sources of operational degradation. See Figure 2.4 for a general overall summary of the types of sensor classes. Factors that impact the selection of sensor are power consumption, size, response time, dynamic range, sensitivity and frequency response. The application of MEMS and nanotechnology will play an important role in the development of advanced sensors. It is these technologies that will provide for integration of sensing capabilities into a very small form factor.

"In an ideal system we would monitor the loads going into every critical component on the vehicle and pass these through a dedicated analytical model of that component; however this would prove unfeasibly expensive. A compromise must be sought between the number of measured components and our ability to infer the loading on one component using measured data from elsewhere. The more we reduce the measuring the more we rely on the analytical model and the more we increase our uncertainty."[8]

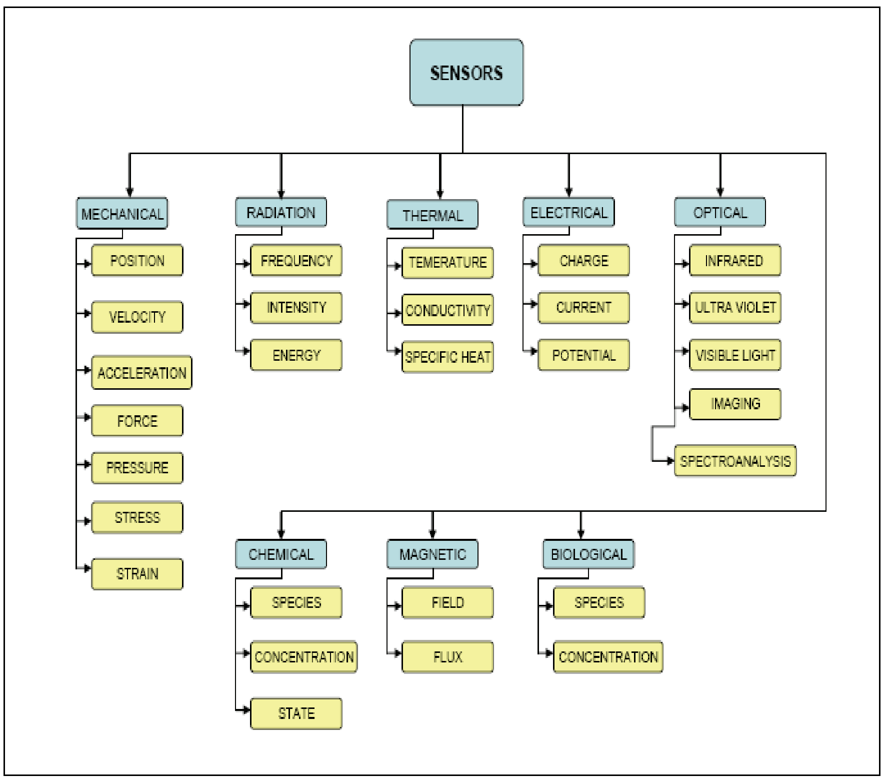


Figure 2.4. Sensor types.[19]

2.3.2.1 Carbon Nanotube (CNT) Based Sensors

The element Carbon comes in many forms even in its pure state as depicted in Figure 2.5. The form we run into the most is graphite (pencils, charcoal, soot). In this configuration, the carbon items are strongly bonded to themselves in only two dimensions. The layers you see in figure 2.5a slough off of each other very easily, making it easy to mark paper or canvas. With substantial application of heat, pressure, and time, the carbon atoms in diamond can be forced into a diamond lattice. Essentially, we have squeezed the layers together so that the atoms are now bonded in three dimensions rather than two.

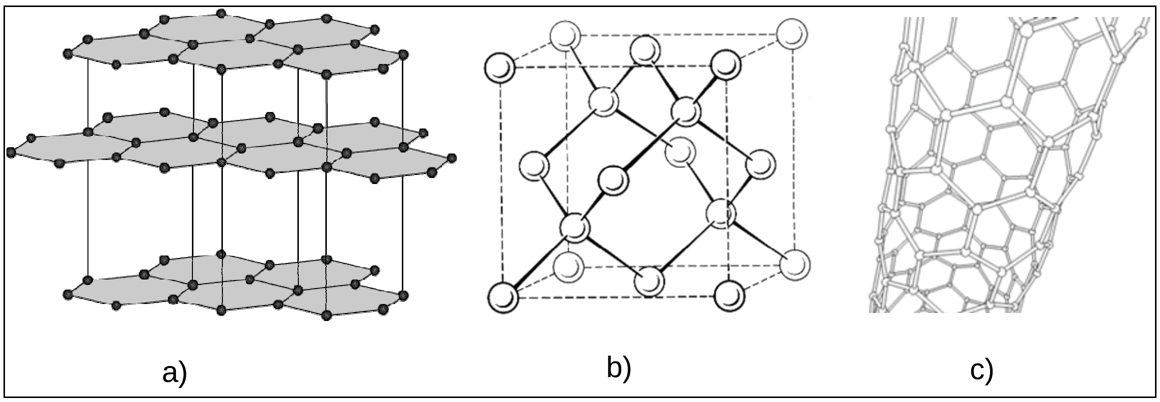


Figure 2.5. Structures of carbon as a) graphite, b) diamond, and c) nanotube.

Using advanced chemical vapor deposition techniques (like making dry ice except for single elements) the carbon can be grown so that it is still bonded in a planar configuration only with the flat layer of carbon rolled into a tube. In essence this would be a single-walled carbon nanotube.

Now think of this tube as a conducting electrical wire. In an analogous sense of using different traditional wire materials such as copper or aluminum, the conductivity (and other electrical characteristics) of a CNT can be altered by selectively doping it. See example in Figure 2.6

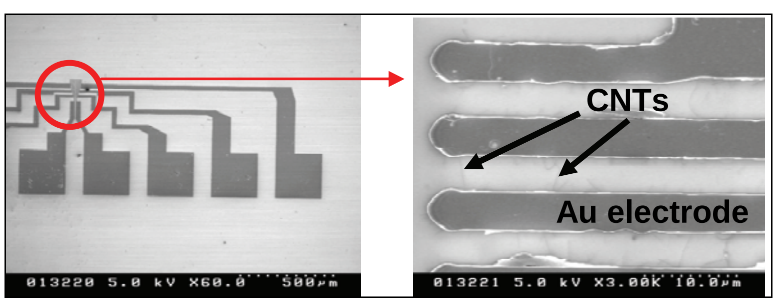


Figure 2.6. Carbon nanotube based field effect transistors (CNT diameters ~ 2 nm).

From the perspective of data collection what this means is that the ability to dope is the ability to sense. Much like biological systems, the CNTs can be designed with specific receptor sites that are activated by specific biological agents or chemicals. While there is a more immediate and obvious chem/bio – hazard detection application, future logistical ramifications are substantial since the devices could be tuned to "smell" wind/weather currents or activities associated with recent hostile activity.

2.3.3 Intelligence: Processors

Until now, microprocessors have been the workhorse for computation at the PC desktop computer, laptop and embedded system level. That said, the tremendous advances in microprocessor technology have provided a springboard for affordable early generation system integration such as Systems On a Chip (SoC), MultiChip Module (MCM) and System-in-Package (SiP). The integration of the processing and communication capabilities currently underway started with placement of microcontrollers and very specific wireless Radio Frequency (RF) communication devices within the same chip package.

The development of the processor or processing engines has made a significant growth in the inception in the last several decades. In attempting to summarize the present market, the processor can be classified by the following types: Microprocessor, Microcontroller, Digital Signal Processor (DSP), Application Specific Integrated Circuit (ASIC) and Field Programmable Gate Array (FPGA). These various types of processors have all been found in embedded system designs that have computation processing requirements along with control of input/output functions, not just simple data collection. The application will strongly dictate the type of device that should be used. Some applications have incorporated a mixture of these processing devices into the embedded system design. The following paragraphs will discuss the application of the microprocessor and microcontroller since they are the most popular and generic implementation for processors. As the task of data collection expands further into the processing aspects, the use of advance processors will have to be employed to address the required computational requirements necessary for on-board self prognostics, a fundamental element of prediction.

2.3.3.1 Microprocessor

The microprocessor is the fundamental building block of the digital age and has a significant impact in most of our lives. It is the Central Processing Unit (CPU) that is found on our desktop and laptop computers. This is an integrated circuit package that provides some fundamental and powerful processing capability in today's computer. Its development started with the Intel Company. Through the development of integrating many discrete components on a very small package, the microprocessor was born. Intel introduced the 4 bit microprocessor as a general purpose device as a marketing decision after the original customer rejected the device in their design. It is from this ominous beginning that the microprocessor has evolved into the fundamental building block of the digital age.

The data bus width has expanded from the original 4 bit into the 64-bit microprocessor found on today's systems. This expansion of the data bus has permitted the increase in memory size that the microprocessor can have access to. The technology has evolved to provide a significant increase in capabilities while reducing the package size at a faster speed of operation. The architectures of the microprocessor have been implemented in different fashions to provide better performance by various semiconductor manufacturers. Even though the fundamental foundations are different, the outcome can be the same. The microprocessor provides the capability to execute a series of repetitive user tasks based on a set of instructions that are defined (or programmed) by the user. It has the capability of interfacing to external memory for retrieving and storage of data. The microprocessor by itself will not operate without sufficient support architecture. It must have external peripherals to support its interaction with the external world. See Figure 2.7 for a typical microprocessor based collection system.

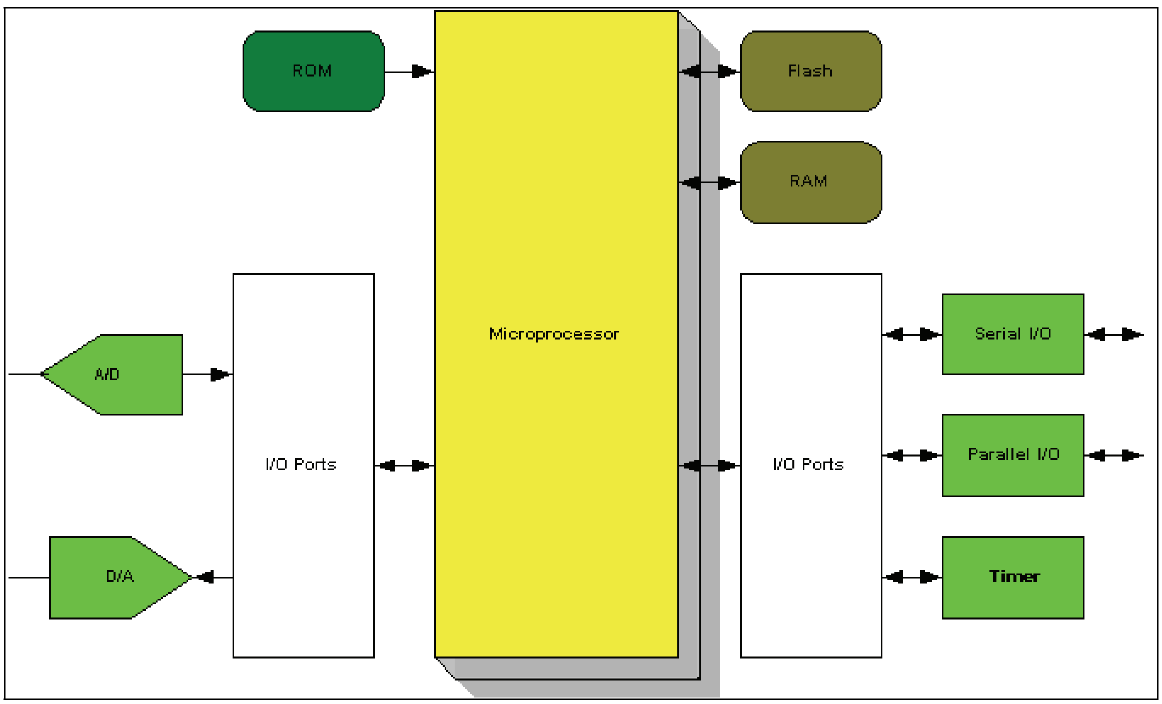


Figure 2.7. A typical microprocessor based collection system.

Since the inception of the microprocessor in the early 1970's, the processing technology has improved and produced many generations of microprocessors. There are many architectures of the microprocessor being offered by several manufacturers. The following table shows some of the microprocessor architectures that have been developed.

Architecture	Manufacturer/developer
X86	Intel
ARM (Advanced RISC Machine)	ARM Limited
SPARC (Scalable Processor Architecture)	SUN
MIPS (Microprocessor without Interlocked Pipeline Stages)	MIPS Technologies
Power PC	Apple, IBM, Motorola
Cell	Sony, Toshiba, IBM
Core Duo	Intel

The overall business/marketing milestone for the microprocessor has been to increase the operating frequency of the CPU and the instruction set speed performance. This is illustrated in Figure 2.8 where the performance and power data for several generations of Intel microprocessors are shown.[20] "Both power and performance have been adjusted to factor out improvements due to process technology over time, and all data have been normalized to the i486 processor." The curve fit of the microprocessors that have processors used on the desktop computers have come with increasing processing capability, but this comes with a cost. The curve fit shows that power is NOT linearly related to performance, but that doubling the performance will cost a little less than a factor of 4 times the power. This is a significant penalty for a data collection system.

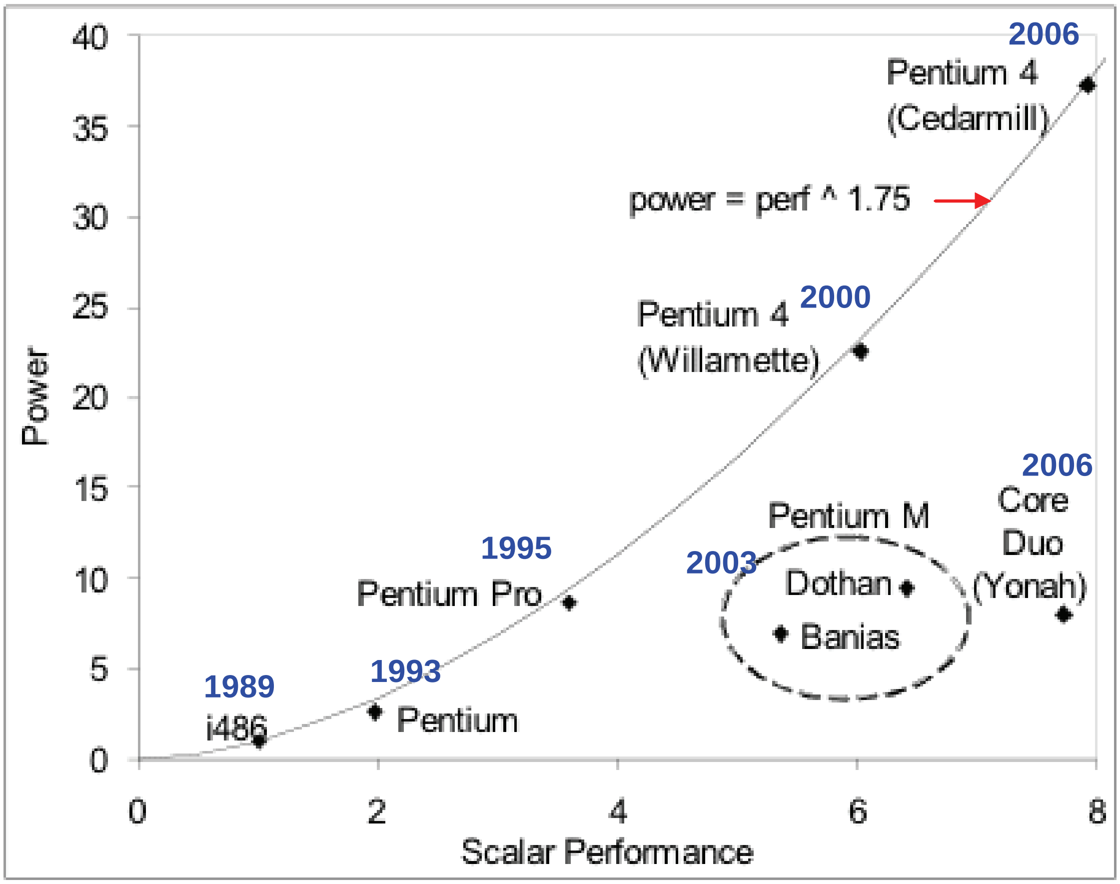


Figure 2.8. Intel microprocessor performance.

The increase consumption of power by the microprocessor did not escape the semiconductor manufacturers. Pentium 4 microprocessor power consumption is more than a 100 W light bulb. Popularity of laptops/notebooks has pushed the manufacturers to produce microprocessors for the mobile applications that may have to operate off of battery power. The Pentium M was Intel's design for laptop/notebook applications.

The microprocessor architecture was modified from the Pentium family to increase the power efficiencies of the chip. Power consumption of the Pentium M is in the order of 25 W or at least a 75% reduction in power over the Pentium 4.

2.3.3.2 Multi-core Processor

As the demand for increased performance is being pushed by media and gaming industries, the requirements are being met with new microprocessor architecture. The industry is incorporating multiple CPU cores onto a single integrated chip package. From the previous graph, the Core Duo (Yonah) microprocessor is a multi-core design. In this case, there are 2 CPU processors on the integrated circuit that shares a common data bus (see Figure 2.9). The design has been able to show higher performance with a reduction in power consumption. This concept is expanded to a quad-core version that Intel has just recently announced.

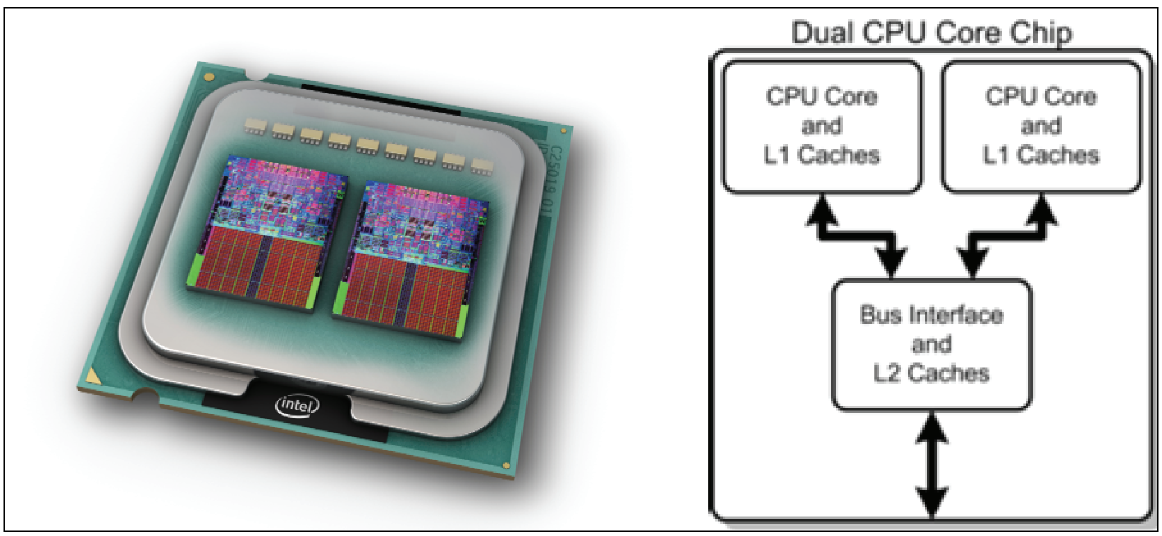


Figure 2.9. Intel dual core processor.

As this next version of multiple processor cores evolves, the necessary computational power required for the predictive process will be able to migrate down to the embedded data collector. The fundamental pieces such as data collection, data storage, security encryption of data for transmission and predictive processing will be able to occur simultaneously in the same chip. The Cell microprocessor is another multiple microprocessor architecture being jointly developed by Sony, Toshiba, and IBM. At the present time, the cell processor is being used in consumer entertainment gaming applications. See Figure 2.10 for cell processor core. The design of the Cell microprocessor is to provide higher computational processing power over what would be used on the typical desktop computer.[21] Applications of using the cell processor for scientific computing have been evaluated by Lawrence Berkeley National Laboratory (LBNL).

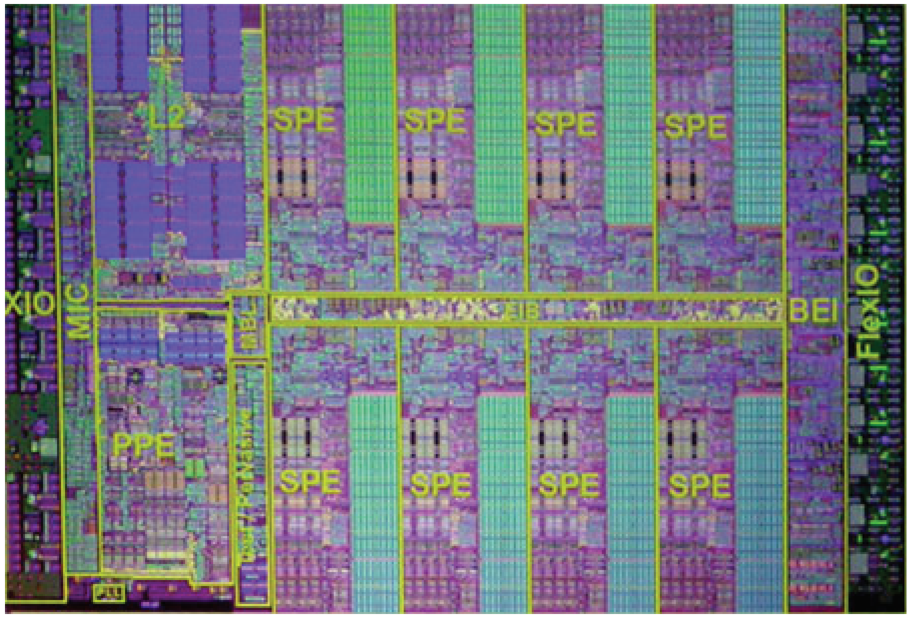


Figure 2.10. The Cell Processor (found on the Sony Playstation 3). There are a total of 9 microprocessors (cores) on this single chip. The core on the lower left (PPE) represents the controller core responsible for *pipelining* tasks to each of the remaining 8 (green) processors.

Presently, time the programming of this type of parallel processor is still in its infancy and difficult. What will be needed is the development of a programming language that addresses the parallel processing power of the multi-core chip. The case study showed that performance advantages can be gained by using the Cell microprocessor in application of scientific algorithms such as dense matrix multiply, sparse matrix vector multiply, stencil computations and 1D/2D FFTs. "The first generation of this technology will instantiate at most two cores per chip, and thus delivers less than twice the performance of today's existing architectures. This factor of 2x is trivial compared with Cell+'s potential of 10-20x improvements." In this case, a Cell+ is modest architectural variant on the Cell architecture. First generation potentially fieldable by 2015, meaning that 2nd generation Cell microprocessor should reach maturity by 2025.[22]

2.3.3.3 Microcontroller

An excellent example of an enabling technology with respect to data collection is the microcontroller. As one of the first proliferated SoC technology, it effectively provides a fundamentally simple data collection system on a single chip (Figure 2.11). As such, it represents one of the most significant advances for the overall capability of digital data collection because:

- magnitude reduction in physical factor for a data collector
- significant energy efficient realized through chip integration
- embedded interfaces to transfer data

- ability to basic on processing of data
- very affordable and cost effective

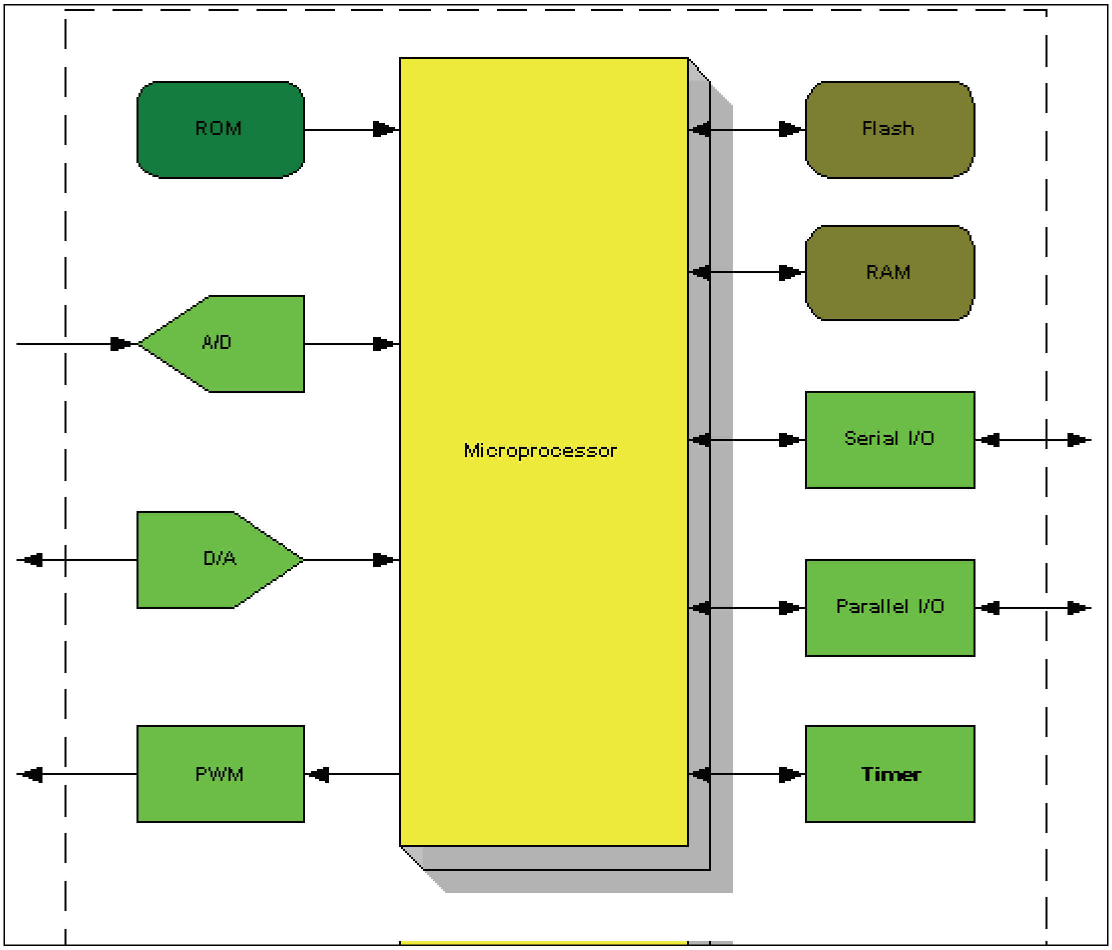


Figure 2.11. Block diagram of typical microcontroller architecture.

A microcontroller is an example of a "system on a chip" concept where the microprocessor and supporting peripherals have been integrated onto a single package. For the purposes of data collection, the processing power of a microprocessor is not necessarily needed. The microcontroller provides a solution for applications where there are no requirements of speed, complex computational capabilities and large memory storage. Similar to the microprocessor, the microcontroller bus comes in various data bus sizes to satisfy applications. The microcontroller as the name implies is typically used for applications where processes need to be monitored and controlled. It has become ingrained in many applications in everyday life. Many critical functions of the automobile are monitored and corrective/preventative actions taken when required, such as braking, air bag deployment and steering control.

One should not think that the microcontroller is an ideal replacement for a microprocessor-based system. There are tradeoffs between a microprocessor and a microcontroller system. The microcontroller does not have a very large nor powerful instruction set associated with the programming of the device. It is not capable of very complex mathematical operations nor does it have the very large internal memory storage. It has been designed to offer many input/output connections. Several sensors can easily be accommodated by a microcontroller. Since a significant number of the peripherals have been incorporated on the same package, the reliability of the microcontroller is better than a microprocessor system due to the reduction in the number of interconnects. It has the advantage of a small physical size to allow design onto a board. The development of applications tends to be simpler since the manufacturer typically provides software/firmware/hardware support. The microcontroller is cost-effective compared to the microprocessor.

2.3.4 Memory

There are two general classes of memory devices: Read Only Memory (ROM) and Random Access Memory (RAM). Both types of memory devices will be used in a data collection system. The acronyms for the memory devices were very descriptive during the early days of the modern electronic computer, but the meaning has become a little muddled as the technology evolved. The ROM is typically very small in size and contains the program code (known as boot firmware) that is executed upon start up of the data collection system. As the acronym indicates, it was originally meant to be read so that the information contained was permanent. The information is programmed in the beginning and any modification requires a physical removal of the memory device. It is not dependent upon a constant source of power in order for the memory device to retain the stored information. The family of ROM devices has developed over the decades to semi-permanent devices with the following names: Programmable Read Only Memory (PROM), Erasable Read Only Memory (EPROM) and Electrically Erasable Read Only Memory (EEPROM).

RAM devices provide the bulk of the memory use for the processor associated with the data collection system. For highly computational computer systems, the RAM memory is the pacing item that dictates the speed of operation in the system. But for a data collection system associated with prediction, speed should not be an issue since attached sensors will not have to be sampled at high enough rates to require data storage that impacts the speed selection of the memory device. RAM is typically divided into two families: Static Random Access Memory (SRAM) and Dynamic Random Access Memory (DRAM). The difference is in the architectural structure of the devices. DRAM requires an infrastructure where the memory device is supplied a refreshing signal in order to retain the stored information. SRAM does not require this support, but the density per unit area is low in comparison to DRAM. Flash memory devices actually fall under the ROM family, but are being used more these days in RAM-type structures.

2.3.4.1 Memory "Stickers"

Small, easily readable memory stickers will function like digital "post-it" notes. One variant is the Memory Spot, an experimental chip being developed by Hewlett Packard (HP). This is another example of a System-On-a-Chip that industry is pursuing. At first glance, it would seem that it is another RFID chip; however, its application is much broader. It is about the size of a grain of rice (2-4 mm) with a built-in antenna, processor and memory (Figure 2.12). There is no power source attached to the chip. Similar to the passive RFID tags, this chip will induce its power from the reader/writer device that is positioned close to it. It is wireless and the reader/writer does not need to make physical contact. The range is in the order of mm versus the meters obtained through RFID. More importantly, the amount of memory on these spots already approaches up to a megabyte, meaning that 1 full page of this text could be stored on a spot smaller than the letter “a.” This spot could then be affixed to a hard copy, giving the user the advantage of both types of media.

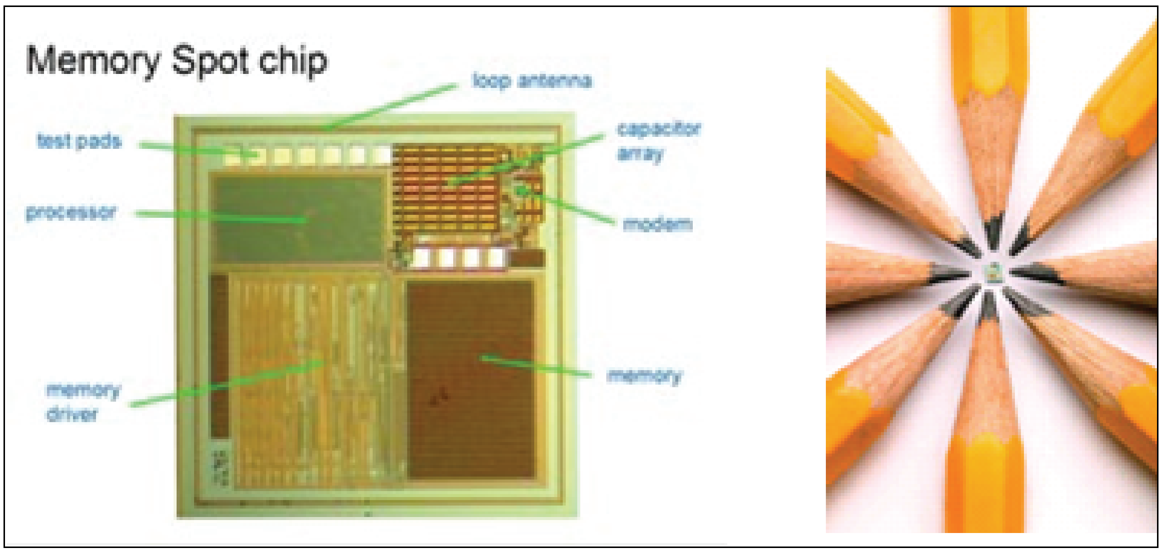


Figure 2.12. Images on the composition of the chip and its relative size.

Presently, this is a read/write device that has on the order of 5122KB. The data transfer is on the order of 10 Mb/sec – roughly 10 times faster than the Bluetooth wireless communication standard. Working prototypes have been able to store images or dozen of pages of text that can be transferred instantly.

2.3.4.2 Memory Types: See appendix D.

2.3.5 Output Interface

There are various means to relay information from a data collection system. There are the standard communication interfaces, as specified in the following paragraph, for hardware communications interfaces. These interfaces are designed for the data transfer between a processor and peripheral devices. A simple indicator such as an audio or simple embedded light might be considered to attract immediate attention if necessary. The problem with this type of output is that it will drain power if there is no response to the alarm. Another option is incorporation of an RF transceiver such that data can be transmitted optically or via short range

RF. The incorporation of a physical mechanism to interface to the data collector is a critical item for consideration in a data collector. When the basic means of automated communication is not available, it is important to have an alternative to removing the data from the embedded data collector. This could be through an interface on a physical connector, or removal of a portable memory module.

There are many types of existing interfaces that have evolved over the decades to transfer data. Data collection systems have employed many of these standard interfaces to exchange data to the electronic devices. The popular interfaces are Ethernet, PCI, USB, PCI Express, Firewire, Compact Flash, GPIB, RS-232/485, and ISA. "Since the accuracy and sample rates of most applications are perfectly within the capabilities of both board- and box-level solutions, other factors must be used to determine which solution is best for a particular application. Here are some of the key factors:

- Distance to the Sensor or Measurement
- Distance is an important consideration for two reasons: First, it is expensive to run long wires in a large system. Second, each foot of wire connecting your sensor or output to a remote host computer increases your susceptibility to noise.
- Portability
- Expandability
- Changing or Upgrading
- Price
- Pure Speed
- See table in appendix E for various bus/interface specifications and application to 16 bit A/D converter[23]

2.3.5.1 Security Issues

A data collection system that has an optical or wireless communication channel may pose a security issue if the system transmits in an operational environment. One would want the capability to disable a communication channel when operational conditions demand for it to be placed in a stealth mode. Encryption may be necessary for certain assets in order to prevent the enemy from using the channel communication to interfere with the mission.

2.3.5.2 Standards

Standards will be necessary to make data useful and accessible across various implementations. Manufacturing information currently exists in multiple databases, but the retrieval of it is vital in order to use the information. Compatibility between various systems will be an issue. There are many standards that have evolved in the data collection world and in the world of communication systems that should be considered in the development of data collector systems. These standards are typically associated with organizations like the Institute of Electrical and Electronics Engineers (IEEE) and International Standards Organization (ISO). An example of a standard is the IRIG106 Chapter 10 for digital on-board recorder standard for digital flight data recorders for aircraft that is the result of efforts by the Range Commander Council, manufacturers, and users. "The standard takes into account all steps in the acquisition process from signal source through to analysis software and provides an easily implemented means for interoperability and data interchange." The following examples highlight the necessity of standards:

- A Metrics Evaluation Tool (MET) is being developed to evaluate the performance and effectiveness of vibration features typically used in HUMS. The Tool allows helicopter manufacturers and HUMS end users to evaluate effectiveness of an algorithm through statistical analysis of normal and fault data. "Many of the lessons learned at this point in the project are centered on the data sets, data population, and client-server interfacing. The availability of well-documented and easily implemented data continues to be an issue. Identifying standards of the raw formats and headers on these data sets and developing ways to automate the data population will greatly improve the likelihood of data making it in the database for use in Metrics Evaluation."[24]
- "What must be standard on ED/EP (Embedded Diagnostics/Embedded Prognostics) applications is the data schema: the formats and interfaces that allow standardized information to be transmitted to standard management information systems over standard communications mechanisms and via standard portable maintenance aids of various kinds. The selection and application of standards for these processes is a fundamental role for EDAPS (Embedded Diagnostics and Prognostics Synchronization), including the designation of commercial standards when feasible."[24]
- A presentation from the Defense Sustainment Consortium entitled "Applying Reusable Architecture and Data Representation to CBM" made the point that is made is "CBM can be implemented at far less cost if standard, reusable architecture and data schemas are employed across multiple platforms
    - Use open architecture
    - Use standard data tagging
    - Use existing maintenance data infrastructures
    - Develop reusable diagnostic and prognostic systems
    - Develop reusable auto data collection and transfer
    - Develop parts usage data

2.3.5.3 Wireless Sensor Networks

Most data collectors are hardwired systems. There is a physical attachment between the sensors and processors which samples and collects the sensors' data. Depending on the complexity of the platform/system being monitored, the installation and maintenance of a hardwired infrastructure could be very costly. Wireless sensor networks may not be realistic for legacy systems or for new concept platforms if requirements are not in place prior to the design and development phases. A newer concept for implementation is that of a wireless sensor network. This sensor network offers the advantages of not requiring a hardwired infrastructure and the flexibility of being adaptable to the complexity of the platform. Sensors can be added or scaled in an "ad hoc fashion" to meet the complexity of the platform and not constrained due to physical limitations. A concept of wireless sensor network is: "Low-cost, rapidly installable, grid of self-forming wireless network of sensors coupled to small computers sufficiently powerful to process the sensor and notify operators of conditions that demand attention immediately or pass the data at selected times upstream for further long term analysis. Wireless sensors minimize the modification to the managed equipment (airframe, for example). These are very small, low-power, low-cost wireless communications platforms that are coupled to very small, standard, low-power, low-cost MEMS- and nano-technology-based sensors."[25]

There are many companies that have integrated wireless communication capabilities with some form of sensor-monitoring functions. Two of these companies are Crossbow and Moteiv. Both companies have evolved from programs on low power, wireless sensor networking conducted at the University of California, Berkeley. One of the important factors that both companies address is the low energy requirements of the entire system from the standpoint of hardware, firmware and operating system. They use the term "mote" to describe their concept of integrating sensors with a microcontroller and transceiver on a small board configuration. See block diagram in Figure 2.13.

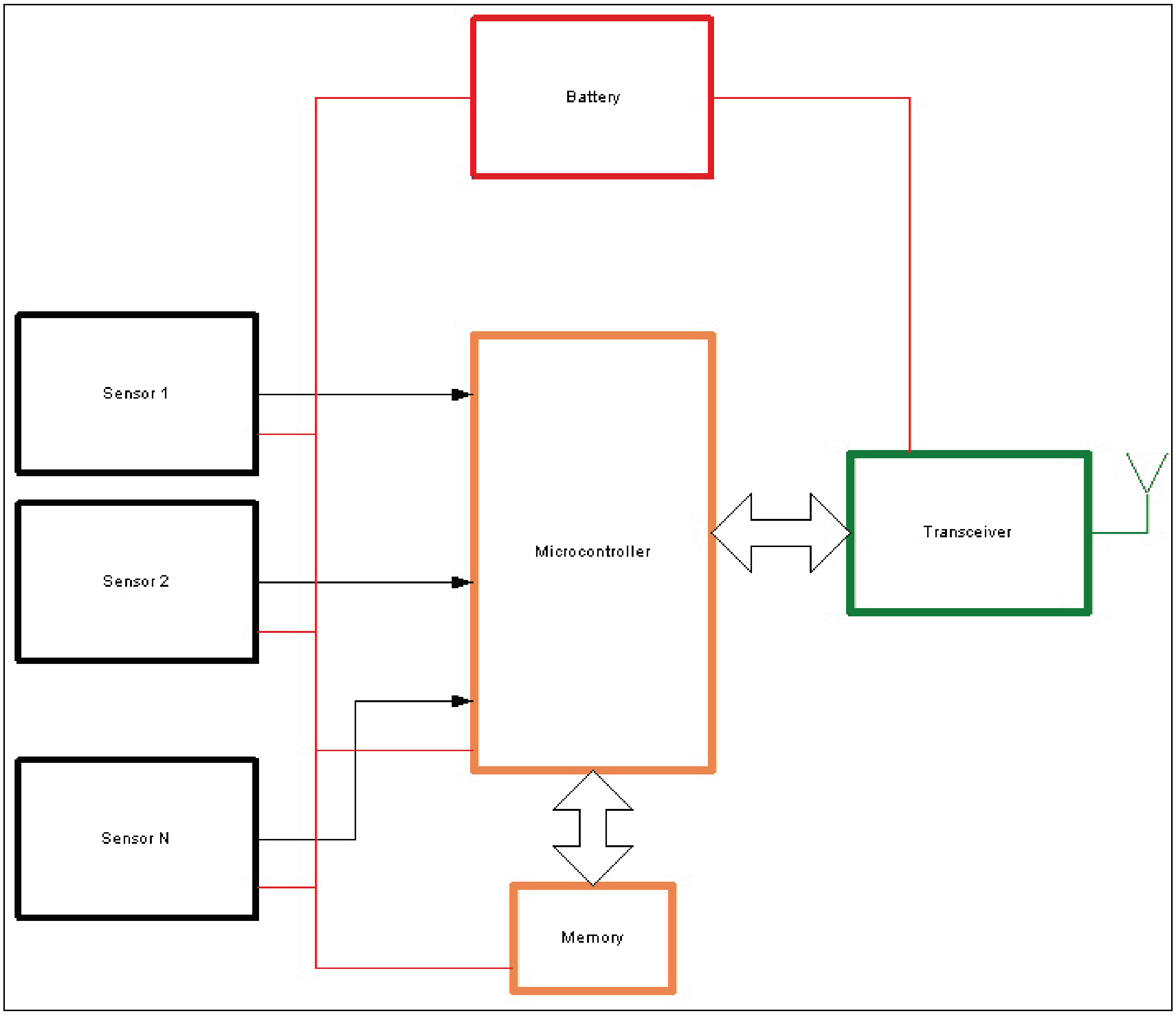


Figure 2.13. Block diagram of wireless *mote* sensor.

These motes are designed for long-term operations with very small batteries such as coin and AA cells. To conserve battery power, these motes are placed in a very deep sleep mode where the energy draw is very small. Periodically, the motes are awakened and the sensors are activated quickly and processed before quickly being placed back into the sleep mode. In addition, they are designed with the attribute of being able to form an "ad hoc" network to provide a reliable, robust and self-configurable configuration. This allows the number of motes to randomly expand/contract while providing the flexibility to configure the communication channels over which to relay the information between each other. Hardware motes are shown in Figure 2.14 below from Crossbow and Moteiv.

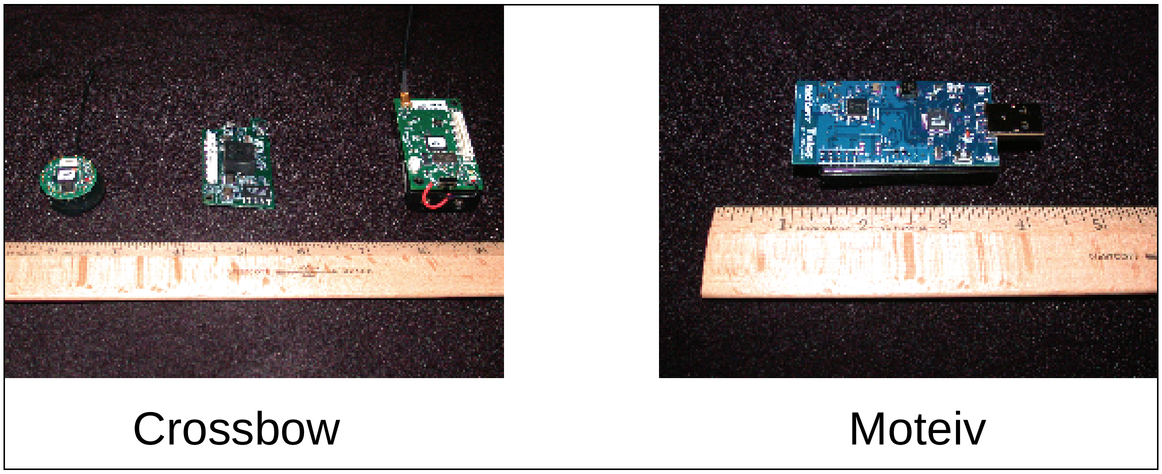


Figure 2.14. Crossbow and Moteiv motes.

Crossbow offers flexibility through various configurations of its motes that can mate with various modular sensor configurations as shown in Figure 2.15. As seen in the table, there are various sensing capabilities such as vibration, temperature, humidity and barometric pressure.

Sensor Data Acquistion Boards

Features	MDA300	MDA320	MDA100	MTS300	MTS310	MTS400	MTS420	MTS510	MDA500
Accelerometer (2 Axis)					●	●	●	●	
Actuator Relays	●								
Ambient Light						●	●		
Barometric Pressure & Temp.						●	●		
Buzzer				●	●				
External Analog Sensor Inputs	● (12-bit)	● (16-bit)	● (10-bit)						●
GPS							●		
GPIO	●	●	●						
Magnetic Field					●				
Microphone				●	●			●	
Photo-sensitive Light						●	●		
Photoresistor			●	●	●			●	
Rel Humidity & Temperature	●					●	●		
Thermistor			●	●	●			●	

Figure 2.15. Summary of state of the art sensing elements suitable for logistical data collection.

2.3.6 Power Issues: Energy Harvesting

Distributed data collection capabilities will be greatly enhanced by the emergence of micropower generation. Whether via ambient energy harvesting or long life betavoltaics, new options will abound to meet the prime power challenges faced by many of the contemporary, initial forays into broad ranging automated digital data collection (e.g., the active RFID tags discussed in section 2.2).

Like money, there are two basic approaches to ensuring sufficient supply: either save or earn (preferably both). Circuit architectures that are designed as power misers constitute much of what is available today for data collection. There are presently data collection systems that are battery operated that will operate over several months to a few years, with as many as 21 sensors and a full GPS capability; all run from a paper-thin battery on a chip for 5 years. Generally, the additional tradeoff for "sipping power" is to reduce the frequency of collection to a minimum. We do not necessarily need the temperature reading of an asset every 5 seconds, but perhaps 4 to 6 times a day is reasonable. Companies such as Crossbow and Telos have helped develop this commercial concept of small, battery efficient data collection system with sensors.

In cases where we expect more frequent data collection, energy harvesting is being pursued to develop alternative means to recharge the system or operate without an external power source. Power reduction strategies are being developed for these wireless sensing elements. For a sensing system that requires only data sampling rates of 1 to 10 Hz, a wireless sensor node may be possible. Strict energy management protocols and good designs are required to make energy harvesting an option for devices such as vibration sensors.[26]

2.3.6.1 Vibrational

MicroStrain, Inc. is working on a wireless strain sensor for tracking damage to Navy helicopters. The company has demonstrated the concept of a wireless sensor attached to an energy harvester.[27] Using the rotating helicopter motion, a sensing system will operate indefinitely by converting the cyclic strains into DC power using piezoelectric materials. Figure 2.16 shows the prototype's implementation.

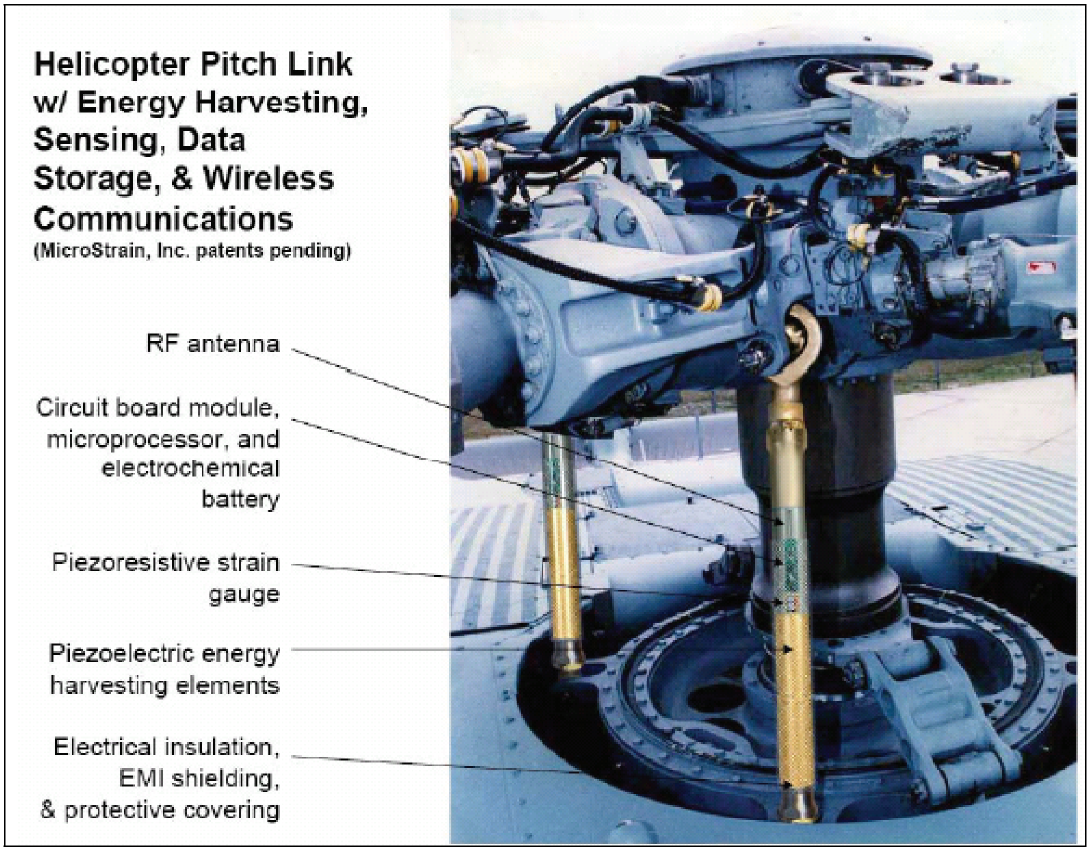


Figure 2.16. MicroStrain's energy harvesting, wireless sensor hardware.

2.3.6.2 Photovoltaics

Solar energy harvesting for embedded systems has been investigated to demonstrate that the concept is feasible to enable a near-perpetual, harvesting-aware operation of the sensor system. Using solar energy harvesting involves complex tradeoffs in the conversion of energy, storage requirements, and power requirements of the sensor system and power management of the embedded system. All of these need to be optimized to ensure overall system efficiency.

2.3.6.3 Betavoltaics

Betavoltaic refers to an energy technology that harnesses the electrons given off in radioactive material during its decay. It is a subset of the field where a power device uses the particle emissions from radioactive isotopes to generate electricity. Just as light interacts with photovoltaic material to generate electrons, radioactivity interacts with betavoltaic material to produce electrons. The key distinction is that the betavoltaic power source carries its "sun" with it. See Figure 2.17 for a cross-section illustrating the operating principle of a betavoltaic.

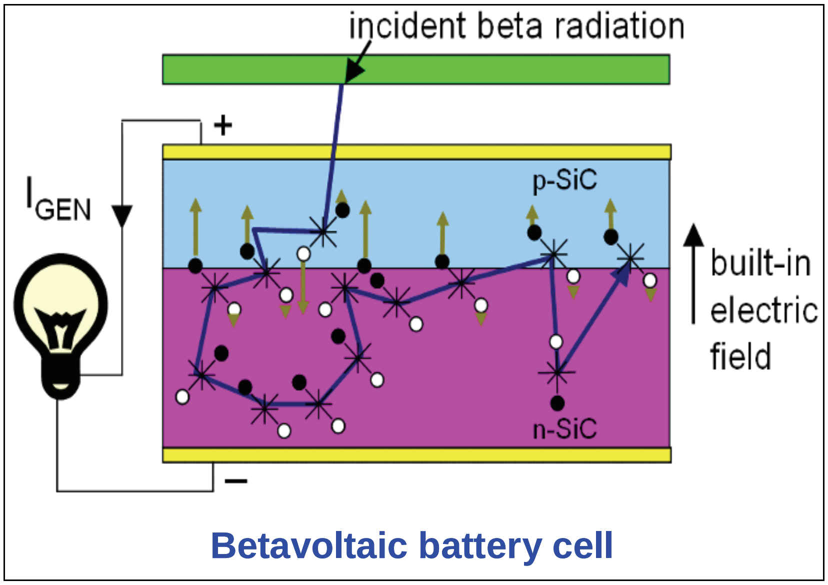


Figure 2.17. Betavoltaic design for implementation into coin cell form factor.

The development of betavoltaics has a long history that goes back at least 50 years. Originally, betavoltaics were conceived to supply high voltage, high current demands, but can be adapted for the smaller power requirements of a data collection system. Although radioactive material is used, the beta particles have low energy and can easily be shielded so as not to permanently irradiate users.

2.3.6.4 RF Parasitic Energy Harvesting

Analogously, parasitic power extraction of RF (from the rapidly filling bandwidth around most urban and suburban centers) is also being investigated. Primary work focuses on coupling efficiency and charging techniques. Relatively small amounts are found since ambient RF is geometrically widespread, making it essential to store the power with high efficiency.

Table 2.1. Performance of parasitic micropower sources.[28]

Energy source	**Performance**	**Notes**
Ambient radio frequency	<1 uW/cm^2	Unless near a transmitter
Ambient light	100 mW/cm^2 (directed toward bright sun)	Number could vary widely with a given environment light
Thermoelectric	60uW/cm^2	
Vibrational microgenerators	4 uW/cm^3 (human motion-Hz) 800 uW/cm^3 (machines-kHz)	
Ambient airflow	1 mW/cm^2	

2.3.6.5 Culmination: Universal Energy Harvester

The use of solar energy may not be applicable in many situations,[29] likewise for vibration. In fact, for any power harvesting approach, there will be situations that do not lend themselves to particular modalities.

However, the concept of using a hybrid approach bears substantial merit. Much like the highly successful hybrid gasoline/electric vehicles that have taken the consumer marketplace by storm in recent years, using multiple modalities greatly extends the tradespace available to the designer or user.

A comparison of the power density from harvesting technologies is shown in the table below with the rankings from high to low.

Harvesting technology	**Power density**
Solar cells(outdoors at noon)	15 mW/cm^3
Piezoelectric (shoe inserts)	330 uW/cm^3
Vibration (small microwave oven)	116 uW/cm^3
Thermoelectric (10^0C gradient)	40 uW/cm^3
Acoustic noise (100dB)	960 nW/cm^3

2.3.7 Display Technologies for Data Collection

Display technologies are important for data collection as mechanisms by which the human being can interface and visualize the information that is conveyed by the data. This technology will be looked at from the prospective of its application for data collection. The technology that will be discussed is not the displays associated with a desktop PC, but variations of a smart mobile technology. The technology can be used for both input and output operations—not strictly output. Nor will the discussion deal with much simpler display technologies such as simple Light Emitting Diode (LED) or alphanumeric displays. A PC computer display can be used, but is not designed to be mobile. The laptop, or its smaller cousin, the notebook, are mobile versions of the PC computer with the ability to operate without hard connections to an electrical power source, significant form factors and weights that are considerably advantageous to applications in the field.

2.3.7.1 Tablet PC

There is no formal definition of what encompasses a tablet PC. The only certainty about the term is that it entails a mobile computer. As the PC world evolved, the need for mobility followed suit. Even the descriptive marketing terminology of laptop and notebook that is used to describe the technology adds to the confusion. The terms are used interchangeably to connote the concept of a portable, light weight, hardware integrated form factor. The names are descriptive and are not necessarily accurate in terms of usage or size. Typical human interfaces to the computer include the keyboard and mouse. Another method of entry is available on the tablet PC. This is the integration of a digitizer that allows information to be translated from a physical entry on the computer screen and the information stored into memory. The digitizer permits an easier form of data entry by human beings. In addition, image scanning and handwriting recognition software has made importing and conversion into a standard storage format an important tool for data entry.

The tablet PC comes in various forms: slates, convertibles and hybrids. The slate is a mobile computer without the keyboard that has the appearance of a writing slate. A convertible is similar to a notebook with the ability of rotating the display panel to form the writing tablet which covers the keyboard. Finally, the hybrids are basically units that have a detachable screen from the keyboards. Since they all are basically mobile PCs, they provide the computation power and storage capability that would be necessary for a semi-autonomous prediction capability. The advantage of these types of hardware is the simple human-machine interface and the large storage capability available through memory. There are many vendors that offer the various forms of tablet PCs. See examples of Tablet PC configurations in Figure 2.18.

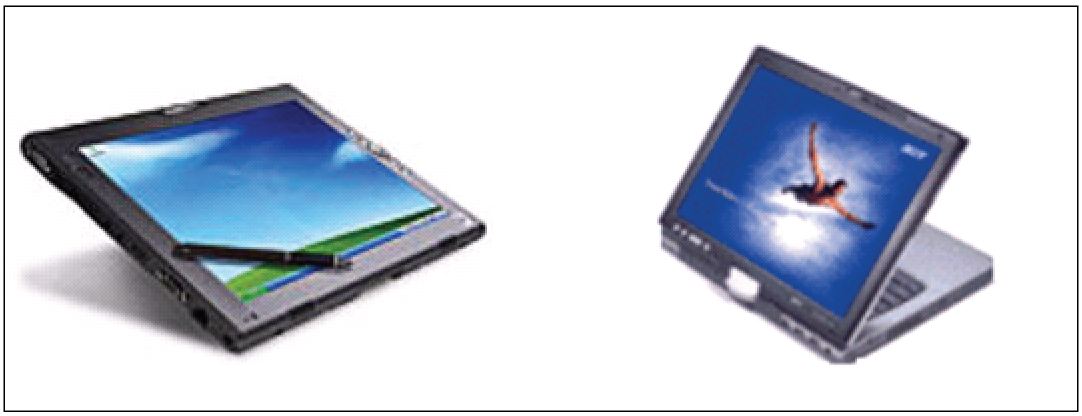


Figure 2.18. Examples of various configurations of the Tablet PC.

2.3.7.2 eReader

Electronic paper or electronic ink is a display technology that is designed to replicate some of the properties of paper. This technology overcomes some of the disadvantages of normal display technology. Traditional displays require constant power to maintain the image on a static display panel. In contrast, eReaders use light reflecting off of the display similar to how one sees the image on paper. The technology permits the display to be very thin, once again similar to paper. Applications are being developed by Sony and iRex Technologies to insert the technology into readers that can electronically store books or be applied as mobile handheld device for application such as receiving and displaying the local newspaper. The functionality is similar to the PDA except that the processing power is not necessarily embedded into the device. Like the tablet PC, the eReader in Figure 2.19 is envisioned as a digitizer so that hand sketch or notes can be inputted and saved. These readers offer the advantages of size and weight over the bulkier laptops and Tablet PC hardware. Commercial versions are being implemented by Sony and iRex as shown in Figure 2.20.

Figure 2.19. With eReaders, forms can be input with a significant advantage in size, weight and cost (compared to a laptop).

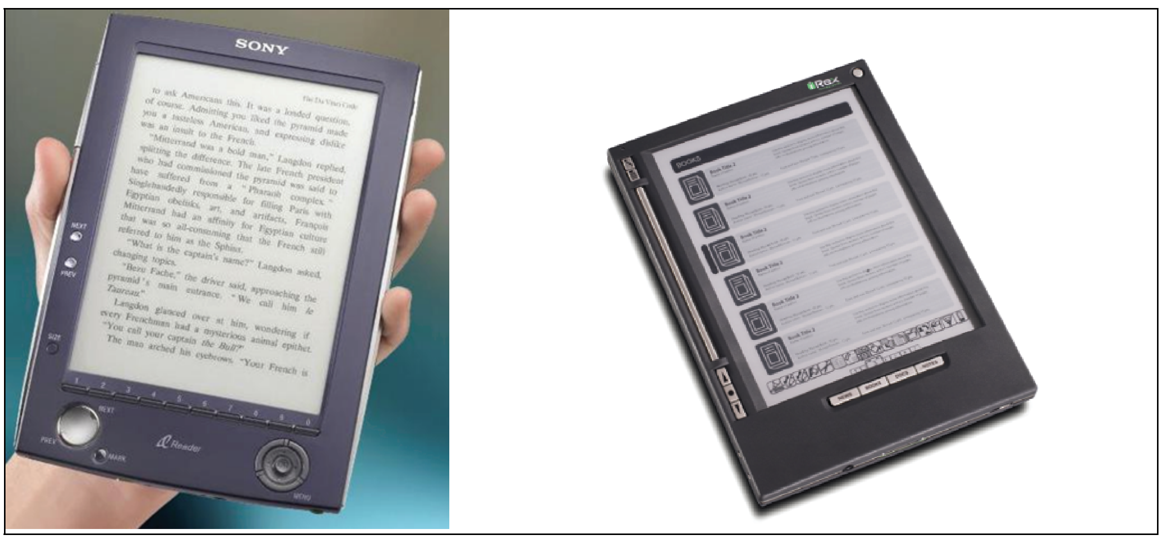


Figure 2.20. eReader versions from Sony and iRex.

2.4 Sources of Data

The predictive process will use many sources of information. Some of these sources exist outside of the data collection system for the asset of interest. These sources may be manufacturers, system developers, embedded systems, fleet operations and maintenance depots (business processes within and outside of the logistics enterprise). Currently, a significant portion of this information does not reside in a form that can be readily accessed. Identifying the important parameters from this extrinsic data will further aid in the fusion/analysis and exploitation aspects of prediction. Integration of these disparate pieces of information will provide a clearer picture than individual pieces of information.

2.4.1 Manufacturers

Design and manufacturing documentation will grow in importance to the logistics community. With regard to prediction, having access to data on assets from the initial manufacturing process will help optimize its deployment for maximum effectiveness. The performance of the sub-components is typically understood by the designer/manufacturer of the part. Computer aided design and analysis software will provide information necessary to formulate information pertinent to its location in the supply chain.

As an example, in manufacturing microprocessors for personal computers, the slower processors actually come from the same process and often the same wafer as the faster ones. Ever so slight variations in the semiconductor manufacturing process, such as impurities or exposure differences, result from geometric location on the wafer, location in the "boat" that carries several wafers in some of the processing, etc. Rather than throw away all of the CPUs that do not perform at the maximum clock speed, the majority of them are still functional, albeit with slower clocking. This maximizes yield (and profit) and also determines where a specific processor ends up. (The "runt" of the litter will not likely be the one selected for use in a high speed, graphic intensive PC).

2.4.2 System Developers

System developers have significant insight into the performance and operation of the military system/hardware. As the lead integrators, they know the theory of operation and performance capability. In the design of the system/hardware, the prototype hardware would have contained some test points used in the development, troubleshooting and evaluation of the hardware. Information collected provides a basis to form diagnostic capability during the design phase. For LPPC purposes, just as with the manufacturer's data, much of this information will be pertinent. The task is simpler if the system developers are tasked to collect and develop some of the foundation for a predictive system. A built-in diagnostic capability can be designed early in the process. As a step further, a built-in prognostics capability can be also designed into the system/hardware. It will of course be imperative to state these requirements in the specifications during the initial development cycle.

2.4.3 Embedded Systems

Many of these embedded diagnostics will provide indicators of the operational condition/performance of the asset. For complex systems, this includes test points and infrastructure that are implemented during the development stage for the evaluation of the operational performance.

As an example, in the development, production, and test evaluation of the PATRIOT PAC-2 fuze, these diagnostic indicators were used to assess the operation of the target detection system. For the design and production engineers, these diagnostic indicators served as essential tools in confirming the proper operations, or as indications of the source of a fault. This design feature may not necessarily be used when put into operational usage, as was the case for the PATRIOT PAC-2 fuze, but it provides excellent input for a data collection system.

Another example of such a structure is the data bus on military vehicles that provides access to the embedded sensors, but does not have an embedded monitoring system. The U.S. Coast Guard conducted a series of field experiments that showed the successful use of diagnostics to effectively evaluate the state of many electromechanical systems on their shipboard systems. They were able to develop a system that could "dive down" to successfully diagnose the failure of a flexible coupling on a link on a pump drive and leakage in a cycling system.[30]

2.4.4 Fleet Operations

The records of operational usage provide some secondary information on the condition of the platform. Although it does not provide (nor was it meant to provide) predictive information, the mining and trending of the fleet operational data should provide secondary information that would be useful for a predictive system. Although this does not provide direct input into a Physics of Failure prognostics approach, the statistical analysis of the fleet records provide secondary information to help identify the potential sources of faults.

2.4.5 Maintenance Depots

Records from the maintenance depots can be used to indicate the sources of failures. Even though failure analysis is not typically performed, there is useful information that can be generated from the repair information. By collecting and sorting the repair records, one should be able to identify the components of concern. Trending the frequency of repairs for the components over time will provide an indicator of the severity of the faults. Integrating this information with a predictive system will provide a significantly better tool to support the logisticians' efforts.

2.5 Examples of Data Collection Systems

The following examples are given to show existing data collection systems. This is not meant by any means to be an extensive list of data collection systems. In these examples, the data collection systems are on operational vehicles that could justify the implementation of a data collection system. In addition to data collection, these systems are designed to provide utility in the areas of diagnostics that would provide some elementary form of prognostics. Implementation of data collection systems across all platforms and supplies would not be cost effective. There will be various implementations of data collection systems to better match the requirements of the host platform.

2.5.1 On Board Diagnostic II (OBDII)

On-Board Diagnostics (OBD) has been used in automotive applications for a couple decades. Since the early 1980's, automotive manufacturers have implemented some form of "On-Board Diagnostic". With the establishment of the Environmental Protection Agency (EPA) and the passage of the Clean Air Act by the U.S. Congress, the automotive industry has used on-board computers to control the fuel injection system to control ("monitor") pollution. At this time the manufacturer implemented the OBD system to monitor and report the status of the operation of the vehicle. The most recent standard is OBD-II which provides standardization of parameters being measured, electrical signal protocols and diagnostic trouble codes (DTC). If a malfunction occurs, the OBD II system stores a DTC and snap shot of the engine's operating conditions at the time of occurrence. The next version, OBD III, is envisioned to have wireless transmitters that will report the health of the vehicles to the local state regulatory agency remotely as it detects a malfunction.[31]

2.5.2 Aviation

Presently, there are some fielded data collectors on military vehicles/platforms, such as the ones manufactured by Goodrich & IAC (Intelligent Automation Corporation). These HUMS boxes are attached to some helicopters under the Army's Vibration Management Enhancement Program (VMEP). The application of HUMS boxes is not a new concept for rotorcraft vehicles. They have been successful in demonstrating the feasibility and usefulness of a data collection system.

Under this program,[32,33] the U.S. Army and South Carolina National Guard have developed a program to monitor the vibration and fault diagnostic. The HUMS box is called a Vibration Management Unit (VMU). This is a lightweight data collector and processing unit based on the PC-104 industry standard bus. See Figure 2.21 for image and technical specifications.

Technical Specification Overview

Temperature Range: -40C to +55C
Input Power: 6-40VDC, MIL-STD-704A
Power: <18 W
Dimensions: 3" x 5" x 9" w.o. mounting ears
Weight: 4lbs 5oz
Mounting: Dzus Rail
Interconnection: MIL-STD 38999 connectors
Environmental Qualification: MIL-STD-810C
EMI/RFI Qualification: MIL-STD-461B

Processor: Pentium compatible 233MHz
SDRAM: 128Mbyte
DiskOnChip: 72Mbyte
Compatibility: PC/AT compatibility, AVA
Com. Channels: two RS232/422/485, 1553 option
Vibration Channels: 24 (6 simultaneous)
Tachometer Channels: 8 (2 simultaneous)
Blade Tracker Channels: 1 channel
General Purpose Analog : 8
Low Signal Level Analog: 8

Figure 2.21. Technical specification of the HUMS box for the VMEP.

There is flexibility in the configuration of the data collector. It is configurable based on the type of flight. The system can be configured to specifically collect engineering data for evaluation and algorithm development, or collect to a standard prescribed data collection format. This flexibility allows the system to be setup for engineering purposes where a significant amount of data can be collected in a raw format for post processing.[34]

2.5.3 AMSAA Ground Vehicle Usage Monitoring Project

Army Materiel Systems Analysis Activity (AMSAA) is conducting a program that is developing usage and prognostics algorithms on ground vehicles. It is "based on measurements of vehicles in test and in-theater operational environments, on finite element analyses (FEA), on fatigue damage models, and on other Physics of Failure methodologies that are fully integratable with the U.S. Army's Common Logistics Operating Environment (CLOE) standard. The selected military vehicles have a J-1708 engine data bus over which the data collection system can acquire information from the vehicles' built-in diagnostic sensors. The only sensors that were added were some accelerometers to provide some measure of the vibrational environment. A GPS (Global Positional System) receiver was also incorporated to provide location and time tagging data.

The actual data collection system is designed around a COTS device. The data acquisition hardware is a SOMAT eDAQ-Lite from the nCode Company. Figure 2.22 shows an image of the data acquisition system.

Figure 2.22. SOMAT eDAQ-Lite data acquisition system from nCode Company.

This COTS hardware was placed inside an enclosure to provide protection from the normal environmental and mechanical shock and vibration that a vehicle is subjected to in the real world. Figure 2.23 shows the ruggedized AMSAA data collection system.

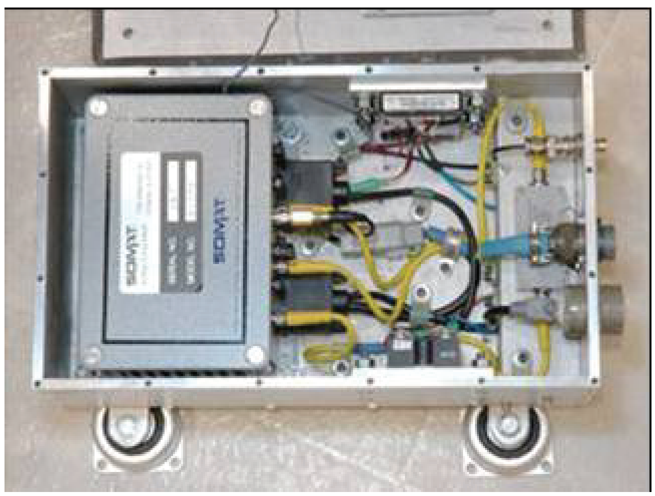


Figure 2.23. AMSAA data collection system.

2.5.4 General Electric Global Research Project

General Electric Global Research performed some research into “the task of selecting the most reliable units within a fleet of vehicles and formulate it as a prediction and classification problem.”[35] The research project monitored fleet data associated with locomotive engines. “The behavior of complex electromechanical assets, such as locomotives, tanks, and aircrafts, varies considerably across different phases of their lifecycle. Assets that are identical at the time of manufacture will ‘evolve’ into somewhat individual systems with unique characteristics based on their usage and maintenance history.” In their data collection and experiment, GE used different sources to collect information. The following categories were used:

- Design & Engineering Data
    - Model, configurations, date of manufacture, date of service, upgrades and software modifications

- Monitoring & Diagnostics Services
  - Time-stamped record of faults, abnormal patterns
- Maintenance Data from Repair Shops
  - Allowed screen of faults records to identify genuine problem
- Use records
  - Odometer miles, total megawatt-hours, hours spent motoring, hours spent in dynamic braking, cumulative engine hours, cumulative engine hours moving

2.6 Beyond Data Collection: Prognostics & Diagnostics

2.6.1 NASA Approach to Sensor Fusion

This example comes from the NASA C-17 Propulsion Health Management Flight Test Program.[36] In this program, data was fused from various sources for data collection, i.e., human observations, maintenance history, fault codes and many embedded sensors. Some of the challenges and insight from this program that apply to the data collection system and processing are quoted as follows:

- "The challenge for proactive engine health management is the development of diverse sensor suites with common interfaces to standardized electronic signal acquisition hardware, and flexible hardware and object oriented software architectures facilitating rapid, economic modification of the diagnostic sensor kit to address unanticipated failure considerations."
- "The value of individual sensors may become less intrinsic and more dependent on synergies gained from data fusion across diverse sensors as more sophisticated diagnostic and engine health management techniques gain acceptance, particularly in compensating for the unacceptably high false positive rates of many sensors and algorithms."
- "The challenge is how to maximize the meaningful information extracted from these disparate data sources to obtain enhanced diagnostic and prognostic information regarding the health and condition of the engine. One approach to addressing this challenge is through the application of data fusion techniques. Data Fusion is the integration of data or information from multiple sources, to achieve improved accuracy and more specific inferences than can be obtained from the use of a single source alone."

The diagram shown in Figure 2.24 was taken from a NASA document that illustrates the different sources of data. As would be expected, there are many and various types of sensors that are embedded and attached to the onboard data collection system. These sensors are distributed at the appropriate location on the aircraft and connected through some type of data bus arrangement. Since the sensors are not sampled at the sample rate, there is some indexing processing that takes place to correctly align the data in the proper sequence that corresponds to the actual occurrence. This is an application of the concept of "metadata" as described in a previous paragraph. This comprises the part of what one would typically envision in a classic view of a data collection system. The diagram illustrates that there are other sources of data. In this example, the built-in diagnostic fault codes were collected. Other sources of data are the maintenance history and human observations that are not part of an embedded data collection system, but part of an overall data collection system. This illustrates the infrastructure and data fusion that needs to take place to integrate disparate sources of data into a common picture for the predictive process.

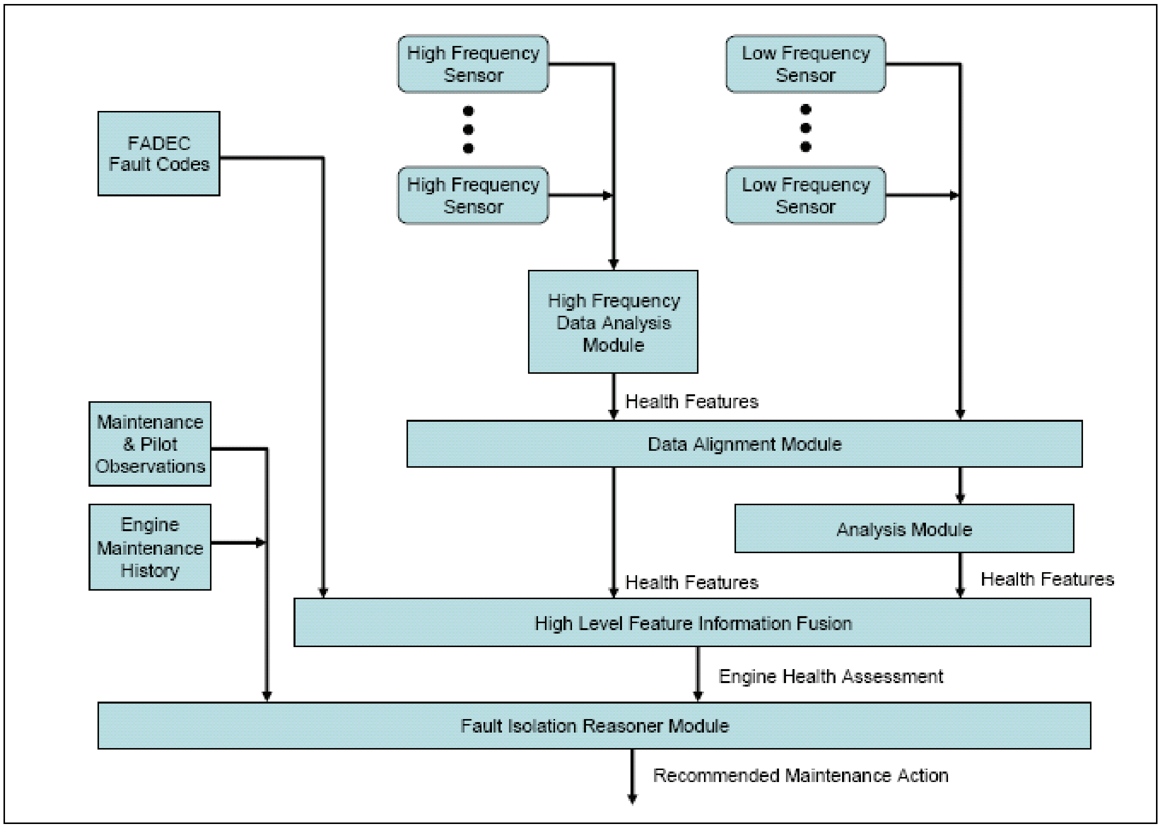


Figure 2.24. NASA data fusion block diagram.[8]

2.6.2 Predictive Outcome [Statistics based]

Pacific Northwest National Laboratory (PNNL) has conducted various R&D programs on prognostics health monitoring for the U.S. Army. They have been able to demonstrate the feasibility of a prognostics health monitoring system for the gas turbine engine used on the M1 Abrams tanks. In their program, the initial prototype system was called Turbine Engine Diagnostics using Artificial Neural Networks (TEDANN), but it was later expanded to include prognostics under the name Real-time Engine Diagnostics-Prognostic (REDI-PRO). This system has inputs from 38 sensors mounted on the AGT1500 engine which feeds the health monitoring system. The engine health is analyzed using artificial neural networks and rule-based algorithms and prognostics analyses to predict the engine health.

The approach to prediction was based on an internal program to PNNL, called Life Extension Analysis and Prognostics (LEAP). It focused on an analytic approach enhancing the quality of predictions by prognostics systems. The following quote summarizes their approach: "To predict a failure—the inability or at least serious degradation of the platform to perform its intended function—three things typically must be known: the system's current degree of fault as quantified by a Figure of Merit (FOM); a theory about the progression of the fault, so as to postulate the system's degree of fault at a particular point in time in the future; and the level of the fault, as quantified by the FOM, that will produce a failure of the platform. The specification of these factors is typically done through engineering/analytical studies such as Failure Modes and Effects Analysis (FMEA). These analyses and expert judgments yield descriptions of how the system fails, what faults can be measured given available sensors, and the values expected for the sensors when these failures occur. Except in unusually simple cases, the FOM determined for a fault, failure, or system condition is a function of a combination of sensor values (i.e., through sensor fusion), rather than a single sensor. As a result, it is typically not sufficient to monitor and trend individual sensor values, independently, to perform diagnostics and prognostics." Figure 2.25 provides an illustration of predicting time to failure.

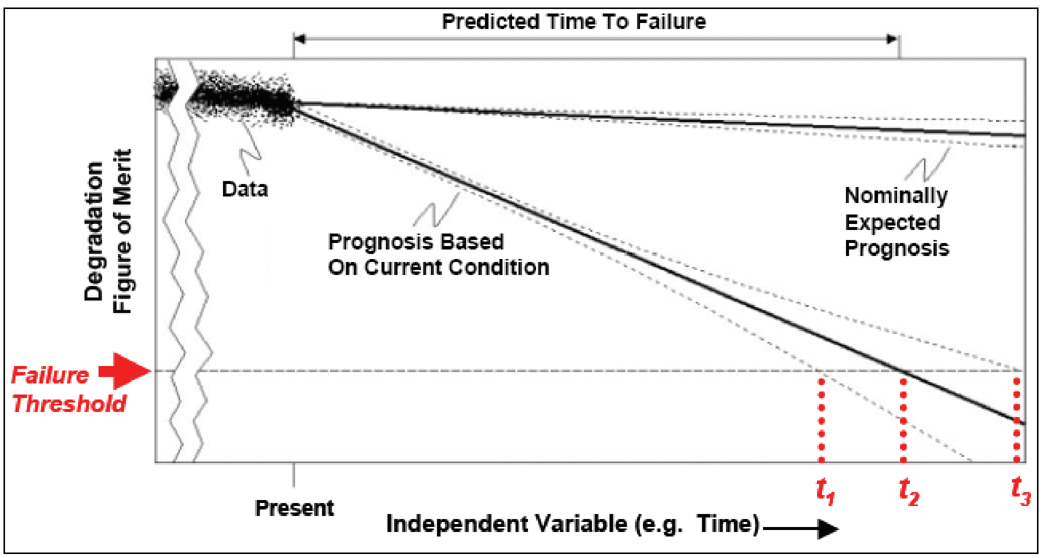


Figure 2.25. Illustration of prognostics prediction: illustrates prediction outcome of the regression models that are applied to the data sets to generate the FOMs. In this figure, a failure occurred at time t_2 with a window of uncertainty as shown by the times between t_1 and t_3. This illustration is used to show that an accurate prediction of life usage can be obtained through the use of sensors to monitor the currently operating conditions versus estimated life usage.

2.6.3 CALCE Demonstration

The Center for Advanced Life Cycle Engineering (CALCE) has set up a consortium to perform research and development on prognostics and health management on electronic products and systems. This center has been active in researching the projects that deal with reliability of electronics. One of the interesting results of their efforts is the outlining of the steps or methodology that would be required in development of a prediction capability. The following steps were outlined for life consumption monitoring process for electronic product[37]:

i. Failure modes and mechanisms analysis (FMMA)

ii. Virtual reliability assessment

iii. Critical parameter monitoring

iv. Measurement data simplification

v. Stress and damage accumulation analysis

vi. Remaining life estimation

In a demonstration, the CALCE Electronic Products and Systems Center performed a case study of a circuit card assembly under an automobile hood to demonstrate the above application to predict failure. In this experiment, a very short limited life, printed circuit card was designed and placed under the hood of an automobile to expose it to a real world environment. This automobile was driven around during the experiment and the environmental parameters (temperature and vibration) were measured, collected and download during the length of the exercise. The demonstration was to show that monitoring the critical environmental/operational parameters as inputs into a computer model could be successful to predict the life expectancy of the printed circuit card. Even though this was a simple experiment, the application proved to be very successful. The results are illustrated in Figure 2.26. The red dashed line represents the predicted life of the simple circuit card based on the computer model based on the first 5 days of data collection. Using measurements from the embedded sensors, the life prediction was revised and illustrated by the blue line. An accident occurred during this experiment which proved to be beneficial in demonstrating the usefulness of monitoring the operational conditions. The resulting shock from the accident reduced the life of the printed circuit card and with the information captured by the sensor; the computer model was able to predict the new end of life trajectory for the printed circuit card. The predicted life was within one day of the actual life.[7]

[7] Additional work in this area is currently being performed under ATO R.LG.2007.01, *Prognostics and Diagnostics for Operational Readiness and Condition Based Maintenance.*

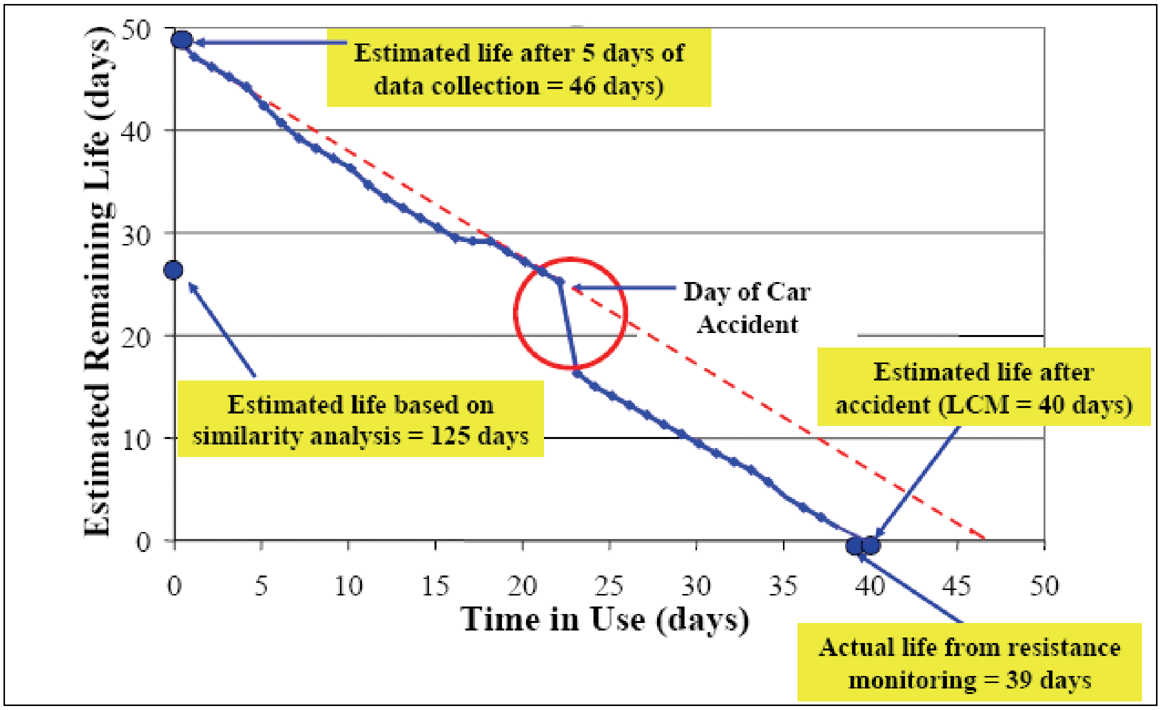


Figure 2.26. Graph of CALCE demonstration results.

2.6.4 Interactive Electronic Technical Manuals (IETM)

Interactive Electronic Technical Manual (IETM) has demonstrated great potential benefits through the experiments conducted by the three armed services. The IETM process is designed to eliminate the paper technical manual associated with military system/hardware. Benefits from this concept go beyond the process of scanning and digitizing paper documents into a computer stored image of the technical manual. Electronic storage is great in reducing the infrastructure necessary for the generation/printing of these documents, updates and distribution. There will need to be a significant paradigm shift in order to realize the opportunities offered by this concept over just the capability of reading a technical manual on an electronic display over paper.

Experiments conducted by the armed services have demonstrated significant improvements in diagnostics/troubleshooting faults. The use of IETMs helped improve quality of correctly isolating faults for both experienced and inexperienced personnel. Fault isolation time was reduced with improved false diagnostics. Results of the operational evaluation by the services are summarized as follows:

- Increased overall comprehensibility and ability to locate required information, leading to greater effectiveness in maintenance performance.
- Decrease in false removal rate of good components.
- Increased effectiveness in successful fault isolation.

- Reduced time in integrating maintenance actions with collateral functions (e.g., with maintenance reporting).
- Improvement in maintenance management procedures.
- Increased enthusiasm shown by technicians for IETM use versus paper-TM use in performing logistic-support functions.
- Potential for significant decreases in technician ("schoolhouse") training time for individual systems, prior to assignment to O-level work centers.

The IETM is a potential source of information that should be explored for its use in the development process for prediction. Embedded data collectors with some intelligence should be able to aid the technician in the troubleshooting and diagnosing fault conditions. For a complex system, where many sensors are being used to monitor the operational condition, the interpretation of the information in an automated system that incorporates IETM will provide improved logistical maintenance functions.

2.7 Essential Data Collection Technologies: Rankings and Quadrant Chart

The following description serves to explain the evaluation and ranking of the selected technologies as applied to the data collection area. Consistent with all of the technologies areas in this paper and described in the Scoring Methodology of section 1.4.1, three primary criteria were used in the evaluation: Probability of Maturity, Cost, and Benefit to LPPC. For each of the primary criteria, there are subcategories of factors used in determining the overall rating. Based on the ratings, all the technologies are summarized in the Quadrant Model chart.

In the area of Probability of Maturity, a series of sub-technologies were developed that impact the development and performance of that particular technology item. These technical factors were selected as benchmarks to access the importance to the individual data collection technology and the level of development by the 2020-2030 timeframe. The range of the Probability of Maturity Score is 1 to 3. A Score of 1 indicates that the confidence level of achieving the technical factor is low, whereas, a Score of 3 indicates a high probability of reaching maturity. The (normalized) Weight and Score factors are then multiplied and averaged across all technologies to obtain the overall total.

In terms of the Cost ranking, the same approach was taken to evaluate the cost of maturing the technology based on cost drivers other than the basic R&D entailed in the technical scoring. When applicable, an attempt was made to apply the same Cost subcategories across all selected technologies.

The last primary criterion is the Benefit to LPPC. The subcategories were based on the list of 19 events identified as those that commanders want to prevent. From the table 1.1 of chapter 1, certain events were selected based on their applicability to the data collection process. The events listed as Running out of Ammunition, Running out of Fuel, Running out of Medical

Supplies, Running out of Water and Running out of Batteries/Fuel Cells were summarized as "Running out of Supplies" for this evaluation subcategory. The other events were Breakdown of Equipment Not Due to Enemy Action, Untimely Delivery of Mission Critical/Essential Parts and Spare Parts and Loss of Common Operating Picture. As explained in the two previous evaluation criteria, the Weight factor is defined similarly. A high number for the Weight factor indicates that the technology has a significant role in the prevention of that event. A high (3) number for the Score factor implies that it has a significant benefit in the prevention of the event.

Multicore processors

Multicore processors Primary Criteria	Index	Pacing/sub-technologies	(1-10) Weight	(1,2,3)=(L,M,H) Score	Totals
Probability of Maturation			31		1.90
	1	Energy efficiency	8	1	0.26
	2	Operating frequency	5	3	0.48
	3	Programming language	10	2	0.65
	4	Operating system	8	2	0.52
Cost			29		1.28
	1	Raw Materials	3	1	0.10
	2	Processing Cost	3	1	0.10
	3	Mfr Scalability	5	1	0.17
	4	Devices	5	1	0.17
	5	Engr-NRE	5	1	0.17
	6	Engr-Integration	8	2	0.55
Benefit to LPPC			33		1.55
		Losing the engagement (Mission) to the Enemy			0.00
		Soldiers dying or being wounded			0.00
	1	Running out of Ammunition	3	1	0.09
	2	Running out of Fuel	3	1	0.09
	3	Running out of Medical Supplies	3	1	0.09
	4	Running out of Water	3	1	0.09
	5	Running out of Batteries/Fuel Cells	3	1	0.09
	6	Breakdown of Equipment Not Due to Enemy	8	2	0.48
		Encountering Bad Weather			0.00
		Encountering Threat Forces			0.00
		Loss of Strategic Lift Assets and Their Cargo			0.00
		Loss of Theater Lift Assets and Their Cargo			0.00
		Closure of APODs and SPODs			0.00
		Closure of Sea Lanes			0.00
		Loss of LOCs			0.00
		Encountering Inaccessible Terrain with Convoys			0.00
	7	Untimely Delivery of Mission Critical Parts	5	2	0.30

	Loss of Comms w/log, intel and ops			0.00
8	Loss of Common Operating Picture (COP)	5	2	0.30

Energy efficiency – This is the primary concern of a stand-alone data collection system where power will probably be supplied by a battery and regular maintenance is minimal. As the processing power increases, the power requirements follow suit. Although the semiconductor manufacturers have taken steps to minimize power requirements, the design requirements are for rechargeable systems. This would not be adequate for a system requiring many years of operation without maintenance.

Operating frequency – The processing speed is directly related to the operating frequency of the processor chip. For complex algorithms, there is a need to compute the algorithms in a real-time fashion. The operating frequency is not expected to be a major hurdle for a data collection system.

Programming language – The majority of programming languages are designed for sequential processing. The algorithms are designed to be executed one step at a time. For the multicore processor, the processing takes place in parallel. This is basically a paradigm shift for programmers.

Operating system – The operating system provides the control, management and integration of the hardware and software components on a computerized system. Fundamentally, it provides basic operation and control over allocating system priorities, memory, input/output functions, networking and file management. This will evolve as the multicore processors start to become more mainstream.

Raw Materials – Material cost is typical for processors. Integration of multiple processors on the same die material increases cost because there is more material.

Processing Cost – As multicore processors come into the mainstream, the processing cost will decrease.

Manufacturing Scalability – Currently, we see the initial generation of multicore processors. The main semiconductor producers are manufacturing devices for desktop and laptop computers. The gaming industry is using multicore processors to accelerate the performance and complexity of video games. Scalability is not an issue.

Devices – The number of devices will increase in the future as the processor devices move into multicore processor configurations. The number of devices will increase naturally as the demand for processing power grows to meet the applications.

Engineering-NRE – The Non-recurring Engineering (NRE) associated with using multicore processors for embedded processing will be high due to the lack of programming capabilities.

Development environments will have to be established that employ the capabilities of this type of processor. Algorithms (for prognostics) will have to be developed that use the increased performance offered through the parallel processing ability of multicore processor devices.

Engineering-Integration – Engineering integration of these devices into a data collection system should be somewhat straight forward. There will be an implementation learning curve that will have to be overcome with the initial application of these devices. Broader availability of these devices and an integrated development environment for these devices will ease the engineering development cycle.

Running Out of Supplies – In this case, supplies include ammunition, fuel, medical supplies, water, and batteries/fuel cells. This application is better suited to identification and tracking and can be achieved through less computational devices for cost effectiveness. The multicore processor would play a significant role if the prognostics algorithms are developed to predict the life expectancy of certain limited shelf life items such as medical supplies and certain materials that might degrade on ammunition (i.e., electronics on smart bombs, composite shell housing on munitions and missiles).

Breakdown of Equipment – Data collectors with embedded prognostics algorithms would play a very significant role in predicting the remaining life expectancy of high value equipment. Algorithms are more likely to involve multiple sensors that require a significant amount of processing power in order to predict the remaining useful life expectancy with a high confidence level.

Untimely Delivery of Parts – The delivery of mission critical/essential parts will depend upon timely prediction and identification of parts or line replaceable units in order to resupply the items rapidly.

Loss of COP – Depending on the significance of the asset, a multicore processor will be needed to provide processing power to determine the health status and implementing prognosis algorithm for predicting useful remaining life.

Microcontrollers

Microcontrollers Primary Criteria	Index	Pacing/sub-technologies	(1-10) Weight	(1,2,3)=(L,M,H) Score	
Probability of Maturation			31		2.42
	1	Embedded memory size	10	2	0.65
	2	Operating frequency	5	3	0.48
	3	Data bus size	8	2	0.52
	4	Energy efficiency	8	3	0.77
Cost			22		1.00
	1	Raw Materials	3	1	0.14
	2	Processing Cost	3	1	0.14
	3	Mfr Scalability	3	1	0.14
	4	Devices	3	1	0.14
	5	Engr-NRE	5	1	0.23

	6	Engr-Integration	5	1	0.23
Benefit to LPPC			58		2.00
		Losing the engagement (Mission) to the Enemy			0.00
		Soldiers dying or being wounded			0.00
	1	Running out of Ammunition	8	2	0.28
	2	Running out of Fuel	8	2	0.28
	3	Running out of Medical Supplies	8	2	0.28
	4	Running out of Water	8	2	0.28
	5	Running out of Batteries/Fuel Cells	8	2	0.28
	6	Breakdown of Equipment Not Due to Enemy	8	2	0.28
		Encountering Bad Weather			0.00
		Encountering Threat Forces			0.00
		Loss of Strategic Lift Assets and Their Cargo			0.00
		Loss of Theater Lift Assets and Their Cargo			0.00
		Closure of APODs and SPODs			0.00
		Closure of Sea Lanes			0.00
		Loss of LOCs			0.00
		Encountering Inaccessible Terrain with Convoys			0.00
	7	Untimely Delivery of Mission Critical Parts	5	2	0.17
		Loss of Comms w/log, intel and ops			0.00
	8	Loss of Common Operating Picture (COP)	5	2	0.17

Embedded Memory Size – Presently, the small size of the embedded memory is a problem for a data collection system that operates over any significant amount of time without the ability to download the data stored in memory. Microcontrollers are excellent processors which can be connected directly to sensors, typically without requiring signal processing interface circuitry. Although manufacturers are increasing the memory size, the size will be dictated by the application of the commercial market.

Operating Frequency – As with the multicore processors, the processing speed of the microcontroller is directly related to the operating frequency. For the case of the microcontroller, the operating frequency is not a major hurdle. The requirement of data collection does not necessarily require a high operating frequency strictly for collecting data.

Data Bus Size – The data address bus size will determine the amount of external memory size that the microcontroller is capable of addressing and storing data to. A significant amount of external memory will be required if the data collection system does not have on-board processing power.

Energy Efficiency – Microcontrollers are presently being designed with energy efficiency as one of their primary characteristics. Manufacturers are continuing to improve this important parameter for portable, battery-operated applications.

Raw Materials – Raw materials are not an issue. Presently, microcontrollers typically cost only a few dollars.

Processing Cost – Processing cost is low. Technology is available from many manufacturers. Competition keeps cost down.

Mfr Scalability – There are many manufacturers of microcontrollers. Manufacturing scalability is not an issue.

Devices – Many of these devices are available with different options. Primarily designed for battery operations, the configurations of these devices are being guided by market applications and cost drivers.

Engr-NRE – Engineering NRE are expected to be typical. Devices are fairly simple and straightforward to program/design. Manufacturers have provided integrated development environment tools that simplify development of these devices.

Engr-Integration – Integration of these devices is fairly straightforward, so not an issue.

Running Out of Supplies – Supplies are a reference to ammunition, fuel, medical supplies, water, and batteries/fuel cells. Microcontrollers are most cost effective to be integrated into data collectors which provide the tasks of identification and quantification. Fairly simple sensors can be attached that measure the capacity of the supplies as they might pertain to water, fuel, and energy-level of batteries/fuel cells.

Breakdown of Equipment – Microcontrollers can be easily integrated with sensors in order to monitor the signals that are generated by the sensors. A complex piece of equipment can be effectively monitored through a distributed network of embedded sensors versus a significant, more powerful central processor.

Untimely Delivery of Parts – Timely delivery of mission critical/essential parts will depend on the timely prediction of parts. Microcontrollers will play a role monitoring the sensors on a platform and can be embedded or attached to the replacement part to provide identification and tracking of the item.

Loss of COP – Microcontrollers are cost effective and energy efficient that they can be attached to assets to provide low level status of assets.

Betavoltaics/ Univ Energy Harvester

Betavoltaics Primary Criteria	Index	Pacing/sub-technologies	(1-10) Weight	(1,2,3)=(L,M,H) Score	
Probability of Maturation			23		1.43
	1	Semiconductor material	8	1	0.35
	2	Energy density yield	10	1	0.43
	3	Form factor/shielding	5	3	0.65
Cost			42		2.38
	1	Raw Materials	8	3	0.57
	2	Processing Cost	8	3	0.57
	3	Mfr Scalability	8	2	0.38
	4	Devices	8	2	0.38
	5	Engr-NRE	5	2	0.24
	6	Engr-Integration	5	2	0.24
Benefit to LPPC			18		1.00
		Losing the engagement (Mission) to the Enemy			0.00
		Soldiers dying or being wounded			0.00
	1	Running out of Ammunition	2	1	0.11
	2	Running out of Fuel	2	1	0.11
	3	Running out of Medical Supplies	2	1	0.11
	4	Running out of Water	2	1	0.11
	5	Running out of Batteries/Fuel Cells	2	1	0.11
	6	Breakdown of Equipment Not Due to Enemy	2	1	0.11
		Encountering Bad Weather			0.00
		Encountering Threat Forces			0.00
		Loss of Strategic Lift Assets and Their Cargo			0.00
		Loss of Theater Lift Assets and Their Cargo			0.00
		Closure of APODs and SPODs			0.00
		Closure of Sea Lanes			0.00
		Loss of LOCs			0.00
		Encountering Inaccessible Terrain with Convoys			0.00
	7	Untimely Delivery of Mission Critical Parts	3	1	0.17
		Loss of Comms w/log, intel and ops			0.00
	8	Loss of Common Operating Picture (COP)	3	1	0.17

Semiconductor material – Betavoltaics use the radioactive decay of isotope to generate energy. As the emission encounters the junction material of the semiconductor material, the material is forward-biased, permitting the flow of electrons. Research has been conducted in betavoltaics for many decades, but the field looks promising with recent advances in identification of possible sources of isotope material and wide band gap semiconductor material.

Energy Density Yield – Betavoltaics were looked to for high-voltage, high-current electrical demands. The application for small portable electronic hardware has, only fairly recently, accelerated the needs of longer life batteries. Energy densities are still low at the moment. Efforts are underway to develop methods of scaling the energy output. This is accomplished by developing porous materials that will effectively increase the surface area of the semiconductor material.

Form Factor/Shielding – Shielding of the material is a concern, but the energy is derived from low-energy particles. Proper shielding should be obtainable with reasonable design. This is not as dangerous as the gamma rays produced from other radioactive materials. Half-life of the material is shorter, making end-of-life a consideration in the design of betavoltaic batteries.

Raw Materials – Raw material is an open question at the moment. Recent advances in materials have led to greater promise for betavoltaic batteries. Research is still being conducted on isotope materials to be embedded into semiconductor material.

Processing Cost – Initial processing costs are expected to be high. Process will need to be developed when the research phase starts to enter the prototype development phase.

Mfr Scalability – Scalability should be accomplished easily once the energy density has been demonstrated to meet the demands of portable electronic applications.

Devices – As with the present market for batteries, the commercial market will the drive the factors that will determine the availability of these devices.

Engr-NRE – The application of betavoltaics, as in a power source, should be straightforward. The only concerns would be with the availability and form factor of a particular betavoltaic device.

Engr-Integration – Integration into a data collection system is a straightforward process. The primary concern will be the availability and the form factor of the device.

Running Out of Supplies – Supplies refer to ammunition, fuel, medical supplies, water, and batteries/fuel cells. Betavoltaics will play a minor role in the prevention of depleting the supplies. They would provide the power on the monitoring systems that provide the health of the item, such as medical supplies.

Breakdown of Equipment – Provides power to the monitoring systems, but it does not play a major role in the prevention of equipment breakdown.

Untimely Delivery of Parts – Little impact, parts delivery.

Loss of COP – Little impact on loss of COP.

Memory

Memory Primary Criteria	Index	Pacing/sub-technologies	(1-10) Weight	1,2,3 (G,Y,R) Score	
Probability of Maturation			33		2.15
	1	Size	8	2	0.48
	2	Operating frequency	5	3	0.45
	3	Energy efficiency	10	2	0.61
	4	Data retention	10	2	0.61
Cost			34		1.65
	1	Raw Materials	7	1	0.21
	2	Processing Cost	7	2	0.41
	3	Mfr Scalability	5	2	0.29
	4	Devices	5	2	0.29
	5	Engr-NRE	5	2	0.29
	6	Engr-Integration	5	1	0.15
Benefit to LPPC			33		1.39
		Losing the engagement (Mission) to the Enemy			0.00
		Soldiers dying or being wounded			0.00
	1	Running out of Ammunition	3	1	0.09
	2	Running out of Fuel	3	1	0.09
	3	Running out of Medical Supplies	3	1	0.09
	4	Running out of Water	3	1	0.09
	5	Running out of Batteries/Fuel Cells	3	1	0.09
	6	Breakdown of Equipment Not Due to Enemy	8	2	0.48
		Encountering Bad Weather			0.00
		Encountering Threat Forces			0.00
		Loss of Strategic Lift Assets and Their Cargo			0.00
		Loss of Theater Lift Assets and Their Cargo			0.00
		Closure of APODs and SPODs			0.00
		Closure of Sea Lanes			0.00
		Loss of LOCs			0.00
		Encountering Inaccessible Terrain with Convoys			0.00
	7	Untimely Delivery of Mission Critical Parts	5	2	0.30
		Loss of Comms w/log, intel and ops			0.00
	8	Loss of Common Operating Picture (COP)	5	1	0.15

Size – Memory capacity will be critical for data collection systems that do not transmit the data on a frequent, periodic basis. For the stand-alone data collection system that does not have a prognostic algorithm, some processing technique will have to be implemented that reduces the data down to a manageable size that the prediction process can use advantageously.

Operating Frequency – The operating frequency of memory needs to be matched to the performance of the processor. Matching the operations of the processor and memory components provide for very low latencies in the exchange of data between both components. This in turn provides for an efficient process that minimizes the energy demands. In present computational engines, various architectural implementations using different memory technologies are being used to mitigate the latency between these two components.

Energy Efficiency – The architecture of the memory chip determines the power consumption of the unit. Presently, faster memory devices require constant power to maintain the data; this is not necessarily good for a data collection system. Memory technologies are using newer storage mechanisms to overcome this constant power requirement.

Data Retention – The retention of data is critical for a data collection system. The main concern is the duration in the memory device when the power is minimized. Newer architectural implementations have significantly longer retention than current flash memory components.

Raw Materials – Raw material is considered to be common for this technology, so there are no issues.

Processing Cost – As with other new technology devices, the processing cost will be high until the process matures.

Mfr Scalability – Manufacturing scalability should be excellent as improvements are made to the characteristics of memory devices. There are many semiconductor manufacturers presently in the market that will continue introducing the capabilities into the market.

Devices – As with the present market, memory devices will be offered in various physical form factor and memory sizes. Trends are to offer the memory devices in larger densities.

Engr-NRE – Engineering development with memory devices will continue to be straightforward. As with engineering development, the associated development cost will be related to the continued availability of the particular components.

Engr-Integration – Integration of memory devices into the data collection system is essential and common. No issues seen.

Running Out of Supplies – Supplies are a reference to ammunition, fuel, medical supplies, water, and batteries/fuel cells. Memory devices will be used to store data from data collection devices. This provides needed storage space for embedded data collection devices that would monitor the health of the attached item, but provides no direct function of preventing the shortage of supplies.

Breakdown of Equipment – This plays an important role for the storage of data on data collection devices that monitor and predict life expectancy through prognostics.

Untimely Delivery of Parts – This is an important element of data collection device. Embedded prognostics algorithms will require storage space in order to operate. Prognostics will provide predictions in order to respond in a timely fashion.

Loss of COP – Collected and processed information will need to be saved until the collection device is queried. Data collection devices need memory devices with sufficient storage capacity to respond in real time with the status of the embedded asset.

Sensors

Sensors Primary Criteria	Index	Pacing/sub-technologies	(1-10) Weight	1,2,3 (G,Y,R) Score	
Probability of Maturation			34		1.71
	1	Microstructure capability	10	1	0.29
	2	Energy efficiency	8	2	0.47
	3	Output interface	8	2	0.47
	4	Physical size	8	2	0.47
Cost			52		2.35
	1	Raw Materials	8	2	0.31
	2	Processing Cost	9	2	0.35
	3	Mfr Scalability	9	2	0.35
	4	Devices	8	2	0.31
	5	Engr-NRE	10	3	0.58
	6	Engr-Integration	8	3	0.46
Benefit to LPPC			75		2.80
		Losing the engagement (Mission) to the Enemy			0.00
		Soldiers dying or being wounded			0.00
	1	Running out of Ammunition	10	3	0.40
	2	Running out of Fuel	10	3	0.40
	3	Running out of Medical Supplies	10	3	0.40
	4	Running out of Water	10	3	0.40
	5	Running out of Batteries/Fuel Cells	10	3	0.40
	6	Breakdown of Equipment Not Due to Enemy	10	3	0.40
		Encountering Bad Weather			0.00
		Encountering Threat Forces			0.00
		Loss of Strategic Lift Assets and Their Cargo			0.00
		Loss of Theater Lift Assets and Their Cargo			0.00
		Closure of APODs and SPODs			0.00
		Closure of Sea Lanes			0.00
		Loss of LOCs			0.00
		Encountering Inaccessible Terrain with Convoys			0.00
	7	Untimely Delivery of Mission Critical Parts	7	2	0.19

	Loss of Comms w/log, intel and ops			0.00
8	Loss of Common Operating Picture (COP)	8	2	0.21

Microstructure Capability – Sensors will have to be developed that sense down to the microstructure level in order to provide information at the microscopic level. The detection of the early fault and its degradation are important to the development of Physics of Failure technology. Present sensors provide lower sensitivity, since they can detect a fault once it has progressed to the point that it is detectable at a macro level.

Energy Efficiency – As stated previously, an embedded data collection system should have a very high energy efficiency.

Output Interface – Incorporation of output interface to data collection would provide an easier integration of the sensors to the data collection system. Employment of standard sensor interfaces would provide modularity and flexibility in data collection systems.

Physical Size – Physical size is important for an embedded data collection system. Sensors should not add significantly to the weight or physical shape of the platform.

Raw Materials – MEMS and nano-technology will play important roles in the development of new sensors. Identification of the materials will evolve as the field applies the new technology to sensor application. MEMS have been successfully applied to accelerometers with semiconductor material.

Processing Cost – Initial costs are expected to be high as the production capability evolves. Production of newer types of sensors will be predicated on the market demands.

Mfr Scalability – As with any new technology, the manufacturers will have a learning curve. Manufacturing tooling and capability will evolve as the benefits and market demands are demonstrated. Initial costs are expected to be high until the capabilities are designed and implemented into the manufacturing capability and testing.

Devices – A variety of new sensors will be expected to come online in the future with application of MEMS and nano-technology. Integration of common interface standards and interface techniques will offer advantages not available on present sensors.

Engr-NRE – Developmental engineering of a data collection system to a particular platform may be high if the design is not developed and incorporated into the early systems design. Complexity of the platform and associated PoF mechanisms will be significant factors in the design implementation of the data collection system.

Engr-Integration – Engineering integration will depend on the platform and where in the systems development process the data collection capability is inserted.

Running Out of Supplies – Supplies refer to ammunition, fuel, medical supplies, water, and batteries/fuel cells. Sensors are critical to gathering information on assets and the health of the supply chain. Sensors can be easily integrated with other devices to identify and track resources.

Breakdown of Equipment – Sensors are critical components in the monitoring and prognostics process. Prognostics require the monitoring of the signals from sensors and processing through a prognostic algorithm in order to predict the life expectancy on any piece of equipment.

Untimely Delivery of Parts – To provide timely delivery of mission critical/essential parts, the life expectancy will have to be predicted. Prediction will require the inputs from the appropriate sensors to detect the progression of faults.

Loss of COP – Sensors provide real time information necessary for a real time common picture.

Flexible Displays

Flexible Display Primary Criteria	Index	Pacing/sub-technologies	(1-10) Weight	1,2,3 (G,Y,R) Score	
Probability of Maturation			32		1.91
	1	Energy efficiency	10	1	0.31
	2	Resolution	8	2	0.50
	3	Size	7	2	0.44
	4	Viewing angle	7	3	0.66
Cost			46		2.00
	1	Raw Materials	8	3	0.52
	2	Processing Cost	8	2	0.35
	3	Mfr Scalability	7	2	0.30
	4	Devices	7	2	0.30
	5	Engr-NRE	8	2	0.35
	6	Engr-Integration	8	1	0.17
Benefit to LPPC			15		1.00
		Losing the engagement (Mission) to the Enemy			0.00
		Soldiers dying or being wounded			0.00
	1	Running out of Ammunition	2	1	0.13
	2	Running out of Fuel	2	1	0.13
	3	Running out of Medical Supplies	2	1	0.13
	4	Running out of Water	2	1	0.13
	5	Running out of Batteries/Fuel Cells	2	1	0.13
	6	Breakdown of Equipment Not Due to Enemy	1	1	0.07
		Encountering Bad Weather			0.00
		Encountering Threat Forces			0.00
		Loss of Strategic Lift Assets and Their Cargo			0.00
		Loss of Theater Lift Assets and Their Cargo			0.00

	Closure of APODs and SPODs			0.00
	Closure of Sea Lanes			0.00
	Loss of LOCs			0.00
	Encountering Inaccessible Terrain with Convoys			0.00
7	Untimely Delivery of Mission Critical Parts	2	1	0.13
	Loss of Comms w/log, intel and ops			0.00
8	Loss of Common Operating Picture (COP)	2	1	0.13

Energy Efficiency – As with the processing unit, the display technology will also have to be energy efficient. The display technology is being considered for applications in the field where size and weight are important. The operation, which may typically be a stand-alone, will probably be conducted on some type of rechargeable battery source. Operations of the display will need to be conducted over a reasonable number of hours/days from its normal power source without the need to replenish.

Resolution – The resolution of the display should match that of a reasonable display monitor capability.

Size – For a portable flexible display, the size of a typical sheet of paper might be a reasonable compromise. This is where human engineering will have a hand in the development of a size that is reasonable for application in the field.

View Angle – Viewing angle is important to the user, but it does not necessarily have to match the highest level obtained by other display technologies. It is important to have the image be readable over a reasonable viewing angle without placing any burden on the user in the field.

Raw Materials – Raw materials will initially be high until the infrastructure is developed to accommodate this technology. Materials for the development of the flexible display are still in the research stage, so the identification of the materials is premature.

Processing Cost – As with any new technology, the initial processing cost will be high. Potential applications across broad spectrum of usage will aid the reduction of the processing cost.

Mfr Scalability – Manufacturing scalability will evolve as the technology potential is demonstrated. Scalability will be expected to follow suit as the technology is licensed to the manufacturers.

Devices – Various devices with different form factors and capabilities will be developed as the applications requirements are defined.

Engr-NRE – Engineering development cost should not be much above the typical cost associated with the development of portable display technology. Standard interface will easy the development cost.

Engr-Integration – Engineering integration should be typical. This should be another form factor of display technology that has a fairly straightforward integration.

Running Out of Supplies – There is no direct impact from flexible displays to prevent supply shortages. There could be a secondary effect on visualizing the collection of supply chain information.

Breakdown of Equipment – There is no impact on the detection/prevention of breakdown of equipment.

Untimely Delivery of Parts – There is no impact on the delivery of parts.

Loss of COP – There is no impact on COP data sets, but could provide a visualization tool for COP.

Standards

Standards (TEDS) Primary Criteria	Index	Pacing/sub-technologies	(1-10) Weight	1,2,3 (G,Y,R) Score	
Probability of Maturation			32		3.00
	1	Subject Matter Expertise	10	3	0.94
	2	Strategic influence/vision	10	3	0.94
	3	Technical process	7	3	0.66
	4	Identification/selection/level of participation	5	3	0.47
Cost			49		2.27
	1	Development methodology	10	1	0.20
	2	Cross agency support-Jointness	8	2	0.33
	3	Maturity of the solution	8	1	0.16
	4	Support to the Triad-Operations, Intelligence, & Logistics	8	2	0.33
	5	Timeliness	6	2	0.24
Benefit to LPPC			9		1.00
		Losing the engagement (Mission) to the Enemy			0.00
		Soldiers dying or being wounded			0.00
	1	Running out of Ammunition	1	1	0.11
	2	Running out of Fuel	1	1	0.11
	3	Running out of Medical Supplies	1	1	0.11
	4	Running out of Water	1	1	0.11
	5	Running out of Batteries/Fuel Cells	1	1	0.11

6	Breakdown of Equipment Not Due to Enemy	2	1	0.22
	Encountering Bad Weather			0.00
	Encountering Threat Forces			0.00
	Loss of Strategic Lift Assets and Their Cargo			0.00
	Loss of Theater Lift Assets and Their Cargo			0.00
	Closure of APODs and SPODs			0.00
	Closure of Sea Lanes			0.00
	Loss of LOCs			0.00
	Encountering Inaccessible Terrain with Convoys			0.00
7	Untimely Delivery of Mission Critical Parts	1	1	0.11
	Loss of Comms w/log, intel and ops			0.00
8	Loss of Common Operating Picture (COP)	1	1	0.11

Subject Matter Expertise – Primary criterion is to have personnel on committees who are experts in the technical area that the standards are being developed for. Typically, this is not an issue.

Strategic Influence/Vision – Standards have a significant effect in the development of products that apply across a board spectrum of applications. Guidance for the development of standards would produce a clear vision for how it would impact the prediction and the preemption process.

Technical Process – The technical process of generating and developing the standards will help provide a robust set of rules for implementation of a product.

Identification/Selection/Level of Participation – There are many standards and groups that develop standards. For the prediction and preemption process, the standards have to be identified that will have a significant impact on the design and development of these systems. Some standards are far enough along that the level of participation required should be minimal, but an active role will need to be played as newer standards evolve.

Development Methodology – The methodology used to develop standards is critical to a successful process. Many organizations have developed standards that can provide guidance for the formulation of methodologies.

Cross Agency Support-Jointness – For military systems, the commonality across the services is important. A unified application of a standard will produce an effective logistical solution across the military, minimizing cost for implementation of the data collection system. The Common Logistics Operating Environment (CLOE) is an architectural framework for the Army that provides for the fusion of information from sensor embedded platforms and logistics. Under CLOE, technical standards, interface and information exchange protocols will be developed that provide interoperability and net-centric capabilities to all users.

Maturity of the Solution – Presently, there are many standards that have reached some fairly high level of maturity. Applications of these standards can be implemented without any/or minor deviations in the standards. This does not require the added expense and burden of generating a new standard that could achieve the same level of performance as an existing standard. For developing standards that would impact the prediction and the preemption process, spiral development would contribute significantly to obtaining a robust solution.

Support to the Triad-Operations, Intelligence, & Logistics – Common data and interpretation will provide benefits to the three functions: operations, intelligence and logistics. Benefits are realized easily when common standards are applied at the beginning of the design cycle.

Timeliness – Identification, application, and/or development are important if this leads to incorporation early in the design cycle. Timeliness is important in the design phases.

Running Out of Supplies – In observing all of the logistical scoring for standards vis-à-vis TEDS, it may be a surprise that it is rated low for logistical impact. Its low rating is predicated on direct impact to that scoring element. Hence, a score of 1 was assigned for *running out of supplies*. Unlike Physics of Failure, which scored 2 in this element, these standards will not directly keep the supply vehicle up and running nor will they be the first line of communication to get more supplies. So in this sense, the immediate logistical impact does not score high. However, as we will see in chapter 6, from a system capability level, they provide the "glue" to put together several other technologies.

Breakdown of Equipment – There is low impact on breakdown of equipment.

Untimely Delivery of Parts – There is no impact on parts delivery.

Loss of COP – There is no impact on COP.

Physics of Failure (PoF)

PoF Primary Criteria	Index	Pacing/sub-technologies	(1-10) Weight	1,2,3 (G,Y,R) Score	
Probability of Maturation			47		1.94
	1	Accelerated stress testing	10	2	0.43
	2	Sensors for microstructure detection	10	2	0.43
	3	Computer model/simulation	10	2	0.43
	4	Validation	10	1	0.21
	5	Identification/ranking of failures	7	3	0.45
Cost			46		2.43
	1	Development methodology	8	2	0.35
	2	Maturity of the solutions	10	3	0.65
	3	Engr-Integration	10	3	0.65
	4	Timeliness	10	2	0.43
	5	Confidence level of solutions	8	2	0.35

Benefit to LPPC			35		2.14
		Losing the engagement (Mission) to the Enemy			0.00
		Soldiers dying or being wounded			0.00
	1	Running out of Ammunition	3	2	0.17
	2	Running out of Fuel	3	2	0.17
	3	Running out of Medical Supplies	3	2	0.17
	4	Running out of Water	3	2	0.17
	5	Running out of Batteries/Fuel Cells	3	2	0.17
	6	Breakdown of Equipment Not Due to Enemy	10	3	0.86
		Encountering Bad Weather			0.00
		Encountering Threat Forces			0.00
		Loss of Strategic Lift Assets and Their Cargo			0.00
		Loss of Theater Lift Assets and Their Cargo			0.00
		Closure of APODs and SPODs			0.00
		Closure of Sea Lanes			0.00
		Loss of LOCs			0.00
		Encountering Inaccessible Terrain with Convoys			0.00
	7	Untimely Delivery of Mission Critical Parts	5	2	0.29
		Loss of Comms w/log, intel and ops			0.00
	8	Loss of Common Operating Picture (COP)	5	1	0.14

Accelerated Stress Testing – The development of PoF is highly dependent on the use of accelerated stress testing. Very controlled experiments must be set up with high fidelity instrumentation to capture the development of a fault. The growth signature of the faults must be captured in relation to principle stress parameters and time.

Sensors for Microstructure Detection – Although there are sensors that can be used to detect faults as the growth develops to the macro level, there is a need to develop sensors that are capable of detecting fault initiation at the microstructure level.

Computer Model/Simulation – The development of computer models/simulations are critical in the development of the PoF field. Accelerated stress testing will provide the necessary data to develop the computer models/simulations to a broader class of components and materials.

Validation – Validation will have to occur to demonstrate the theory of the PoF has sufficient resolution and accuracy. A somewhat surprising result of the scoring for this technology is that it does not quite make it into the upper right quadrant primarily due to the technical score in *validation*, which is highly dependent on the platform in question. While the physics of failure algorithms will certainly exist at a high level for a few platforms such as aviation and ground vehicles, the proliferation of this technology to other, lower cost platforms (that lack the same return on investment) will take longer to implement, verify, and validate.

Identification/Ranking of Failures – The identification of the major source of failures and the importance of such identification will play a significant role in the guiding the development of the PoF. A prediction system will not be able to forecast all possible failures, but should be able to account for the ones that will significantly impact the performance of the platform.

Development Methodology – With PoF in its infancy, a methodology that could be implemented across the various areas of evaluation will result in a consistent product.

Maturity of the Solutions – A mature PoF will significantly reduce the design and development costs associated with the data collection system of a particular platform. A system based on statistical process will provide a potential indicator of post fault at some point in the future without providing sufficient information to predict time of fault.

Engr-Integration – Incorporation of PoF into the data collection system in the design and development is critical to the effectiveness of the system to the prediction process.

Timeliness – The availability of the solutions that are offered through the PoF is important only if they are available early in the design and development cycle. Timeliness is critical.

Confidence Level of Solutions – A high incidence of false alarm will mitigate the solutions provided by a predictive data collection system. It is critical that a PoF system provide accurate results with an acceptably low false alarm rate.

Running out of supplies – PoF provides the mechanism to determine the health of the transport vehicles as well as the supplies themselves, especially in the case of medical supplies and certain ammunition.

Breakdown of Equipment – PoF is critical in the prediction of the equipment life expectancy.

Untimely Delivery of Parts – PoF will provide the critical prediction of end of life. With this information, logisticians will be able to provide necessary response keep the parts flowing sufficiently to continue operations.

Loss of COP – POF provides the capability to conduct real time assessment on the asset.

2.7.1 Data Collection Technologies Quadrant Chart

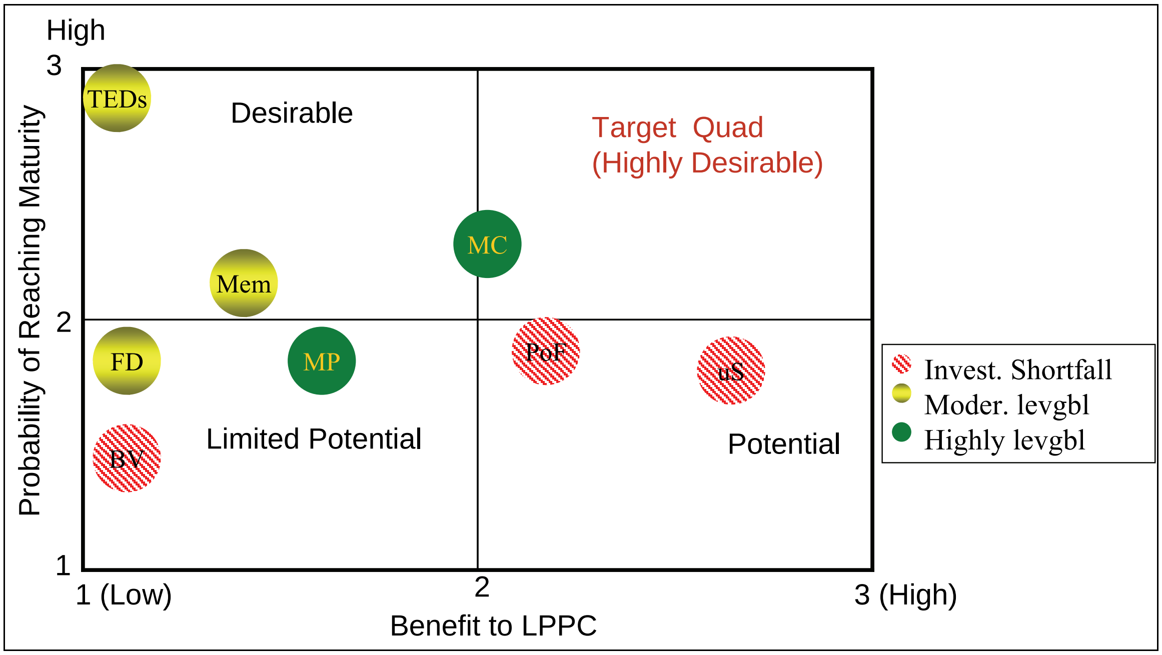


Figure 2.27. Data collection quadrant model.

Symbol	Technology	Section
MP	Multi-core Processors	2.3.3.2
MC	Microcontrollers	2.3.3.3
BV	Betavoltaics (parasitic vibr, RF, universal harvester)	2.3.6
Mem	Memory (Memory stickers,)	2.3.4.1
uS	Microscale sensors (MEMS, Nano)	2.3.2
FD	Flexible Displays	2.3.7
PoF	Physics of Failure (Platform Prognostic) Algorithms	2.6.1
TEDS	Transducer Electronic Data Sheets (also includes Standards)	2.3.1

2.8 Data Collection Conclusions

Data collection is a process that is not new to the military or to history. There are many data collection tasks currently being conducted on a daily basis as part of normal operating procedure. This data collection occurs in both manual and automatic processes with the information being transmitted through various mediums: written, verbal, and electronic. The fundamental components of an automatic data collector are well known. Technology has provided the building blocks (i.e., sensors, processors, and storage devices) for data collectors for many decades. As with any modern technology, the enhancements in the technological areas of microelectronics, processors, memory, sensors and energy sources provide many opportunities to develop robust data collectors that are better suited to the logistics enterprise prediction and preemption capability. The data collector will exist in many forms to match the simplicity or sophistication of the resource/platform being monitored. For the military, the benefit will be that most of the advancements in technology will come from developments in the commercial world.

Of the fundamental components in a data collector, the sensor technology area will be a very significant area of interest. Developments in the area of MEMS and nano-technology will play an important role in the development of new sensors that will provide higher sensitivities and resolutions than what can be obtained today. One area of ambiguity for the data collector is identifying collection parameters and the best sampling rate. Standards for sensor interface will play an important role in the providing flexibility, interchangeability, adaptability and modularity to a data collector. In general, standards will play a very significant role in the successful integration of the data collector with communication and data fusion components of this logistics prediction and preemption experiment. While the numerical results of Figure 2.27 do not ostensibly support this importance, we will revisit this discussion in chapter 6 as we consider cross-cutting aspects.

Implementation of capabilities to automatically monitor the operational condition of a platform and its resource consumption rate, diagnostics assessments, identification of expendable supplies, and current status is readily achievable. The next step up in predicting the remaining life expectancy of a platform with precision and a very low probability of false alarm will be a challenge. This differentiates prognostics from diagnostics capability. Prognostics are an important embodiment of the prediction capability. The development of Physics of Failure of hardware is an important element of Prognostics. It is not clear that the commercial world will develop this field to the level that the military will require to predict platform failure in a sufficient timely manner.

Processing capabilities for the data collectors will easily be accommodated through microcontrollers and multicore processors. Microcontrollers can easily provide the processing capability required on low intensity data collection requirements. On the other end of the processing spectrum, the multicore processor provides not only capabilities to the complex data collector, but the processing power that will be needed for data fusion and analysis. Data collection will require a significant amount of storage capability that can be easily achieved through solid state memory devices.

With an automated data collection system, the amount of data will drastically increase to overburden the communication channels and central processing centers if the architecture and infrastructure are not designed to complement and to integrate into a flexible, robust organizational configuration. The commercial world is presently integrating the microcontroller and communication transceiver into the same microelectronic package. For the complex platform, the multicore processor will provide the capability to process the raw data on the embedded data collector itself, therefore, providing real-time status and health assessment and reducing the overall communication bandwidth that would be required in the transmission of the raw data. This would require the necessary algorithms be from the evolving field of Physics of Failure.

2.8.1 The Next step: Transmitting the Collected Data

The concept of data collection is not a new notion. There are many examples that one can find throughout history. Data collection provides a fundamental basis for the future of Logistics Prediction and Preemption capability. The Army must implement a program to develop automatic data collectors in order to leverage the benefits from data collection supporting an LPPC. The fundamental building blocks of data collection systems are the same for all the different types of platforms. However, having an infrastructure of automated, real-time, data collection systems provides little benefit if the data can not forward in an appropriate, timely manner. Real-time, effective communication is essential and vital to the foundation of a Prediction and Preemption process. Chapter 3 will explain the communication technologies that will be fundamental to data transmission.

---

[5]"A Review of data fusion models and architectures: towards engineering guidelines", Jaime Esteban, Andrew Starr, Robert Willetts, Paul Hannah, Peter Bryanston-Cross, Neural Computer & Application, 2005
[6]Designing for Health; A Methodology for Integrated Diagnostics/Prognostics, Raymond Beshears, Larry Butler, Autotestcon, 2005, IEEE
[7]"Avoiding Death by Data", Dr. Michale Pagels, DARPATech 2005, August 9-11, 2005
[8]pHUMS-Prognostics Health and Usage Monitoring of Military Land Systems, Dr. Andrew Halfpenny, nCode International, Part I- Anatomy of a HUMS System
[9]"Realizing the Potential of Digital Flight Data Recording", Richard Bond, Evaluation Engineering, March 2007
[10]COTS Approach to Dynamic Flight Data Acquisition for HUMS/OLM Applications, Richard H. J. Fielding, ACRA Control LTD
[11]ibid
[12]BBC News 12 December 2000
[13]"Hardening Computing", Greg Slabodkin, Defense Systems, February 2007
[14]"Development of an Information Fusion System for Engine Diagnostics and Health Management", Allan J. Volponi, Tom Brotherton, Robert Luppold, Donald L. Simon, NASA/TM-2004-212924, ARL-TR-3127, February 2004
[15]"Open standards for condition-based maintenance and prognostic systems", Mitchell Lebold, Michael Thurston, paper under Office of Naval Research through OSA-CBM Boeing DUST (Grant N00014-00-1-0155)
[16]"Implications of an Open System Approach to Vehicle Health", David Followell, Dan Gilbertson, Kirby Keller, The Boeing Company, 2004 IEEE Aerospace Conference Proceedings Management
[17]The TEDS Smart Sensor Revolution, Ryan Wynn, IEE Computing & Control Engineering, August/September 2004, pp 25-27
[18]Integration of Material-Based Simulation into Prognosis Architectures, Loren Nasser, Robert Tryon, 2004 IEEE Aerospace Conference Proceedings
[19]Logistics Prediction and Preemption Experiment, Phase 1 – Overview, Final Product, Gerald Dolinish, William Koenig, Dr. Thomas Ferryman, Robert McKay, Jack Stevenson, LIA
[20]"Energy per Instruction Trends in Intel Microprocessors", Ed Grochowski, Microarchitecture Research Lab, Intel Corporation
[21]Overview of the architecture, circuit design, and physical implementation of a first-generation cell processor Pham, D.C.; et al., IEEE Journal of Solid-State Circuits, Volume 41, Issue 1, Jan. 2006 Page(s):179 - 196
[22]"The Potential of the Cell Processor for Scientific Computing", Samuel Williams, John Shaff, Leonid Oliker, Shoaib Kamil, Parry Husbands, Katherine Yelick, Computational Research Division, Lawrence Berkeley Research Division
[23]"Another One Rides the Bus", Bob Judd, Evaluation Engineering, January 2007

[24]Metrics Evaluation and Tool Development for Health and Usage Monitoring System Technology, C. Byington, M. Watson, P. Kalgren, R. Safa-Bakhsh, American Helicopter Society 59th Annual Forum, May 6-8, 2003
[25]"Operational Sense and Respond Logistics, A White Paper", Norman Messenger, CACI, Inc-Federal
[26]Power Management for Energy Harvesting Wireless Sensors, S.W.Arms, C.P.Townsend, D.L. Churchill, J.H. Galbreth, S.W. Mundell, SPIE Int'l Symposium on Smart Structures & Smart Materials
[27]Press Release, MicroStrain, Inc., July, 2006
[28]Energy Scavenging for Mobile and Wireless Electronics, Joseph A. Paradiso and Thad Starner, IEEE Pervasive computing, January-March 2005, Vol. 4, No. 1
[29]Design Considerations for Solar Energy Harvesting Wireless Embedded Systems, V. Raghunathan, A. Kansal, J. Hsu, J. Friedman and M. Srivastava, Department of Electrical Engineering, University of California, Los Angeles
[30]"Diagnostic Indicators for Shipboard Systems Using Non-Intrusive Load Monitoring", LT Thomas DeNucci, USCG , Steven B. Leeb; James Paris; CDR Timothy J. McCoy, USN; Christopher Laughman; CDR William C. Greene, USN, 2005 IEEE Electric Ship Technologies Symposium
[31]"Analytic technology: Diagnose What Ails Your Auto", Greg Vrana, EDN, December 20, 2001
[32]"Automated Helicopter Vibration Diagnostics for the U.S. Army and National Guard", Paul Grabil, Dr. John Berry, CW5 Lem Gran, Jesse Porter, American Helicopter Society 57th Annual Forum, May 9-11, 2001
[33]The U.S. Army and National Guard Vibration Management Enhancement Program (VMEP): Data Analysis and Statistical Results, Paul Grabil, Dr. Tom Brotherton, Dr. John Berry, CW5 Lem Grant, American Helicopter 58th Annual Forum, June 11-13, 2002
[34]U.S. Army Material Systems Analysis Activity (AMSAA) Ground Vehicle Usage and Prognostics Program, Mark S. Bounds, ARL/AMSAA Prognostics Workshop, August 31, 2006
[35]"Predicting the Best Units within a Fleet: Prognostic Capabilities Enabled by Peer Learning, Fuzzy Similiarity, and Evolutionary Design Process", Piero P. Bonissone, Anil Varma
[36]A Survey of Intelligent Control and Health Management Technologies for Aircraft Propulsion Systems, Jonathan S. Litt, Donald L. Simon, Sanjay Garg, Ten-Heui Guo, Carolyn Mercer, Richard Millar, Alireza Behbahani, Anupa Bajwa, Daniel T. Jensen, NASA/TM-2005-213622, ARL-TR-3413
[37]Life Consumption Monitoring for Electronics Prognostics, Satchidananda Mishra, Sathyanarayan Ganesan, Michael Pecht and Jingsong Xie, 2004 IEEE Aerospace Conference Proceedings

Chapter 3. Data Transmission

G. Mitchell

"What throws you in combat is rarely the fact that your tactical scheme was wrong … but that you failed to think through the hard cold facts of logistics."

- General Matthew B. Ridgway

For the purpose of this paper, data transmission will mean the transfer of information bits between functional elements over or through a medium (fiber, air, wire) according to a defined protocol. Data transmission is an essential element throughout the entire logistics enterprise for a combat prediction and preemption capability (LPPC). The LPPC is heavily dependent on data, information, and knowledge from the many sources previously outlined in chapter 2. These sources provide data, information, and knowledge elements in currently disparate forms (written hard copy, written electronic, sensor electronic, etc.) and software languages. Transmitting these essential elements to command nodes where fusion and analysis for the development of courses of action (COAs) (see chapter 4) and implementation (see chapter 5) is absolutely critical. This chapter is dedicated to the explanation and evaluation of capabilities for current and future technologies (through the year 2030) that will lend themselves to the goal of rapid, secure, and accurate disbursement of information throughout not only the logistics enterprise but also between the functions of the logistics enterprise and other components of a Joint-Coalition force within global and local communication networks worldwide.

The purpose of this chapter is not to evaluate technologies based on a single overriding approach to data transmission. Because Army logistics is fundamental to Army success worldwide and in venues which are various and ever-changing, only through a collaboration of different communications technologies will the Army achieve the best results. Therefore, this chapter evaluates technologies on an individual basis using the same rating system for all technologies across the board. This rating system will be further explained at the end of this chapter where the technological rankings are presented. This chapter will also present suggestions on how to make the best use of the described technologies.

By ensuring that the essential elements of the LPPC are transmitted and received on a timely basis, fusion and analysis can occur within the decision cycles of both the enemy and the combatant commander. This is required for the development of robust, viable COAs to support effective decisions for the specified combat mission.

The communication technologies addressed in this chapter will fall under the realm of either optical devices, radio frequency (RF) devices, or sometimes both. Explanation of basic components and techniques will be followed by a description of the current state-of-the-art, i.e., technologies that are in popular use in both military and commercial communities. Separate sections are dedicated to each and serve to describe present day and emerging technologies in order to provide a baseline for the forecasted technologies presented at the end of each section. The forecasted technologies are those with the greatest potential to benefit logistics communication for prediction and preemption in the 2020-2030 timeframe. The technologies described in this chapter will cover devices, network topologies, and communication standards, which will all play crucial roles in the future of logistics communication capabilities.

3.1 Optical Technologies: Primer and Future Status

Optical communication systems use light as the transmission medium, gaining the benefit of superior data transfer rates by taking advantage of the speed at which light travels. Using light as a medium has its disadvantages as well, many of which have forestalled the adoption of long-range, high capacity free space optical (FSO) links, even though their link characteristics are theoretically superior to many characteristics of current radio frequency (RF[8]) technologies. Fiber-optic cables, which have allowed for the global internet as well as many other successful applications, have started to run up against bandwidth and other practicality barriers as user demand continues to increase. This section on optical technologies explains the background and current state of optical communications devices. Understanding the present technical status of these devices will provide the background necessary to later understand how the predicted future state of optical communications has been extrapolated from current trends. Finally, this section also illustrates the promise and limitations that optics offers in terms of data transmission from the standpoint of logistics and prediction.

3.1.1 Optical Overview

This section explains the fundamental concepts of optical communication devices and theory. The overview section does not serve to demonstrate the situational functionality of certain optical communication capabilities, but rather serves to educate on how optical communication devices work and why optical communications have the inherent properties that separate them from other forms of communication. These fundamentals will be as important for defining and understanding optical technologies of the year 2030 as they are in understanding the capabilities of current and emerging optical technologies.

3.1.1.1 Basic Optical Communication Components

This section gives a brief description of the individual components of an optical communication link. These descriptions will clarify the idea of how light waves are converted from an electrical signal, transmitted, received, and decoded into information at the receiver. Understanding the roles of each component is necessary for the general understanding of optics and its future

[8]Note that while we use the term “RF” generically to cover 1 MHz to 1 THz, this includes microwave, millimeter-wave, sub-mm wave regimes. The engineering design disciplines between each of these vary as much as going from L-band (~900 MHz) to fiber optics.

progression because, even if advances in component capabilities are made, the roles each component plays in the communications process will remain the same.

3.1.1.2 Optical Fibers

The defining aspect of an optical communication system (OCS) is the use of light waves to transmit data. Fiber-optics uses light pulses guided through fibers of silica or glass to move high volumes of data over both long and short range links. Fiber-optics dwarfs current RF technology with data rate capacity of greater than 10 Gbps by taking advantage of huge amounts of bandwidth. However, because of the multitudes of users who operate over fiber-optic connections simultaneously, bandwidth and data rates are divided between them so that no one user will realize the ideal benefits of a fiber-optic network. Fiber-optics is also immune to any surrounding electrical interference due to the shielding that takes place in the fiber-optic cables. This shielding resolves the issues of attenuation and signal strength loss that plagued communication via copper wires for years beforehand.

This section serves to give a brief overview of the more important topics underlying the technologies discussed in this chapter. Hopefully, these short descriptions will give readers sufficient knowledge to serve them through the evaluations of the various technologies to follow without causing any unnecessary confusion. It is not important to dwell on the details of this section, but it is important to understanding how the author reached certain conclusions. This section should give a sufficient background to any reader.

The fiber traditionally uses glass as the transmission core, and is capable of transmitting data with negligible bit-error-rates (BER). A BER defines how many bits are received in error per bit received correctly. See the Optical Amplifiers section to see how fibers can cover such extraordinary distances without the need for expensive repeaters, as depicted in Figure 3.1. Because the light beam is completely confined within the transmission core, optical fibers are able to eliminate signal deterioration due to noise with minimal attenuation.

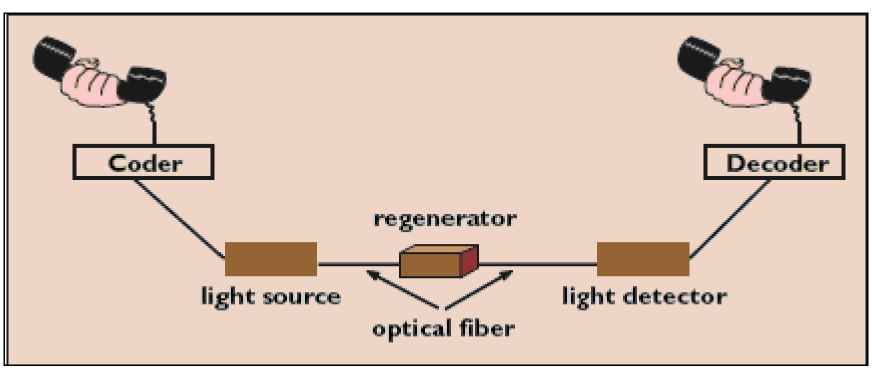


Figure 3.1. Block diagram of the typical structure for a fiber-optic cable.

3.1.1.3 Optical Transmitters

Optical transmitters may incorporate light-emitting-diodes (LEDs) using coherent light to form light pulses or injection laser diodes (ILDs) using incoherent light to form waves. Due to high dispersion effects because of a large spectrum, LEDs are most effective at relatively low bit rates of 10-100 Mbps and relatively short distances of a few kilometers. See section 3.1.1.7.4 for more on the limitations caused by spectral dispersion. ILDs, on the other hand, have a much narrower spectrum allowing much higher data rates due to reduced dispersion effects.

The transmitter may incorporate direct modulation using an electromagnetic current applied directly to control the emission properties of the emitted light wave. External modulator devices may also be used to eliminate potential frequency fluctuations over long transmission distances at higher data rates. The light is then repeatedly emitted as pulses or nulls, which represent the ones and zeros of an information bit stream.

3.1.1.4 Optical Receivers

The most important component in the optical receiver is a simple photodetector that converts received light into electricity. The photoelectric effect says that if light waves are emitted on a metallic surface the photons or light particles will be absorbed and produce a current. An optical-electric converter uses this current to produce a digital electric signal from the incoming optical signal. Depending on the crystalline properties of the receiver, only radiation above a certain threshold frequency will be absorbed. Because frequency is related to wavelength by a constant value—the speed of light—this means that only optical signals above a certain wavelength will be successfully received. This is similar to the tuning and filtering involved in the receiver of the RF system discussed in section 3.3.2.4 and 3.3.2.5.

3.1.1.5 Optical Filters

An optical filter is a device which selectively absorbs or passes through light within a certain range of wavelength. Absorptive filters are designed to reflect some wavelengths of light while absorbing others. Filters are usually made of gel or glass in addition to elemental compounds with properties of absorption for light at specific wavelengths.

Reflective filters are designed to reflect the unwanted wavelengths of light and absorb the remainder by using a reflective coating that is added to the filter prior to implementation. Reflective filters are particularly suited for high-precision tuning, since their exact filter band can be selected by precise control of the coating. They are, however, usually much more expensive and delicate than absorption filters.

3.1.1.6 Optical Amplifiers

Traditionally, optical fibers used repeaters to cover long distances by receiving the signal, converting it to electrical domain, and then retransmitting an identical signal at a higher intensity than when it was received. The optical amplifier achieves the same amplification without any conversion of the signal to the electrical domain. These amplifiers are known as erbium-doped amplifiers. A separate light wave excites ions within the erbium, which alters the medium into an amplifier. Amplifiers are far more convenient because they can amplify signals of any bit rate, modulation, or wavelength shorter than that of the amplifier's internal light beam, which repeaters suffer the same limitation in acceptable wavelength or modulation frequency as optical receivers.

3.1.1.7 How Can You Fit So Many Signals on Such a Skinny Fiber?

While it might be intuitively obvious to imagine one person (Alice) on a small island communicating with another person on a different island (Bob), over a single line, using say, Morse code with a set of light pulses to signal one another back and forth, it is not as straightforward to explain how hundreds to thousands of communication channels could be squeezed into that same line at the same time. To accomplish this, various forms of multiplexing (interleaving) are used.

3.1.1.7.1 Wavelength-Division Multiplexing (WDM)

Wavelength-division multiplexing (WDM) is a simple concept that takes advantage of the large bandwidth of optical communication channels. Several different signals of different wavelengths are all transmitted simultaneously along the same optical fiber or wireless channel for FSO. A large number of light wave signals can coexist in a small space because photons can share the same space without interfering with each other's properties. This property is illustrated by the fact that if a person shines two flashlight beams through one another, the beam continues along its original path undistorted.[38]

To continue our analogy, WDM is the equivalent of each new pair of communicators on the same line using a different color light to transmit their signal. Now, Alice and Bob are signaling each other with red light while Charlie and David are signaling each other with blue light, etc. (All are still on the same line).

WDM and optical amplifiers are what make high data rates possible over the large distances spanned by optical fibers. By using separate channels for text, audio, and images, WDM provides faster uploading of web pages for an internet user by allowing the link to send all these separate data types over the same fiber at the same time.

The word multiplexing means that the information bits are used to modulate the light waves at many different wavelengths, and then are propagated along the same wire. Inverse multiplexing or de-multiplexing is simply the separation of each of the received signals by wavelength onto its own individual channel as illustrated in Figure 3.2.[39]

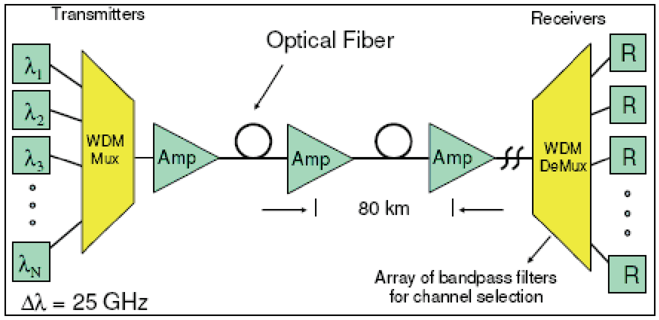


Figure 3.2. Block diagram showing how light waves of different wavelengths are combined for propagation over an optical fiber, and separated into different receiver channels at the other end.

3.1.1.7.2 Optical Time Division Multiplexing (OTDM)

Optical time division multiplexing (OTDM) is the interleaving of separate information signal pulses in time. This means that during the transmission process, alternating pulses will be part of different data sets. By using this method, OTDM divides a single channel into sub-channels, whereby multiple signals can travel on the same channel at the same time without interfering with each other.

In optics, WDM already allows for multiple light pulses to be on the same channel at the same time, but OTDM's usefulness comes into perspective when it is used in conjunction with WDM. If the data rate of the multiple information sources feeding the optical fiber is less than the maximum data rate capacity of the fiber, then the use of OTDM means that information from alternating channels is fed into the fiber during the transmission downtime. This downtime is due to the disparate data rates of the information sources to that of the fiber-optic transmission line.[40]

In the case of TDM, Alice and Bob would be allowed to carry on their conversation for periods of 5 minutes, then alternating with Charlie and David who would converse for the next 5 minutes, and so on.

3.1.1.7.3 Index of Refraction Effects

Scattering loss, or Rayleigh Scattering, is the main cause of signal degradation in fiber-optics. Accounting for up to 96% of transmission losses, scattering is caused by variations in the refractive index of the glass or silica used as the transmission medium in the core of the fiber. These variations are caused during the production process of the fiber when the medium's density does not remain constant during the cooling process.[41] As the light pulses travel, they are reflected off the surface of the transmission medium, and if the angle of refraction is not constant throughout the fiber, then the pulses will not be reflected in the desired forward path. If the scattered light maintains an angle that supports forward travel within the core, no transmission loss would occur, but if the light is scattered at an angle that does not support continued forward travel, the light is diverted out of the core and degradation occurs. Depending on the angle, light may be totally degraded, partially degraded, or even reflected back towards the source emitter. Short wavelengths are scattered more than longer wavelengths, and any wavelength that is below 800 nm is unusable for optical communication because losses due to Rayleigh Scattering is too high.[42]

3.1.1.7.4 Dispersion Effects

Dispersion is a phenomenon that causes the separation of a wave into spectral components with different wavelengths. Dispersion in a waveguide results in signal degradation, because the varying delay in arrival time between different components of a signal spreads out the arrival of information pulses in time. This happens because the wavelength of the information pulses is directly related to the pulse's speed of propagation stemming from the inverse relation of wavelength to frequency. Due to the wavelength threshold of the optical receiver, changes in wavelength will affect the absorption of the light pulse at the receiving end of the link as well as the traveling speed.

Furthermore, if dispersion is too high, a group of pulses representing a bit-stream will spread in time and merge together, rendering the bit-stream unintelligible. This limits the length of optical fiber that a signal can propagate without regeneration. Note that an optical amplifier can't replace a repeater in this case because the original signal must be re-transmitted to prevent the effects of increased dispersion. Dispersion management is extremely important in communications systems based on optical links. There are different forms of dispersion that affect multi- and single-mode fibers differently, but the end results for the various forms of dispersion are the same, and the inherent differences are beyond the technical scope of this paper.[43]

3.1.2 Fiber-Optic Cable

Fiber-optics are currently the most reliable high speed communication device, and are widely incorporated in a variety of areas. A single fiber is capable of data rates in excess of 1 Gbps, and multiple fibers on a single line can conceivably achieve up to 20 Gbps by providing multiple communication channels simultaneously. For static networks, fiber-optics provides a very practical means of communication networking. However, there are many drawbacks to fiber-optics when faced with the demands of a highly mobile network.

The most formidable drawback is when occupying new areas that do not incorporate existing fiber-optics infrastructure, deploying a fiber-optic network requires time and planning that may not be available. Also, the long lengths of wire become costly, and for large networks, degradation in the fiber or outer shielding can cause link failures that are difficult to pinpoint. For mobile forces fiber-optics simply doesn't work. Simple point-to-point links would have limited mobility dictated by the length of the wire, and for mobile mesh style networking mobility becomes even more limited. PAN (Personal Area Networks, section 3.4.4) sensor nets within mechanical systems may not be feasible if the wires interfere with rotating parts, and the heavy weight of the cabling may weigh down lightweight airborne platforms.

Though fiber-optics is an important aspect of high speed networking, and in fact is the pivotal aspect of the only current global internet network, the Army must invest research in wireless forms of communications for preemptive PAN networks and increasingly mobile networks. Fiber-optics will be a part of networking for the foreseeable future, but the infrastructure of fiber-optics severely limits its applicability in many future Army applications.

3.1.3 Infrared Wireless

Infrared wireless is the only wireless optical standard that is in widespread use for short range, relatively low data rate links between handheld computers, or, more commonly, in remote controls for televisions or cameras. These broad-beam free space optical (FSO) links generally link a single transmitter with a single receiver. A single device may send signals to several receiver nodes, but not in a point-to-point fashion. In other words, all the receiver nodes will get an exact copy of the one transmitted signal.

These broad-beam links tend to have data rates less than 10 Mbps because they use low power emitters such as light emitting diodes (LEDs) and because they spread their light over such a large area there are not enough receivable light particles to support a very high speed data rate. However, recent advances in the area of FSO have shown that wireless optical links are capable of achieving very high data rates over significant distances. More on the potential of FSO technology will be addressed in section 3.2.1.

Figure 3.3. Example of a handheld infrared wireless device.

3.2 Future Optical Communication Technologies

There are major drawbacks to fiber optics such as lack of mobility, heavy dependence on existing infrastructure, or infrared wireless issues such as short range, low data rates, and being limited to a point-to-point link topology. Research has shown promise in the area of free-space optical (FSO) communications systems, but currently the technology is not mature enough to compete with wireless RF technology. Investments in the development of FSO communications system technology would be a crucial step in increasing the ability to transfer large amounts of data over vastly increased areas in comparison to currently existing wireless platforms. Similarly, fiber-optic communications will always play an important role in high-speed networking in areas where the necessary infrastructure is available.

3.2.1 Free Space Optical (FSO) Communication

Free space optical (FSO) communication links have great potential to alleviate the bandwidth problem facing the Army's future fighting force. Not only do FSO links provide virtually unlimited bandwidth, but are also capable of transmitting data at speeds greater than 10 Gbps which greatly surpasses the abilities of even our highest data rate radio frequency (RF) or fiber-optic links. The greatest problem facing FSO links is the amount of signal degradation caused by atmospheric turbulence such as wind, cloud cover, or fog. Other factors such as vibration at the transmitter and receiver will also significantly degrade the quality of an FSO link by affecting the direction traversed by the transmitted laser beam.

The extremely narrow beam used by an FSO link makes interception of the signal by unfriendly sources nearly impossible without the need of encryption of further security measures. Though this is a great advantage of FSO for secure transmissions, this narrow beam means that the point-to-point link between the optical transmitter and receiver must be precise, and even a variation as small as 0.0057° in the propagation angle may cause severe link degradation.[44] However, because of the phenomenal increase in data rate, large amounts of parity bits may be inserted as redundant information to help improve the BER even in the presence of signal degradation. A much larger capacity for error correction can be exercised by FSO devices because they can afford to transmit greater amounts of redundant information to correct transmission errors. However, even with signal fading due to interference lasting as short as 1-100 μs, the high data rates can still amount to losing consecutive bits in order of magnitude up to 10^9 bits.[45] The amount of parity needed to correct an error block of this size would be astronomical even with sophisticated correction algorithms. Also, the receiver would experience long delays in processing essentially eliminating the advantage of high FSO data rates. These problems make long distance communication, one of the most attractive characteristics of FSO, problematic for terrestrial based links. Much research is focused, and should continue to focus for the foreseeable future, on the improvement of these terrestrial links, but even with today's current technology, FSO can be extremely useful for satellite-to-satellite communication in outer space.

The superior performance of FSO in the absence of atmospheric turbulence can be used in satellite communications to great effect. Global communications involving large amounts of data can be realized using a network of global satellites serving as a multi-hop platform as depicted in Figure 3.4. The satellites can retrieve information from one point on the globe and transmit to a distant area of the globe with speeds greater than those of fiber-optic internet cables. The large bandwidth capabilities of these optical satellite links will relieve the high demand and limited access for usage of fiber-optic bandwidth to relay information from overseas as described in the Army's report for future FCS bandwidth requirements.[46] A multi-hop satellite network will be a key component to the realization of the Global Information Grid (GIG), which benefits logistics by creating global awareness of supply chain demands so that necessary depots can have adequately stocked supplies in a more timely fashion.

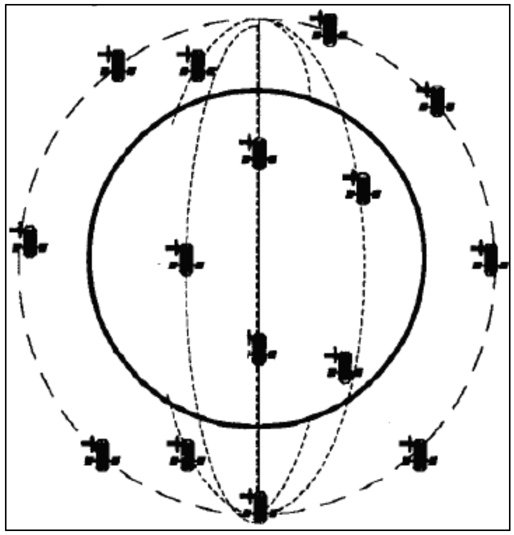


Figure 3.4. Illustration of a global satellite communication system.

However, the complex pointing system of FSO satellite links and their high cost are formidable barriers to their implementation on a widespread scale. To have successful communication between two satellites, the line of sight of their respective transmitters and receivers must be aligned during the entire transmission period. However, mechanical vibration to the pointing system causes vibrations of the beam in the receiver's plane.[47] This is similar to the effect of propagation alteration in terrestrial FSO links discussed earlier.

The complications and cost of FSO networking shows why RF transmissions are so heavily favored in current wireless Army communication networks. However, crowding of the frequency bands and limited bandwidth capabilities make the integration and development of sophisticated FSO links extremely necessary. These facts make the move toward hybrid RF/FSO networks inevitable, and this will become one of the focuses later in this chapter describing future communications research efforts. FSO links will become the main development that leads to the near real-time worldwide communications capabilities necessary for the future of the logistics prediction and supply chain efforts. The following sections describe some of the key features of FSO communications in greater detail to give background on how the transformation to a more widespread optical networking capability may unfold.

3.2.1.1 Technical Risk: Environmental Effects

Because FSO links use light as the transmission medium, the way light is reflected and absorbed can decrease the strength of a signal or change the path of a signal. In fact, a typical 4 km FSO link will only be able to transmit up to 150 m in dense fog. The degradation of range due to different types of atmospheric turbulence is depicted in Figure 3.5. Signal fading is not the only effect caused by changes in the optical transmission medium. Depending on what environment the wave travels through, the speed of light will also differ. Therefore, when designing an FSO communication link, the designer must take into account these data rate effects.

Weather	Precipitation	Visibility	dB per km Loss at 785 nm
Dense fog		0–50 m	>340
Thick fog		50–200 m	85–340
Moderate fog		200–500 m	34–85
Light fog	Cloudburst (100 mm per hour)	500–1,000 m	14–34
Thin fog	Heavy rain (25 mm per hour)	1–2 km	7–14
Haze	Medium rain (12.5 mm per hour)	2–4 km	3–7
Light haze	Light rain (2.5 mm per hour)	4–10 km	1–3
Clear	Drizzle (0.25 mm per hour)	10–20 km	0.5–1
Very clear		>20 km	<0.5

Figure 3.5. Performance of an optical link in different types of atmospheric turbulences.

Similarly, depending on the transmission medium, the light's path of propagation may experience bending. This phenomenon is known as diffraction. A familiar example may be the distorted reflection seen by a person staring into a pool of water, or the multi-colored effect of shining a beam of light through an optical prism. Because FSO devices require precise point-to-point links, when arranging the transmitter and receiver, the designer must take into account possible propagation changes caused by the surrounding environment.

The most intuitive effect that needs to be considered is the absorption of light by solid objects. This is in sharp contrast to radio wave properties. While radio waves can travel through a thin concrete barrier, or because the radiation pattern of an antenna may propagate a single RF signal over a wide area, radio transmissions may travel through or around many solid objects. The transmission beam for FSO is so narrow that even seemingly small objects may block the transmission path of the link, and all non-transparent objects will absorb a beam of light making it impossible for the link to travel through certain barriers the way an RF signal can. When evaluating the usefulness of an FSO link, investigation of the potential barriers and environmental conditions and how they will affect the propagation of the optical data is a critical part of the process.

3.2.1.2 Technical Risk: Spatial Diversity/Coherent Detection

Coherent detection is simply the process of using multiple receivers and multiple transmitters to transmit a signal over several different channels. For FSO links, this means that by transmitting the signal simultaneously using multiple transmitters spaced apart at predetermined distances, a signal may propagate over multiple paths that will each experience different types of atmospheric interference. Using this logic, it is intuitive that for several propagation paths or more, the chances are higher that one of the signals has a good chance of minimizing the effects of atmospheric turbulence on the link's effectiveness. Although this approach may seem like it would require each FSO device's area to increase drastically to compensate for the addition of several new transmitters and receivers per device, because the laser beams are so narrow, they can be spaced centimeters apart without risking interfering with one another. This is in sharp contrast to RF links that need a much greater distance of separation for coherent transmission / detection schemes.[48]

3.2.2 Photon Counting Receivers

In many applications, photon counting is required in order to achieve the highest detector performance for laser transmissions and is also desirable because of its small size. Photons are the subatomic particles that make up light, and photon counters function by absorbing these photons from a transmitted light beam. Photon counters do not actually count photons, but are atomic photoabsorption processes rendered individually detectable by an amplification of some sort. Usually, the photoabsorption process is detection of a current generated by an excited electron using the energy of an absorbed photon. Each photon absorbed results in a photocurrent pulse, but a high gain amplifier is necessary to detect these relatively weak pulses.

Because the photocurrent pulses are so weak, photon counters suffer from dark counts, which are simply erroneous detections caused by noise in the circuit. The two sources of dark counts are the leakage currents of the diodes and the thermal noise of the amplifier. Since photon counters operate best when source beams are made of low density light—fewer photons—the dark counts of the photo counter can greatly influence the accuracy of the data received.

The data rate suffers greatly from these low-density photon transmissions. But, eavesdropping on the transmissions becomes extremely difficult, especially in the presence of the dark count effect. Unfortunately, friendly receivers also suffer from this disparity, but with the development of sophisticated filtering and threshold algorithms, friendly receivers may be able to use a sophisticated key to distinguish between the two.

Photon counters have the potential to be a very useful and secure means of communication for FSO devices. Advances in device technology to reduce the number of dark counts as well as to increase detection rate capabilities will allow photon counters to be applied across a wider range of applications.

3.2.3 Adaptive Optical Mesh Networks

An all-FSO adaptive-style mesh network will greatly increase the communication capabilities of logistics data transmission from the battlefield. FSO networks offer high transmission rates that can satisfy the need for broadband communication in the wireless field, while enjoying an unregulated spectrum and license-free operation. While successful point-to-point links have been demonstrated over a variety of ranges in the optical realm, there still exists a need to develop adaptive mesh networking capabilities for an all-optical wireless network.

Adaptive networks will adjust to degrading atmospheric effects by dynamically adapting link parameters to respond to changes in the environment. Moreover, the network topology can be reconfigured through moveable transceivers if changing the link parameters is not sufficient. Current FSO links are stationary due to the complex pointing systems and high misalignment sensitivity of current FSO links. Developing moveable transceivers would greatly increase the robustness of FSO networks, but their implementation introduces great technical challenges.

Network reconfiguration would have to be nearly instantaneous, which is difficult considering how perfectly aligned an FSO link has to be to make communication feasible. Modulating Retro-Reflectors (MRR), discussed in section 3.2.4, have been shown to increase the field of view of the transceiver, but at the cost of much lower data transmission rates and shorter ranges. To take advantage of the high channel capacities offered by FSO links, faster pointing algorithms will need to be combined with intricate lookup tables of surrounding nodes and their precise locations in respect to all other surrounding nodes in a network. Ideally, the speed of recovery should be of the order of speed of switching, and requires the reconfiguration algorithms to have little processing overhead.

Also, while this makes FSO networks more robust these algorithms still do not allow for the mobility enjoyed by RF networks. Though select nodes may have mobility, a majority of the optical links would need to be ground stations. As discussed in section 3.2.4, even if MRRs are successful in giving FSO links broadcasting abilities, they require a power ground node to provide enough transmit power to make the MRR link feasible. This starkly contrasts with RF mesh networks, where all nodes can technically be completely mobile. A limited mobility characteristic will also limit the applications where this type of network can be applied, unless further developments in optical broadcasting links or high-speed pointing systems are made.

3.2.4 Modulating Retro-Reflector (MRR)

Modulating retro-reflectors (MRR) will reduce the form factor of the optical circuit to expand the optical networking to smaller, less capable platforms. For this reason, MRRs are best suited for asymmetric communication links. For example, using an MRR on an unmanned aircraft system, (UAS) shifts most of the power, weight, and pointing requirements to a ground station, thereby making longer range communications on this type of lightweight, low power platform feasible.

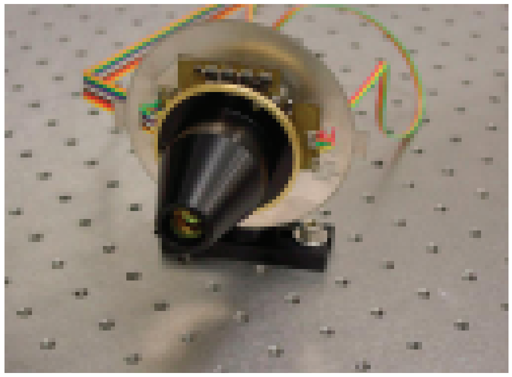


Figure 3.6. Example of a modulating retro-reflector.

MRRs can be divided into two classes made up of those with focusing optics and those without. Non-focusing reflectors are known as corner cube retro-reflectors (CRR), and focusing reflectors are known as “cat’s eye” retro-reflectors (CERR). The latter comes in several different variations, and there is no one retro-reflector for all MRR systems, but the retro-reflector must be chosen based on the specific requirements of the system for which it is intended.

CRRs are small, lightweight, and use materials that are readily available. They do not have focusing capabilities of their own, but instead imprint data onto the beam of the interrogator which is then reflected back to the interrogation node. Also, CRRs have a limited field of view that is heavily dependent on the index of refraction of the reflective material used. Higher indexes of refractions yield a larger FOV, but these materials are more expensive. The size of the modulator, the main component of the MRR, governs the communication range so that a larger modulator is needed to communicate over larger distances. This negates one of the main advantages of using CRRs, making them more suitable for highly asymmetric links where small size or light weight is critical. Furthermore, CRRs are better suited for lower data rate and lower range applications because current state-of-the-art devices have been demonstrated at 5 Mbps at 1.6 km. CERRs help alleviate some of the drawbacks of the CRRs, but they require more power, a slightly larger form factor, and are more expensive. By using mirrored reflective surfaces, CERRs allow for smaller and faster modulators that are capable of achieving data rates of up to 70 Mbps over a 4 km link.

MRR systems are more robust than a typical FSO system, although their range and data rate capabilities are lower. Because the FOV of the MRR dictates how sensitive the receiver is to pointing misalignments, they do not require the precise pointing mechanisms that the previously described FSO systems do. In fact, CERRs can tolerate misalignment up to 30˚ and CRRs up to 60˚ in comparison to the 0.0057˚ of optical satellites. This makes MRRs much more robust in the face of vibration disturbances.

MRRs are still in the initial stages of development, and will become a crucial piece of the puzzle that makes optical links smaller and less expensive. Currently, they are a viable alternative to RF links because they are able to traverse greater distances at comparable data rates. Similarly, their large FOV make them ideal for a broadcast type of interrogation as opposed to the precise point-to-point requirements of more powerful FSO systems. As research continues, their range and data rate capabilities will continue to improve.

3.2.5 Hybrid Free Space Optical (FSO)/RF Networks

The hybrid network will use a combination of FSO and RF links to ensure the highest quality performance of a mobile data network. Network-centric operations, including integrated sensors, mobile networks, localized prediction capabilities and global communications infrastructure, will rely on the high data rates (>100 Mbps) offered by FSO and high performance RF links. FSO links provide the fastest available wireless data rates, longest transmission ranges, and offer the greatest security to jamming and interception using their narrow, directional laser beams. RF links also provide ever increasing data rates, are useful in broadcast communications for ad-hoc networks and in adverse weather conditions where the reliability of the FSO link fails. The greatest challenge to this type of hybrid network is the topology control or reconfiguration between the switching of RF and FSO links depending on link quality and link degradation. Mobile node reconfiguration algorithms, similar to those under investigation for RF mesh networking, are also important due to the required mobility of many nodes in a hybrid network such as airborne UAS nodes.[49]

3.2.5.1 Reconfigurable Networking

Nodes within the hybrid network incorporate two types of links, and ideally whichever link achieves the greatest link quality, usually determined by the lowest BER, will be the link used for data transfer. Unfortunately, because FSO links have such a higher capacity—greater than 1 Gbps versus 100 Mbps for RF links when degradation of an FSO link occurs—shifting the data payload to an RF link becomes a significant problem. This may cause large delays in the transfer of data when communicating from a system collecting immense amounts of data.

One promising solution to this problem is known as bi-connectivity. Essentially, this means that each node has two destinations to which it can knowingly communicate. Therefore, if one of the links degrades, the node can quickly reconfigure itself to a second link without having to run time-consuming link evaluation algorithms that will cause delays.[50] This preemptive approach would allow a greater efficiency because it reduces latency involved with calculating new link paths on-the-fly. Also, calculating the link quality for a new backup can be done in the background without interrupting the flow of data. However, in a rare case where both nodes fail, new solutions must be found on how to use a slower RF link to move the data while searching for a reliable FSO link to re-establish the desired flow of data within the hybrid network.

3.2.5.2 Pointing Tracking and Acquisition

Because of the minute divergence angle of FSO links discussed in section 3.2.1, pointing an optical laser with enough precision to acquire the necessary connection to an optical receiver is impossible without significant delays. The complicated pointing algorithms used to point space satellites are impractical due to limited processing power and near real time requirements of most terrestrial communication links. However, the relatively large tolerated divergence angle for RF links makes establishing ad-hoc connectivity within a mobile network feasible. This also means that the node can use the RF link to assess whether an optical receiver is available for connectivity quickly and without wasting resources trying to connect the optical link to an unavailable connection. Once the RF connection is made and knowing the physical positioning of the FSO link with respect to the RF link, the optical connection can be made with a significantly reduced scanning area.[51] Without the combination of RF and FSO links for each node in the network, achieving the high optical data rates and robustness of an ad-hoc network is not possible. This demonstrates the necessity for hybrid networks to be developed in order to ensure the greatest efficiency and reliability of net-centric communications.

3.2.5.3 UAS Networking

UAS networking has a wealth of applications within the framework of a hybrid network. Airborne relays will extend communication ranges of typical mobile networks, allow for airborne mobile optical wideband communications, and create methods for overcoming obstacles obstructing point-to-point communication links. Another unique feature of UAS communication links is they can alter their flight paths to come within range of otherwise unreachable locations.[52] For instance, a UAS may receive battalion information hovering over a remote location and then fly back to the command center to relay the information to the appropriate sources and vice versa. An optical link on a UAS could even allow uplinks from terrestrial communications devices to global satellite networks by uploading the information and then rising to an altitude above cloud cover to mitigate many of the adverse environmental effects on an FSO link as illustrated in Figure 3.7.[53] With large enough memory capacity, UASs may also act as sensors themselves for the prediction effort especially in the area of weather prediction, or as large data storage units that could store and deliver data payloads to out-of-range links within a several kilometer flight range. Because the communication capabilities of UAS units would be determined by the communication technologies onboard and not by the advancement of UAS technologies, introducing UASs as a central part of a communications network is key to the idea of the Common Data Link (CDL) for network-centric communications for future Army applications.[54]

Figure 3.7. Example of simultaneous multi-band communication of a UAS with the battlefield and the GIG via satellite uplink.

The hybrid network will use a combination of FSO and RF links to ensure the highest quality performance of a mobile data network. Network-centric operations, including integrated sensors, mobile networks, localized prediction capabilities and global communications infrastructure, will rely on the high data rates (>100 Mbps) offered by FSO and high performance RF links. FSO links provide the fastest available wireless data rates, longest transmission ranges, and offer the greatest security to jamming and interception using narrow, directional laser beams. RF links also provide ever increasing data rates, are useful in broadcast communications for ad-hoc networks and in adverse weather conditions where the reliability of the FSO link fails. The greatest challenge to this type of hybrid network is the topology control or reconfiguration between the switching of RF and FSO links depending on link quality and link degradation. Mobile node reconfiguration algorithms, similar to those under investigation for RF mesh networking, are also important due to the required mobility of many nodes in a hybrid network such as airborne UAS nodes.[55]

3.3 Radio Frequency (RF) Technologies

Radio Frequency (RF) technologies are already a key aspect of the Army's combat forces both for logistical, situational awareness, and battlefield communications capabilities. RF links allow information to be networked throughout all levels of the command and supply chains allowing for up-to-date decisions and ensuring viable communications between field units. Though fiber-optic local area networks (LANs) will still play an important role in the future of Army information exchange, wireless local area networks (WLANs) are increasingly taking over in situations requiring increased mobility or where necessary infrastructure for fiber-optic LANs is not available.

Even as RF moves to higher frequency bands with greater bandwidths, the crowding of these bands and the transmission range limitations will always be overshadowed by emerging FSO technologies with longer range and greater bandwidth capabilities. The usefulness of future RF will be in shorter range mobile networks, areas of more robust terrestrial communications, and less costly monitoring systems that take advantage of the standardization of RFID monitoring systems. This means that much of the future of RF technologies will be in the standardization of networking infrastructure and interoperability as demonstrated in ongoing research efforts like the Joint Tactical Radio System (JTRS) and the Warfighter Information Network-Tactical (WIN-T) program. Integration of current RF capabilities with FSO to provide a common net-centric communications capability for the Army will play heavily in the future of RF technical advancements. Therefore, the understanding of current and emerging technologies becomes even more important for RF devices because their future lies in implementation advances more than in the advances of specific technological devices, as in the FSO realm.

3.3.1 Radio Frequency Overview

This section explains the fundamental concepts of RF communication devices and theory. The overview section does not serve to demonstrate the situational functionality of certain RF communication capabilities, but rather serves to educate on how RF communication devices work and why RF communication has the inherent properties that separate it from other forms of communication. These fundamentals will be as important for defining and understanding RF technologies of the year 2030 as they are in understanding the capabilities of current and emerging RF technologies of today.

3.3.1.1 Radio Frequency Links

An RF link is simply a wireless link allowing for the transfer of data between multiple systems through the use of radio waves. From simple car radios to cell phones and complicated interplanetary satellite communication systems, today's wireless devices all employ RF links. RF links are defined by many things, all of which will be discussed in greater detail in the coming sections, which are explicitly defined in the wireless standards that lay out all the rules and characteristics of a link including networking protocols, power consumption, data rate, transmission range, etc. For more on RF standards or wireless protocols see section 3.3.1.2.

RF links allow for mobile communication networks that can incorporate anything associated with current internet or telephone capabilities. RF links permeate daily life in so many ways that most people just take them for granted, and do not take the time to understand the subtleties and complications of the technologies that this chapter attempts to bring to light. The rest of section 3.3 will be dedicated to the evaluation and more detailed explanation of the concepts and technologies associated with RF links.

3.3.1.2 Radio Frequency Standards

Every RF device has a standard of operation which defines all of its characteristics. These standards vary from country to country so even if a technology abides by a certain standard here in the United States, always be careful to ensure in the design process that an RF device will abide by the communication laws of any foreign countries where it may operate. For instance, in this country all communication laws are defined and enforced by the Federal Communications Commission (FCC).

In Figure 3.8, all the pertinent existing and emerging RF standards are depicted along with their most defining characteristics. This table gives an idea of the different aspects of a wireless link that an RF standard must define. Though some of the properties of a given standard will overlap with those of another, an RF designer can't mix and match properties of different standards as he or she sees fit. Instead they must decide what standard best fits the application of their device at the outset, and strictly abide by the rules set out by that individual standard.

WIRELESS LAN/PAN TECHNOLOGIES

Property	802.11 Wi-Fi	Bluetooth	ZigBee	UWB	UHF	Wireless USB	IR Wireless	Near Field Magnetic
Operating frequency	802.11 b/g 2.4 GHz 802.11 a 5GHz	2.4 GHz	868 MHz (Europe) 902-928 MHz (The Americas) 2.4 GHz (Worldwide)	3.1–10.6 GHz	260-470 MHz 902-928 MHz	2.4 GHz	Infrared 800-900 nm	Magnetic Coupling
Data rate	11 Mbits/s 54 Mbits/s	1Mbits/s	20 kbits/s 40 kbits/s 250 kbits/s	100-500 Mbits/s	10-100 kbits/s	62.5 kbits/s	20-40 kbits/s 115 kbits/s 4 & 16 Mbits/s	64-384 kbits/s
Range	100 meters 50 meters	10 meters	10-100 meters	<10 meters	10 meters- 10 miles	10 meters	1-9 meters Line-of-sight	1-3 meters
Networking	Point-to-multipoint	Ad hoc piconets	Ad hoc, star, peer-to-peer, mesh	Point-to-point	Point-to-point	Point-to-point	Point-to-point	Point-to-point
Complexity	High	High	Low	Medium	Lowest	Low	Low	Low
Power consumption	High	Medium	Very low	Low	Low	Low	Low	Low
Applications	WLAN hotspots	Wireless headsets, PC-PDA-laptop connections.	Industrial monitoring and control. Home automation and control. Sensor networks. Toys, games, medical, automotive.	Home entertainment networks. Streaming video.	Coded remote control. Remote keyless entry, garage doors.	PC peripherals	Remote control. PC-PDA-laptop links.	Wireless headsets. Automotive.

Figure 3.8. Table of the characteristics defined by the various wireless standards listed across the top of the table.

3.3.1.3 Frequency Allocations

The operational frequency of radio waves literally acts as a way to organize different types of wireless communication into different bands of the radio frequency spectrum. Current frequency bands and the types of wireless technologies associated with each are illustrated in Figure 3.8 up to about 60 GHz. The terahertz frequency band, on the order of 1,000,000 GHz, is currently unoccupied, but current indications are strong that technological advances in the near future will allow wireless standards to exist within this range of frequencies allowing for greater operational bandwidth.

Selection of a frequency band is important because a crowded band means more potential sources of interference. Also, without proper secure modulation schemes and encryption methods, wireless signals can be intercepted intentionally or unintentionally by other users of the same band. A simple example is the older versions of the cordless phone, operating at about 50 MHz, which is right in the middle of the Low End Devices band of Figure 3.9. This band also incorporates things like garage door openers, alarm systems, and remote control cars. When using a cordless phone outside, users may notice a lot of static in the background caused by various other wireless sources in the area operating at the same frequency. Users may also notice that sometimes they can hear a neighbor's conversation clearly in the ear piece of their phone. The latter instance is a specific example of unintentional interception as previously mentioned. Note here that cordless phones are not the same as cell phones, but are equivalent to the telephonic LAN lines of a traditional household phone. However, the cellular band is also crowded, but users will not hear anyone else's conversation because cell phones incorporate spread spectrum modulation. The detals of this are beyond the technical level of this section, but suffice it to say, this modulation technique makes both intentional and unintentional interception of wireless signals virtually impossible no matter how crowded the bands become.

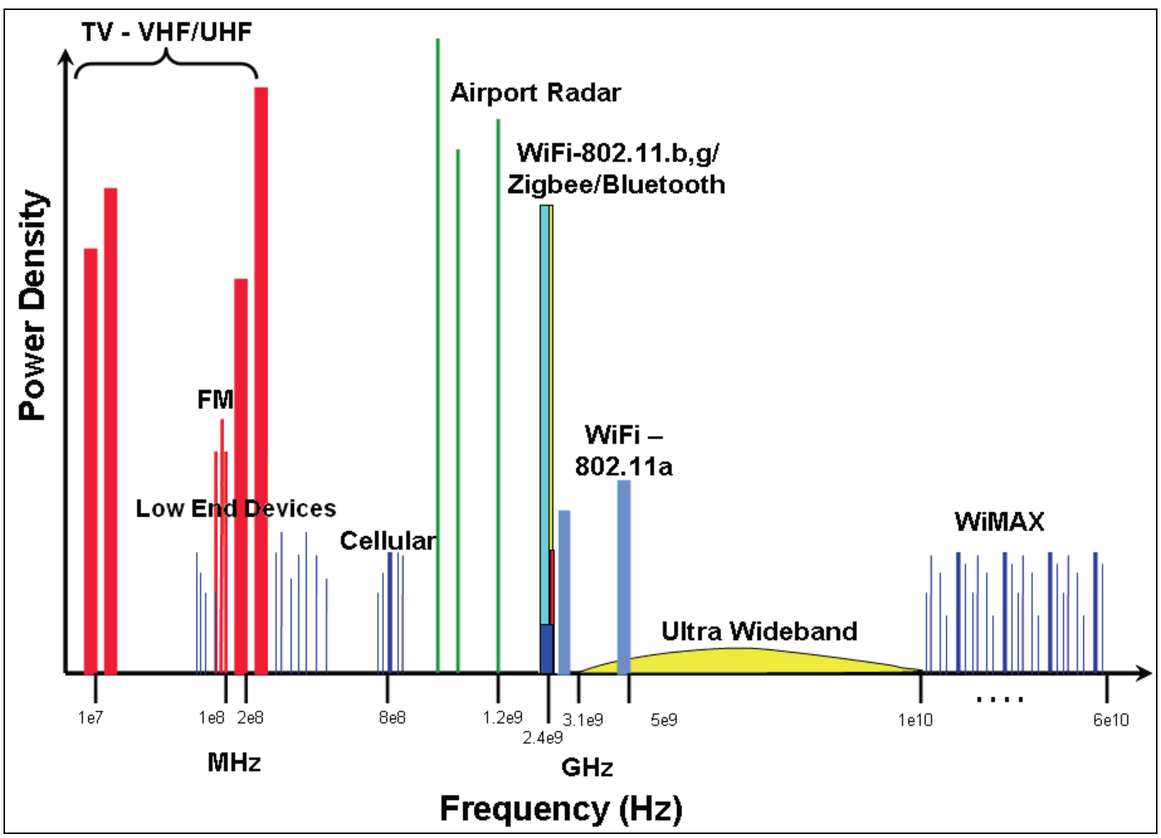


Figure 3.9. Illustration of where different RF technologies reside in the radio wave frequency spectrum.

3.3.2 Basic RF Components

This section gives a brief description of the individual components for a wireless RF device. The descriptions of these devices and their functions within the scope of the RF circuit framework give a basic idea of how a radio wave is created, transmitted, received, and decoded. Also, some of the other fundamental ideas such as frequency allocations may be made clearer by seeing how they are incorporated into the functionality of an RF circuit.

3.3.2.1 Transceiver

In RF devices, a transceiver means a unit containing both receiver and transmitter circuitry in the same housing. Here both the transmitter and receiver functions will be discussed in turn.

In general, the receiver circuit usually incorporates a tuner, a filter, and a pre-amplifier, and serves the purpose of interpreting incoming electronic signals into text, voice, audio, or visual data. The tuner simply defines the frequency of the filter, while the filter limits the incoming bandwidth to a narrow channel centered on the frequency of the incoming signal. See section 3.3.2.4 for more details on RF filters. By doing so, the signal-to-noise ratio (SNR) is improved because the power of interference at other frequencies is limited without affecting the power of the desired signal, and the ratio of signal power to noise power is increased. A strong SNR is crucial for accurate performance of the receiver. Receiver performance is characterized by the BER of the system. A low BER means that a small number of bits are received in error for a given number of transmitted bits. A BER of 10^{-6} or lower, i.e., 1 per 1,000,000 bits in error, usually means that the communication system is operating effectively. A low noise amplifier (LNA) attempts to achieve a similar increase in SNR by amplifying the signal as it comes in through the antenna. In order to avoid amplifying interfering signals as well, the RF designer must engineer the tuner to narrow the incoming bandwidth as much as possible.[56]

A transmitter is responsible for the propagation of an electromagnetic wave through the aid of an antenna, and usually incorporates a modulator, amplifier, and an oscillator as its devices. Electromagnetic simply means that the radiation of the waveform creates an electric and a magnetic field. The modulator is responsible for performing modulation on an information signal to encode the information in an envelope signal of different frequency. Figure 3.10 depicts the resulting encoded waveform after modulation takes place. The reason for doing this is simple. Suppose we are operating in the 2.4 GHz frequency band, but the information waveform has a frequency of 40 GHz. In order for our signal to be received, the frequency must be shifted to 2.4 GHz or the filter will not pass the signal through to the receiver. By encoding the information waveform into an envelope of the corresponding frequency, the waveform will travel at the desired frequency, but none of the information will be lost. Demodulation is simply the inverse process of extracting the original signal from the encoded envelope. The amplifier is responsible for increasing the gain of the signal and making the signal easier to detect on the receiving end. However, the amplification stage decreases the overall efficiency of the total RF circuit and requires more power. The best approach is to optimize the relationship between this amplification stage and the gain of the antenna, as discussed in section 3.3.2.5. The oscillator is simply a device that is used to tune the output frequency of the transmitter. This ensures that the signal travels at the appropriate frequency in order to pass the RF filter on the receiving end as previously explained.[57]

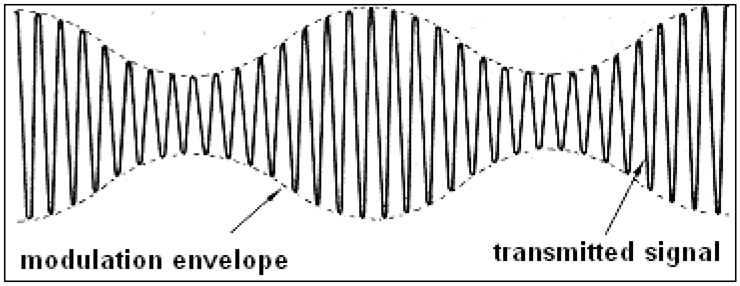


Figure 3.10. Demonstration of a basic Amplitude Modulation (AM) radio signal.

3.3.2.2 Mixer

Mixers are used extensively used in RF circuitry, and though mixers come in both linear and non-linear forms, only the non-linear mixers are used in RF applications. The defining difference is that a linear mixer performs an addition of the incoming signals while the non-linear mixer performs a multiplication. Incoming signals entering a non-linear mixer at a given frequency create additional frequencies as byproducts of the mixing process. A single signal entering would be expected to generate simple harmonics, while multiple signals at different frequencies act to create additional mixer products known as spurs or intermodulations. A simple mixing process and the resulting output are depicted in Figure 3.11. The output acts as the basis for determining the dynamic range of a receiver, as discussed in section 3.3.3.3.

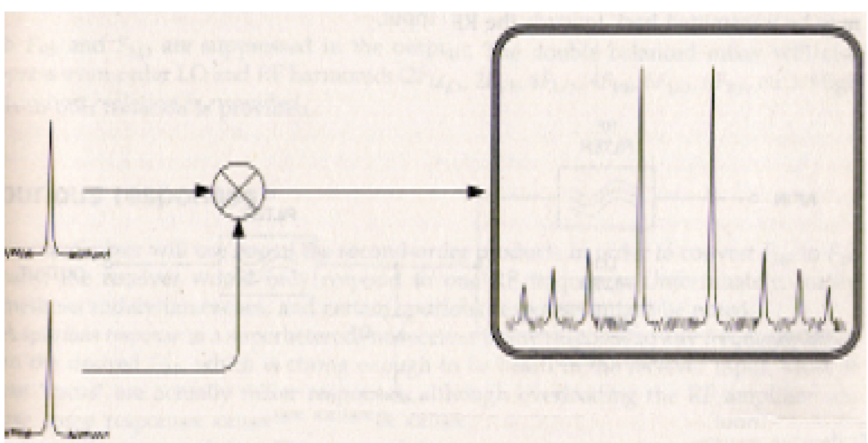


Figure 3.11. Results of the mixing process come in the form of undesired harmonics or spurs.

Though other devices can be used to superimpose incoming signals on new frequencies, the mixer is extremely useful because it serves to preserve the modulation of the incoming signals, as illustrated in Figure 3.11. Demodulation is essential in the receiver of an RF circuit, making the mixer an essential part of the RF receiver's architecture.[58]

3.3.2.3 Local Oscillator (LO)

The local oscillator (LO) is used as an input to the mixer depicted in Figure 3.11, and serves to define the frequency shift imposed on the incoming signals. By defining the LO frequency to a specific value, the mixing performed on any incoming RF signals will shift the frequency of those signals down to baseband, by the same frequency amount of the LO. The output of this mixing process is called the intermediate frequency (IF), and serves to shift the signal based on the tuned frequency of the RF amplifier.[59]

3.3.2.4 Filter

RF filters simply serve to limit the range of frequencies coming into the receiver of the circuit. The logic behind this is that since the desired signal is at a specific frequency, any other signals at other frequencies are interfering signals, and the more signals that come into the receiver, the greater the chance of there being a powerful signal that will distort the reception or decrease the SNR of the receiver. A simple band-pass filter is shown in Figure 3.12. Here the visualization of the filter's configuration is apparent, in that only signals at the frequencies within the width of the filter are passed on to the receiver. Band-pass means that the allowed bandwidth is restricted to a small amount within the middle of the surrounding frequency range. The technical details of the implementation for band-pass filters are not necessary for the scope of this report. There are also low-pass and high-pass filters, but these are based on the same fundamental concept. Band-pass filters have a point of diminishing returns such that at some threshold, the narrower the window or bandwidth of the filter the less effective the filter becomes. However, current windowing methods yield sufficiently narrow filters to allow for the accurate reception of even low power signals in an RF system.

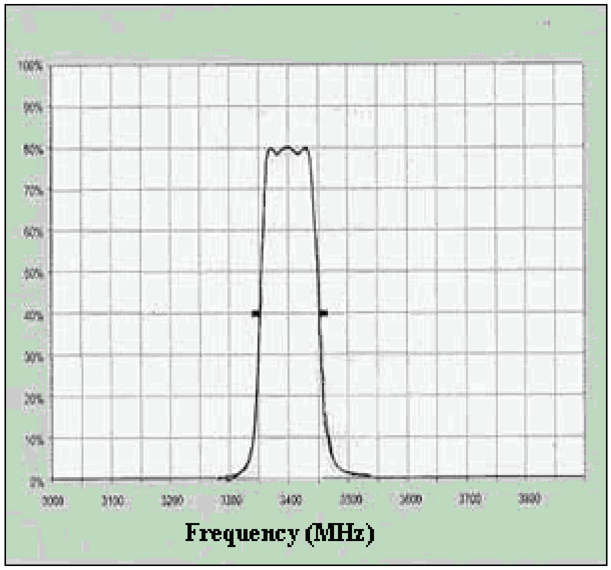


Figure 3.12. Depiction of a band-pass filter, where signals within the depicted band-pass region are received and signals outside are negated to zero.

3.3.2.5 Antennas

Antennas are devices that serve to radiate or receive incoming radio signals. As a radiator, the antenna takes an electrical signal from the transmitter and converts the signal to a radio wave that propagates at a predetermined frequency. This frequency can be altered by tuning the antenna, which will be discussed shortly. As a receiver, the antenna captures radio waveforms, and relays them to the RF receiver chip that converts the radio wave into an electrical signal. Usually, the transmitter and receiver chips are integrated into a single transceiver, so called because the chip can act either as a transmitter or receiver while switching back and forth. For this reason, a single antenna either receives signals or transmits signals, but can't do both at the same time.

Because antennas radiate signals best when their length is matched to the wavelength of the radiated signal frequency, tuning the antenna helps to optimize performance. Wavelength and frequency are inversely proportional to one another and differ by a factor of the speed of light. This constant relation makes finding the optimal length of an antenna for any given frequency simple. However, because when operating in the MHz frequency range the calculation yields results in multiples of feet, often an exact fraction such as a 5/8, 1/2, 1/4, or 1/8 wavelength antennas are commonly used to achieve shorter antenna lengths. At higher frequencies this becomes less of an issue.[60]

Antenna gain and the associated tradeoffs is the main measure of effectiveness for any given antenna. The gain of an antenna is the ratio of radiation intensity in the direction of strongest intensity compared to that of a standard reference model. An antenna is not capable of adding extra power to increase range, but it can redistribute available power along a given path. When this happens, the antenna achieves a high gain and increases range when oriented along this path, but the gain in other directions becomes very weak. This type of multi-directional radiation for a triangular array antenna is depicted in figure 3.13, where the lengths of the lines are proportional to the gain in that direction.

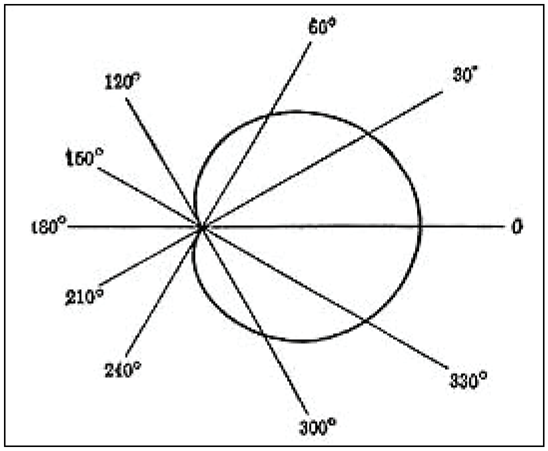


Figure 3.13. Shows how the radiation intensity affects the transmission power of the antenna in a specific direction.

A realizable example is a dish antenna used for deep space applications that has phenomenal gain in a specific direction, but to be useful the antenna must be set to a specific set of coordinates with expert precision because a slight change in orientation will render it useless. On the other hand, radio station antennas have a very weak gain because the signal must radiate at equal power in many directions so that radios in all directions and in numerous separate locations can pick up the signal. This explains why radio stations have a relatively small broadcast range even though the antennas they use are very large.[61]

3.3.3 Technical Risks

3.3.3.1 Environmental Effects

The environment in which an RF waveform propagates can alter the signal properties or even negate the signal altogether. A transmitted signal will have ideal properties in free space, which is generally an open air environment free of any other forms of noisy interference or obstructing mediums such as thick concrete or metal barriers, large bodies of water, etc. In free space, properties such as SNR, transmission range, or BER will yield the best possible values, but when taking a potential RF communication system into consideration, the operating environment is crucial.

For instance, cell phones are unlikely to get good reception when in an underground parking garage or a closed elevator. Here the environment is playing a crucial role in whether or not a recognizable signal can be transmitted or received. Radio waves can travel through solid concrete barriers or through solid earth barriers, but these will have a drastic effect on the overall range of a given transmission, and if the barriers are indeed thick enough, then the range will be reduced to a point where the signal can no longer get through the barrier at all. Similarly, radio waves will not travel through a metal barrier of any kind. If a transmitter is entirely encased in a metal container with no gaps or cracks then no radio signal will ever get through. The best case scenario is that for a signal centered at a high enough frequency, the wavelengths can be short enough that the signal can escape through very narrow cracks in a metal casing, say where two sides meet if the seal is not weather proof.

Though the above two instances are extreme, they are also commonplace in certain scenarios, but any environmental obstructions will affect the ability of a transmitted signal to get out of or into that environment. It is best to observe or estimate the transmission patterns beforehand and to arrange nodes in a configuration that is optimal for the application.

3.3.3.2 Multipathing

Radio waves behave the same as any other wave you may be familiar with, in that waves may interfere destructively or constructively when they arrive at the same point in space and time. With wireless signals, because of the radiation pattern of the antenna, the wave does not simply traverse a straight line path between the transmitter and receiver, but may take any number of paths simultaneously. This tends to cause more problems in enclosed spaces as opposed to open or outdoor spaces because for multiple paths to be reflected at the same point at the same time there need to be multiple surfaces to reflect the signal off of. Figure 3.14 shows the difference between the number of paths in an open space versus an enclosed space. Also, keep in mind that this figure of the enclosed space only takes into account single bounce paths, but that a wave may bounce multiple times off any surface before traversing the distance to the receiver. However, the more bounces or longer the traversed path, the lower the power of the received signal due to propagation losses, so these high bounce paths tend not to affect the received signal very significantly. Also notice that for the enclosed space, there tends to be a clustering of path lengths that increases the likelihood of multiple signals arriving at the receiver at the same time.

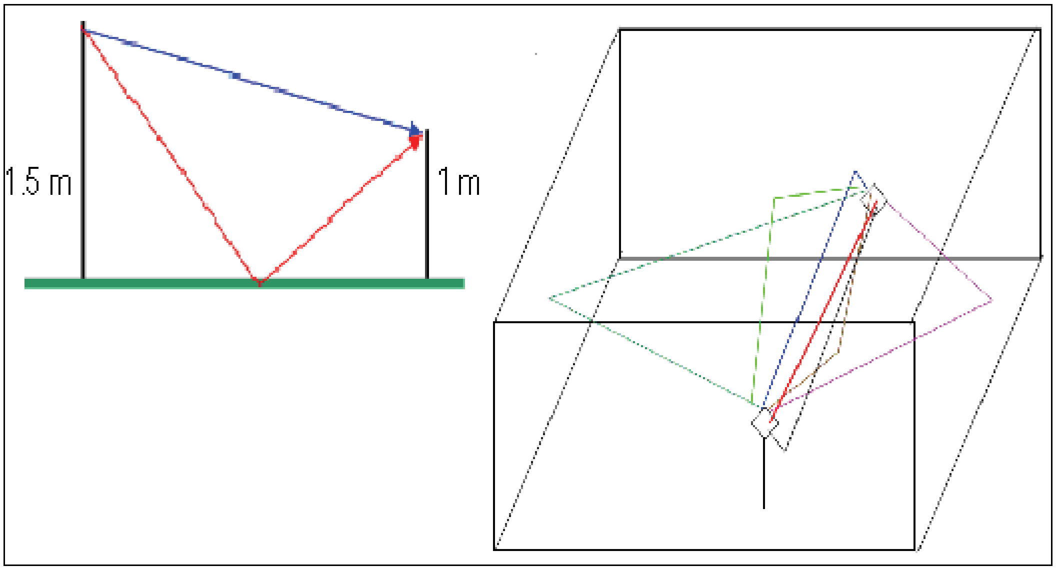


Figure 3.14. Effects of RF multipathing in an open and enclosed three dimensional space.

Constructive interference tends not to be an issue because increasing the power upon reception of a signal doesn't change the information contained within the radio wave, but makes it easier to receive by increasing the overall SNR. Destructive interference lowers the SNR, which can result in bit errors. Although this example encompasses a very short time window—on the order of fractions of a second—the received signal will not have a constant power level over this time interval because of the nulls in signal power resulting from the destructive interference.

As a quick example of how to alleviate multipath issues, error correcting codes are additional bits added to the information block in the form of parity, which are used along with specific decoding algorithms to correct potential bit errors in a transmitted signal. Any number of errors in a sequence are theoretically possibly to correct, although there are many tradeoffs associated with error correction. Similarly, modulation techniques decrease the probability that for a given signal to noise ratio any bit will be flipped during the transmission process, and there are several different forms of modulation with varying degrees of effectiveness and additional tradeoffs.

3.3.3.3 Dynamic Range-Analog and Digital

The effectiveness of any RF link is based on the ability of the receiver to reproduce transmitted signals. Although the properties evaluated in figure 3.15 are all critical to the performance of a wireless communication system (WCS), these properties are predetermined by the selection of an existing standard, whereas dynamic range is an inherent property of the selected RF hardware. Spurious Free Dynamic Range (SFDR) shows a receiver's ability to filter out potentially strong interfering signals and receive the proper signal undistorted. This criterion is of utmost importance because interfering signals, whether they are man-made or natural, exist at all frequency bands and in all physical locations.

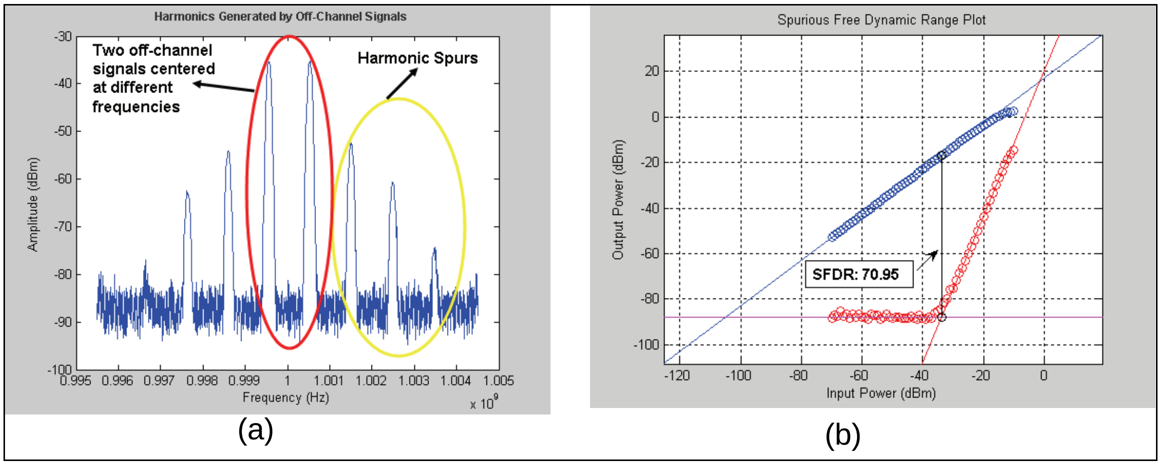


Figure 3.15. (a) Dynamic range measurement where the slopes of the first and third order mixing products are plotted. (b) Frequency domain plot of third order mixing products (yellow).

To clarify the role of SFDR, imagine that an application requires signals to be transmitted at a very low transmission power either because of pre-imposed power constraints or to avoid detection by unfriendly receivers. In this case, the SFDR of the receiver would have to be very high because the potential strengths of interfering signals could be much higher than the strength of the desired signal. If the strengths of the signals are interchanged, then a large SFDR becomes less critical because filtering out undesired signals becomes easier if the strength of the desired signal far outstrips them.

3.3.3.3.1 Analog SFDR

Analog receiver architecture, i.e., with no digitization of the received signal, suffers degradation in the form of undesired on-channel signals produced by the harmonics of interfering off-channel signals. The channel is the operational bandwidth or frequency range in which the signals propagate. The receiver is affected by off-channel signals because filtering of the signals does not occur until after they have been received by the antenna. If the receiver circuit produces previously non-existing on-channel signals, or spurs, then when the filtering takes place the spurs will be preserved along with the desired signal causing distortion. As the strengths of surrounding off-channel signals increase, the strengths of the resulting spurs increase and eventually generate the results of Figure 3.15.

Plot (a) graphically shows the production of undesired spurs in the received signal pattern indicated by those in the yellow oval. The signals in the red oval are the original off-channel signals, and as their amplitudes increase so do the amplitudes of the spurs. In plot (b), when the strengths of the red off-channel signals are low, the spurs will not be present, while the signals in the red oval in (a) will be, but with reduced amplitudes. SFDR is the measurement of the maximum tolerated strength of the off-channel signals before the interfering spurs first appear.

3.3.3.3.2 Digital SFDR

Though the above definition of SFDR is useful, it is not complete, and must be altered when a WCS requires the digitization of a signal upon its reception. This is becoming increasingly more commonplace in systems which require onboard reception and processing of received signals because a signal must be digital to perform signal processing. The SFDR may also be determined by the bit resolution of the analog-to-digital converter (ADC). Here, resolution means the number of bits used to represent each value of the digitized signal, and a higher bit resolution means greater precision in the recognized signal. The resolution is limited by the sampling frequency of the ADC. Nyquist's Theorem states that to digitally represent a signal, it must be sampled at twice the signal frequency. Therefore, the higher the frequency of the original signal, the lower the resolution of the ADC, and consequently, the lower the SFDR of the receiver. Though the definition for analog SFDR still holds, in this case the actual SFDR of a digital receiver will be determined by whichever of the two SFDR measurements yields the lowest value.

The theoretical limits on sampling frequency and bit resolution for current state-of-the-art ADCs are depicted in Figure 3.16. The different line plots represent physical limitations imposed by the physics of the ADC device itself, and the area of operation has been highlighted. This figure illustrates why it is currently impossible to have resolution greater than 10 bits at a sampling frequency greater than 1 GHz, thereby limiting the value of the SFDR of such a WCS. Also, note that most ADC devices do not use state-of-the-art technology due to cost, so that the SFDR may be limited even further.

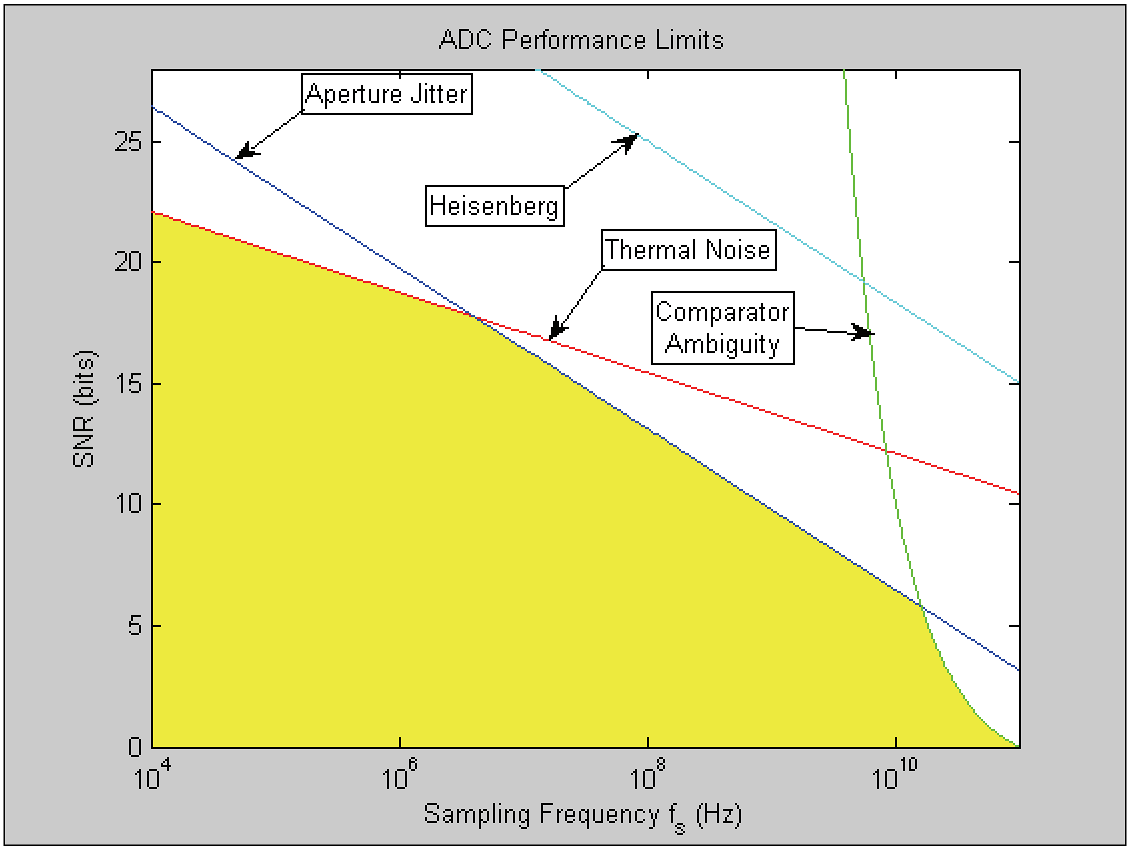


Figure 3.16. Operating range of frequencies determined by the resolution of the ADC in a digital RF receiver.

3.4 State-of-the-Art and Near Term Emerging Technologies

The technologies described in this section represent several areas that, while emerging within the next 5 years, are expected to remain in use well into the 2030 timeframe. The strictly military technologies, by virtue of the acquisition process will linger in inventory substantially longer. Conversely, the commercial standards described refer mainly to the protocols to be used. Unlike specific circuit designs and to a lesser extent, for discrete devices, the protocols are designed by large committees, generally striving for a robustness that will allow them to be used for many years. These protocols/standards themselves are a significant contribution to the field and count as technologies because they delineate the trade space for a specific class of hardware. As such, their use is substantially longer lived than many instances of the hardware itself. The best example is the TCP/IP protocol. It has been the basis for the world-wide-web/Global info Grid for decades, even as significant hardware advances such as cable internet and T3 LAN have enabled improvements over the 56k modems of the past.

Understanding and further optimizing these technologies is important because they form the bridge of today's technological capabilities for logistics communications and the outlying technological capabilities the Army's LIA hopes to achieve by the year 2030. In fact, investment in some of the following technologies is strongly encouraged because of the integral role they play in some of the concepts of the future of communications requirements for logistics prediction by the year 2030. These areas will be highlighted in the following sections, and further described in the technologies of interest portion at the end of this chapter.

3.4.1 Joint Tactical Radio System (JTRS)

As part of a program extending to 2020, JTRS will use the common software communication architecture (SCA) to ensure that legacy and future Army RF systems implement interoperability, portability of application programs, and the ability to leverage commercial off-the-shelf (COTS) technologies.[62] The SCA takes advantage of recent developments in communications technology that allows software applications to replace hardware intensive designs on legacy RF systems. More powerful microprocessors allow designers to execute waveform generation, encryption, and signal processing functions using software in conjunction with the computing abilities and memory storage capabilities of smaller, faster processing units. Because the software can be applied to a broad spectrum of processing units without altering the transmission protocol, Army RF systems will no longer be limited by manufacturer propriety and all RF systems employing the SCA can intercommunicate no matter what the differences in hardware design.[63]

Interoperability is important because, for different missions, different objectives will dictate what hardware is necessary to fulfill the communication requirements. Because different manufacturers' hardware may be best suited for different mission objectives, having the SCA will allow designers to design with different hardware without sacrificing the ability to communicate with other RF systems involved in other missions executing simultaneously. This is because all the RF systems are controlled by the same SCA.

Another characteristic of the JTRS RF system will be multi-channel communications. Although this already exists in RF applications, it is not standardized, and, to achieve the appropriate levels of interoperability, all JTRS radios must be able to exchange data on a multi-channel basis. Multi-channel communications allow for simultaneous messages from the same system or platform. This can increase the data rate of an RF system by splitting the message into multiple portions and transmitting them individually across multiple channels at the same time. This multiplies the data rate by as many separate channels as are incorporated into the system. Another application is the parallel transmission of separate types of data such as voice, video, and sensor data.

Though JTRS technology has been successfully demonstrated by proof of concept, there are still significant developments required in a key area before widespread deployment will be feasible. One of the fundamental aspects of the JTRS RF solution is the ability to reprogram systems over the air as opposed to in a laboratory. Unique waveforms and modulation schemes are necessary to achieve this goal, and waveform development is currently the major technological hurdle for a full JTRS implementation. The concept has been proven for isolated waveforms, but the SCA will require a wide variety of waveforms for a variety of reprogramming scenarios, and the widespread replication of isolated waveform porting success stories seems unlikely without a significant thrust in the associated research.[64]

Figure 3.17. Prototype JTRS radio system module.

3.4.1.1 Avionics Full Duplex Switched Ethernet Databus

AFDX is an enhanced avionics subsystem interconnection standard for communication between critical aircraft systems. Avionics are literally aircraft electronic systems, and safety critical systems such as the autopilot flight control system, need reliable communications in real-time. AFDX networks allow data transfer up to 100 Mbps, which is a significant improvement over legacy systems with data rates of only 100 kbps. Similarly, the AFDX network allows arbitrarily large numbers of subsystems to be connected to an end system, where legacy avionics networks were limited to twenty.[65] This causes the need for the installation of additional end systems, increasing data transfer overhead and the overall weight of the aircraft in legacy systems.

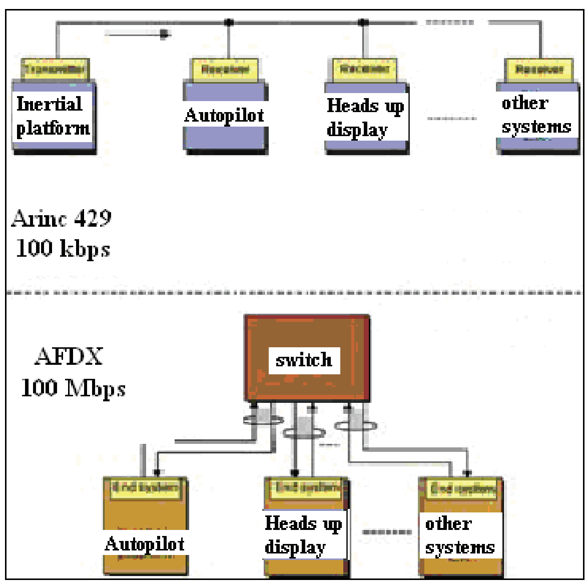


Figure 3.18. Illustration of the topological differences between legacy and AFDX networking.

The critical element of the AFDX structure is the switch that allows arbitrarily large numbers of connections to an end system. Without a switch, traditional Ethernet protocols simply allow separate subsystems to transfer data simultaneously, causing potential packet collisions. A packet collision initiates each subsystem to randomly select a time window to resend the original data. This networking protocol, although effective for traditional internet data transfer, can still potentially allow repeated collisions of the same data transfers to a given end system, producing significant delays. AFDX differs from this process by allowing the storage of data in a memory buffer at the receiver of an end system. Therefore, the receiver only needs to switch between its connections to subsystems to receive data. If multiple subsystems are transmitting simultaneously, instead of collision, the receiver simply stores the data in memory until the end system has the opportunity to switch over and access that data. This is known as First-in First-out (FIFO) networking.[66] This trades the potential for substantial delays for a guaranteed delay with a significantly reduced time window due to the time needed for the switching between subsystems interconnects. Using intelligent design parameters, this short delay or jitter can be reduced on the order of microseconds.

Logistics can benefit greatly by the significant increase in speed, and the ability to connect large numbers of subsystems. For effective prediction, intensive data monitoring is necessary to acquire the indicators of potential future failures. End systems would be responsible for the processing of algorithms and would need data in near continuous time from large numbers of subsystems to perform the necessary prediction that allows logistics to see the future need for maintenance requirements, and supply the necessary components to perform that maintenance in a timely manner.

3.4.2 Mesh Networks

Mesh networks use devices as routers to create multiple paths from one node to any other node within the network. The main advantage of this type of connectivity is that if any node goes down, there will be other paths that a signal can traverse in order to reach its final destination. This makes the network more robust in the face of harsh weather, tampering, or any other events that may temporarily or permanently render a router disabled. The concept of mesh networking will become important later when ad-hoc networks come into discussion. This type of network has no predetermined configuration, and furthermore, nodes may enter the network, leave the network, or change their positions within a network. In mobile networks of Soldiers or vehicles, mesh networking becomes crucial because it allows for redirectional connectivity so that nodes that are rapidly changing position in relation to other nodes can redirect their connections as they reposition themselves. The connectivity of a small mesh network is illustrated in Figure 3.19. Notice that a mesh network need not have multiple links at every node, but should be optimized such that the networks reliability is uncompromising.

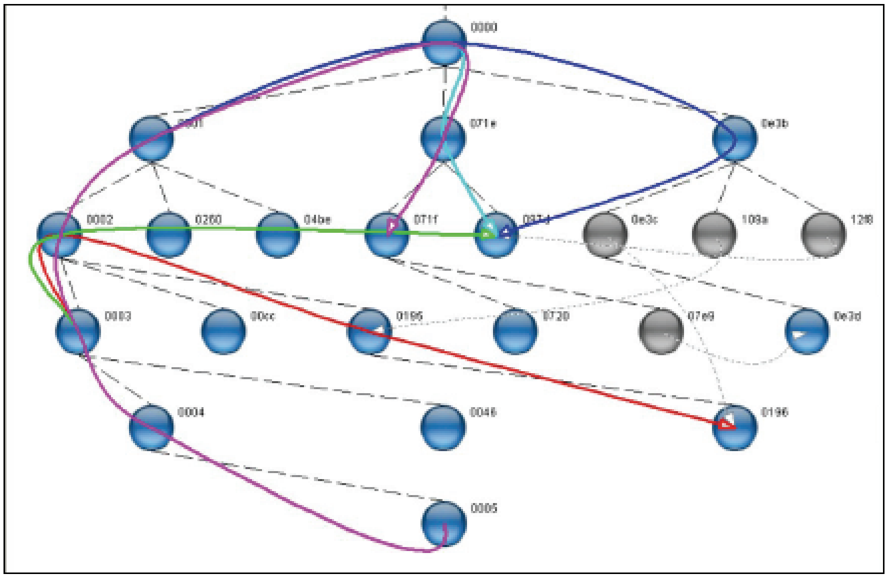


Figure 3.19. Shows the advantage of having multiple route paths and reconfigurable route paths in a multi-hop RF network.

3.4.3 Wide Area and Local Area Networks

Network topologies belong to one of two basic groups. Local area networks (LANs) connect many devices that are relatively close to each other, usually in the same building, although fiber optics has allowed the LAN topology to extend to devices that are several km apart. For example, library terminals that display book information would connect over a local area network. Wide area networks (WANs) connect a smaller number of devices that can be many km apart. If two libraries at the opposite ends of a city wanted to share their book catalog information, they would most likely make use of a WAN topology.

WANs are networks that use routers and public communications links to connect LANs and other types of networks together, so that users and computers in one location can communicate with users and computers in other locations. Typically, a WAN consists of a number of interconnected switching nodes. A transmission from any one device is routed through these internal nodes to the specified destination device. These nodes are not concerned with the contents of data; rather their purpose is to provide a switching facility that will move the data from node to node until they reach their destination. This is in sharp contrast to LANs whose sole responsibility is the accurate transmission of data from point A to point B. The largest and most well-known example of a WAN is the Internet.

In comparison to WANs, LANs are faster and more reliable, but improvements in technology continue to blur the line of demarcation. Fiberoptic cables have allowed LAN technologies to connect devices tens of kilometers apart, while at the same time greatly improving the speed and reliability of WANs, which are capable of achieving user data rates greater than 10 Mbps. Both WANs and LANs will be essential parts of a combat logistics network, ensuring that not only are battlefield nodes able to relay information between each other, but that this information is also accessible to the GIG through a WAN relay link.

3.4.3.1 WiMAX (802.16)

This standard will enable rapid worldwide deployment of interoperable multi-vendor broadband wireless access alternatives to wireline systems and encourages worldwide spectrum allocation. WiMAX will provide wireless coverage with a wireline backbone to the Internet the same way as WiFi only by using more power for the transmission. Also, direct antenna pointing, as opposed to the omni-directional pointing system employed by other RF broadcasts, allows for a data rate of 30 Mbps over a range of 8-12 kilometers. This far outstrips the current capabilities of other RF data networks both in terms of capacity and range.

The WiMAX network requires fixed base station (BS) sites that provide wireless connectivity to users or subscriber stations (SS). However, WiMAX also supports mesh networking because the SSs can act as routers to other users that may not have line-of-sight capabilities to the BS. The SS has a unique capability to employ either time division multiplexing (TDM) or frequency division multiplexing (FDM). TDM uses a single frequency, but divides the transmissions into blocks where some blocks of time are used to upload data and other blocks are used to download data. This enables a SS to save bandwidth as necessary, especially when other SSs associated with the same BS require increased bandwidth capabilities. FDM divides the downloading and uploading into different frequencies, which means that more bandwidth can be allocated to that SS when necessary to deliver high data payloads with minimal latency. This adaptive technology is an important reason WiMAX is able to achieve such high average transmission rates.

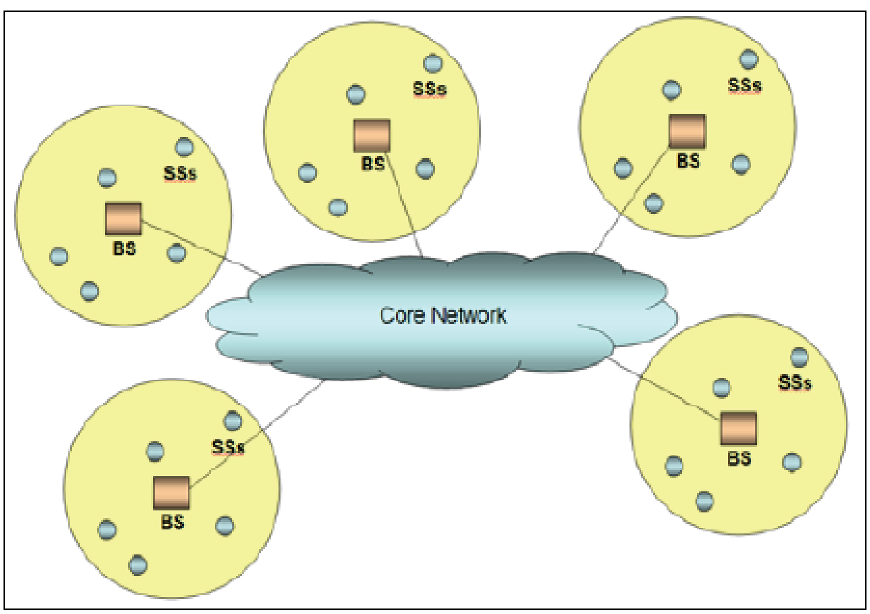


Figure 3.20. Example of several WANs incorporated into the core network of a WiMAX network.

WiMAX has great potential to enhance logistics communications abilities, but cost has kept the commercial industry from investing in its adoption. Also, competition from already established commercial wireless standards such as WiFi has slowed the progress. The BS infrastructure is analogous to the current cell phone networks of today, but because of the tremendous benefits from a move to WiMAX, as well as unified interest from industry and government, the move towards adoption and standardization in the near future by commercial entities seems very likely.

3.4.3.2 Wi-Fi

Wi-Fi comprises of a family of standards for local and metropolitan area networks, sometimes denoted 802.11(n) or 802.11(x). The scope of this standard is to develop the specifications for wireless connectivity for nodes requiring rapid deployment, which may be portable, hand-held, or may be mounted on moving vehicles within the scope of the wireless local area network (WLAN). This standard also serves to regulate access to one or more frequency bands for the purpose of local area communication within the 2.4 GHz and 5 GHz frequency bands regulated by the FCC.

As the first popularly accepted wireless data network, Wi-Fi access is generally available around the world. However, even though a mesh network is achievable using the Wi-Fi standard between wireless routers, at least one router in the network must have a physical connection to the internet in order to provide internet access to the WLAN as depicted in Figure 3.21. This physical connection represents the bridge between the Wi-Fi LAN and the wide area network (WAN) represented by the internet at large. In order to avoid transmission delays in a larger network, many routers must incorporate physical connections to the internet. These connections already exist where there is Wi-Fi access, but a secure military Wi-Fi network could not piggyback on these pre-existing connections because it could potentially expose the entire network to any other Wi-Fi user in the area.

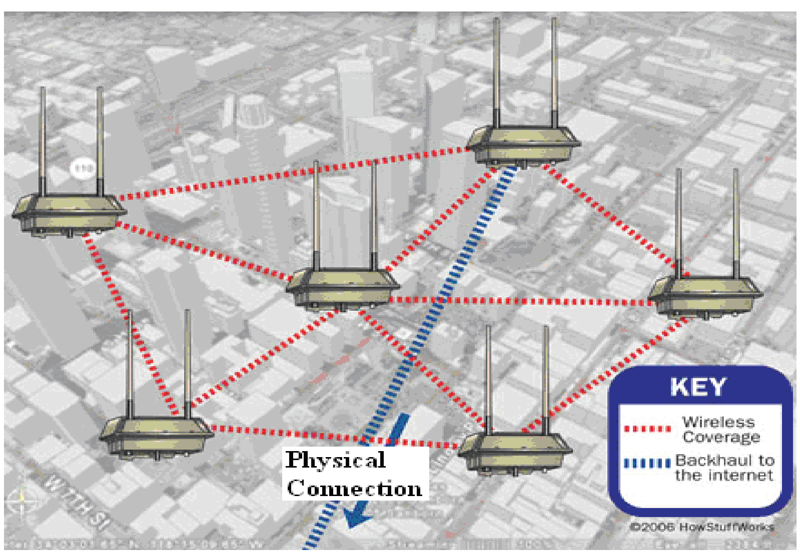


Figure 3.21. Example of a Wi-Fi network topology.

To address this issue, Wi-Fi uses a shared key encryption method to protect the data within the WLAN. A numeric key is pre-programmed, or otherwise shared through a secure channel, into all nodes within the network. This key, which is never transferred over the air itself, is used upon reception to decode the encryption scheme securing the transmitted data. The same key is used to encrypt the data as well, making it difficult but not impossible for others to eavesdrop on the network. Each network should have its own unique shared key to avoid unintentional or intentional penetration of the network by outside nodes. This is why on university campuses or in coffee houses with Wi-Fi access, those wishing to join the network must know the numerical key upon connection.

Perhaps the biggest drawback of Wi-Fi is that it consumes more power than any other wireless standard to achieve its high data rates and long data ranges. The power consumption relative to other standards is depicted in Figure 3.22. Therefore, unless there is a constant or substantial power supply to all wireless nodes in the WLAN, Wi-Fi networks will be ineffective because they will only be operational for a brief period until the power source can be replenished or replaced. However, Wi-Fi is faster, up to 54 Mbps, and has a greater transmission range, up to 100 meters, than other wireless standards. Ultra-wide band (UWB) has a greater data rate, but has the shortest transmission range of any active standard. Improvements over both the range and data rate are realizable within the emerging WiMAX standard, but access isn't widely available and will be very costly to implement on a large scale. Therefore, Wi-Fi seems likely to be the best available technology for high-speed and long-range WLANs in the near future. However, investments in the improvement of Wi-Fi capabilities would be unjustified since further development of WiMAX technology will incorporate improvements in almost all aspects of the Wi-Fi standard.[67]

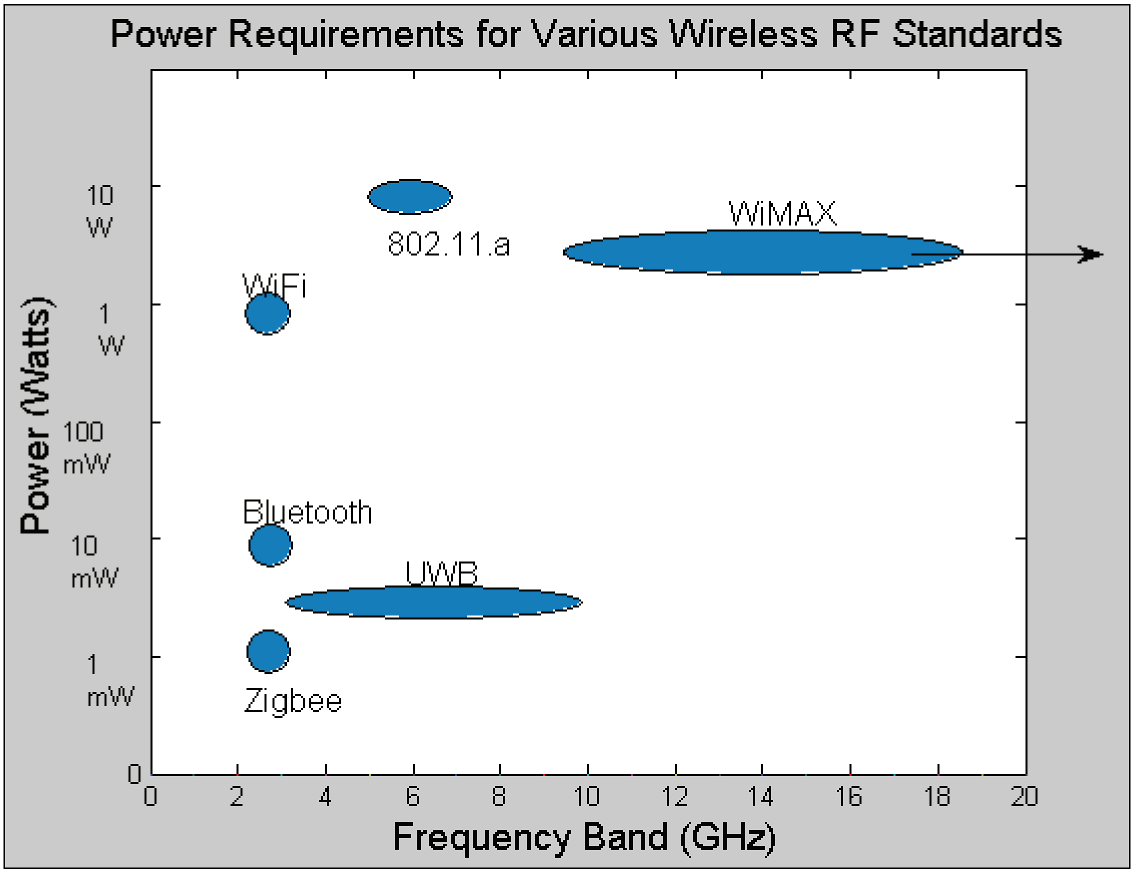


Figure 3.22. Power dissipation comparisons of various RF standards. (Note that the WiMAX standard spans the 10-60 GHz range, but for visual clarity the graphic is not expanded out this far).

3.4.4 Personal Area Networks (aka Ad-Hoc Networks)

Personal area networks (PANs) are small range networks that can incorporate a very large number of nodes which are usually mobile. This means that the nodes are not stationary, and therefore, must continually reconfigure themselves and update their routing protocols within the PAN as they move around. Sensor networks are a good example of how such a PAN may function. A group of Soldiers may represent tens or even thousands of sensor nodes within a single PAN. Each individual Soldier would represent a node, even though in this case each Soldier may be equipped with their own unique PAN to monitor vital signs, equipment, food supply, etc. For now, consider that each Soldier is transmitting to an officer whether or not they are mission ready, so all the other data used to reach this conclusion is not important for this simplified example. Because no Soldier is expected to stay in a single location forever, in order for the officer to query an individual Soldier at an arbitrary time, the Soldier's link must be able to find the most direct path to the officer's link no matter how the structure of the overall PAN is dynamically changing.

This type of connectivity and reconfiguration require the implementation of a mesh network. In the above example, a mesh network would allow the officer to query the status of an individual, even if there is no line of sight link between the officer and Soldier. Also, in a battle scenario, an officer can monitor the status of his Soldiers constantly, even as they are moving around within a relatively large area. Ad-hoc simply means that there is no overriding network structure meaning that the number of nodes as well as positions may arbitrarily change. For our purposes, an ad-hoc network and a PAN represent the same thing.

3.4.4.1 ZIGBEE (IEEE Standard 802.15.4)

The Zigbee standard, sometimes called 802.15.4, defines a simple, low-cost communication network allowing wireless connectivity in applications with limited power and relaxed throughput requirements. The main objectives of a Zigbee PAN are ease of installation, reliable data transfer, short-range operation, extremely low cost, and a long battery life, while maintaining a simple and flexible protocol.[68] This is an example of a self-organizing mesh network that allows for close range data transfer among an arbitrarily large number of nodes. Though the algorithms for routing redefinition suffer from a noticeable latency, the fact that this is an ad-hoc network means that it is a non-issue to add or remove sensor nodes and alter the network structure on the fly.

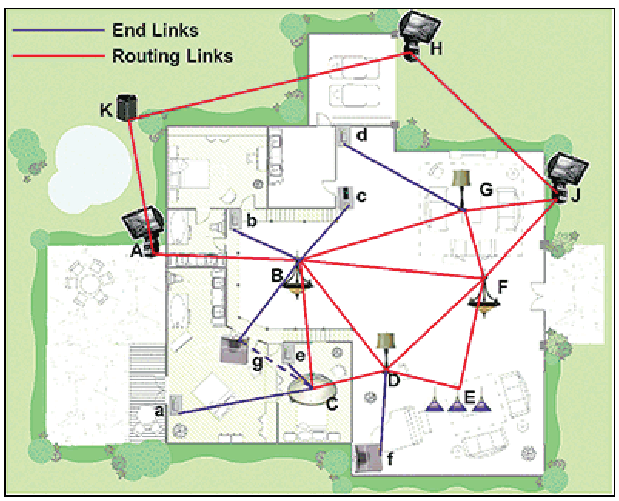


Figure 3.23. Example of a Zigbee PAN topology.

Zigbee is an excellent standard for low bandwidth communications. Tailored for frequent transmission, due to an inability to support the throughput necessary to transfer large amounts of stored data, a Zigbee PAN would operate ideally during military operations to offer real-time updates of key assets. Also, in establishing a network, nodes will automatically scan available channels and choose the one with the least interference. Low power transmissions extend battery life, and make over-the-air signal interception more difficult.[69]

A common stack profile defines network, application services, and security parameters for the entire network. Because software defined radio allows for the microprocessor's software to control the functions of the RF circuitry, different hardware and sensor applications are interoperable as long as their microprocessors share the same stack profiles. This important characteristic makes Zigbee compliant with the ongoing Army Joint Tactical Radio System developments. One drawback to Zigbee's mesh networking and reconfigurable route discovery is the need for continuous power supplies for the routing nodes. This feature makes mesh and reconfigurable networks undesirable for stationary applications in remote areas because power supplies would need to be monitored and replaced.

3.5 Far Reaching RF Technologies: (2020-2030)

This section extrapolates current trends of investment and research to predict the communications capabilities for Army logistics by the decade of 2030. The foundations for these technical areas are firmly based in the current and emerging technologies previously described in this chapter. Those descriptions are what give credibility to the claims made in this section because many of the technologies to follow directly incorporate or build off of the development timelines of more current technological endeavors.

Because of the range and bandwidth limitations of RF communications, the greatest advances in the future will be in FSO data links and their incorporation into the already existing Army communication infrastructure. There will not be an overriding communications solution, but instead a combination of all forms of communication. FSO, RF, and fiberoptic will be required to achieve the fused networking capabilities desired for future of Army capabilities. Much of the specific technological developments will be in the optics devices area, but the most important developments will be the topologies and algorithms incorporated into the networks to the greatest overall benefit for communications of all types whether they are local, wide-area, global, or interstellar.

3.5.1 Optical and RF Combined Link Experiment (ORCLE)

ORCLE is a DARPA program to develop a prototype system combining FSO and RF communications to provide compact, high-bandwidth, mobile communications. For battlefield and logistics communications, ORCLE intends to incorporate the high data rates of FSO laser and the high reliability of RF communications to develop the Army's own version of a hybrid RF/FSO communications network.[70] This effort stems from an effort known as Terahertz Operational Reachback (THOR) that attempted an all-optical approach to airborne communications, but was not realized because, for too many aircraft, it was not feasible for all of them to obtain the necessary link quality for initial connection without the aid of RF devices. The Department of Energy's Terahertz Lightbeams Program at Brookhaven National Laboratory is a similar research program that uses the terahertz frequency of the electro-magnetic spectrum for communications.

A unique aspect of the ORCLE hybrid network is that both the optical and RF links will always be active at the same time. Though this doesn't do much to optimize the bandwidth any further because any contribution made by the RF link will be dwarfed by the capacity of the FSO link, it reduces the complexity involved in switching from one link to the other. Having parallel links also provides an opportunity to evaluate the link quality using the RF link without interrupting the high data flow through the FSO link. The RF link can also be used to scan for other route paths in case the quality of the data link should degrade.

Initial link tests hope to achieve air-to-air communications greater than 200 km and air-to-ground communications of greater than 20 km.[71] Disparity between the expected ranges is due to increased atmospheric turbulence of communicating from above the cloud line to the ground, where at high constant altitudes this becomes less of an issue.

The ORCLE project will serve to benefit the logistics communications community greatly. Not only will the network benefit from the robustness and reliability of the RF/FSO hybrid network described previously, but instantaneous communications over greater distances helps mitigate the latency issues involved with fiber-optic communication. Also, these ORCLE networks will be ad-hoc which eliminates the long, arduous, and costly task of planning and laying the miles of coaxial cabling needed to create a fiber-optic network. Real-time situational awareness will be the greatest benefit for all parties involved, and greatly outweighs the price tag of FSO devices, which is quickly dropping below $2,000 for an entire system including processing capabilities.

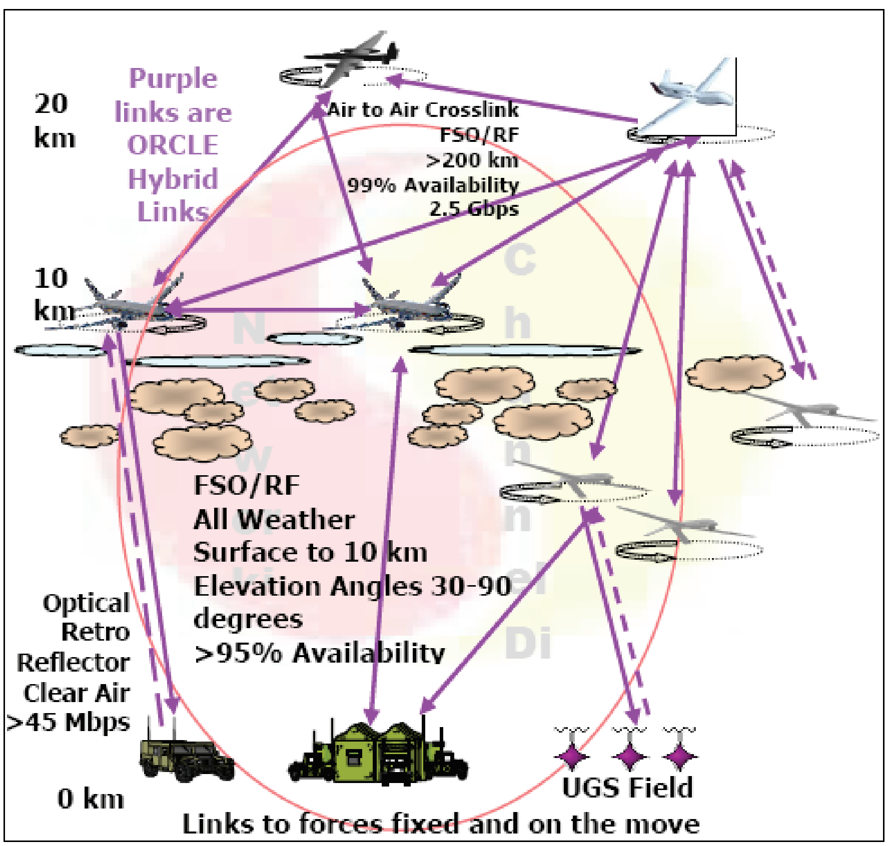


Figure 3.24. ORCLE hybrid networking concept.

3.5.2 Meta Materials

Meta-materials are artificial structures engineered to exhibit unusual electromagnetic properties. The potential to use these materials to manufacture RF and antenna devices with greatly improved characteristics in comparison to those currently available has inspired a recent surge in the research activities associated with meta-materials. Most defense agencies have a meta-materials program, but even with the increase in interest, researchers are far from fully realizing the potential benefits of meta-materials on electronic devices.[72] Much of the research being conducted on meta-materials is not open to public release. The following is a brief description of some published examples of the usefulness of meta-materials development in the area of communications.

Meta-materials are characterized by the negative electromagnetic properties depicted in Figure 3.25, which produce unusual effects on radiating bodies and RF devices. These unique properties allow for miniaturization of antennas and other microwave devices used in the fabrication of RF circuits.[73] By miniaturizing the required length of an antenna while still increasing its gain, communication capabilities remain unaffected while the smaller form factor of the antenna reduces visibility and possible targeting by enemies on the battlefield. Similarly, miniaturization of components lends itself to overcoming some of the inherent difficulties in shrinking down RF devices to the nanoscale.

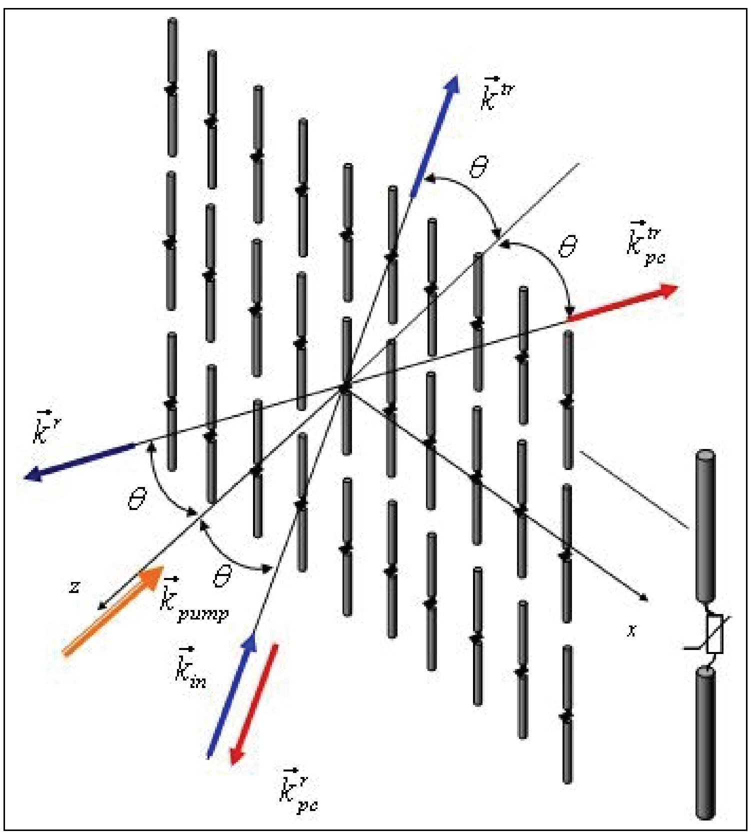


Figure 3.25. Negatives refraction effects of a metamaterial.

Scanning capabilities of antennas can also be improved because conventional antennas have the drawback of only having half-space scanning or only being able to scan in the forward direction. By combining a conventional scanning antenna with a meta-materials based antenna, systems can achieve radio scanning in all directions, reducing the delays in reconfiguring a mobile network.[74]

Initial proof of the benefits gained by the investment in meta-materials shows how realizable this technology could be with the proper funding and resources. Benefits spanning several areas illustrates why Army investment in meta-materials is necessary, mainly because there is little commercial interest in this technology.

3.5.3 Microfabricated Vacuum Electron Devices (μVEDs)

The vast majority of advances in RF comms systems over the past 25 years have resulted from the improvements in processing, materials, and device design based on RF semiconductor materials (typically Group III-V on the periodic chart). Gallium Arsenide (GaAs and numerous alloys) in particular have enabled advanced mixers with lower conversion loss, amplifiers with higher gain (reducing the antenna size requirements), and lower noise. The one area where semiconductor materials have fallen short of their predecessors, vacuum electronics, is in output power. For electronic warfare and many radar units, these higher output power devices are still the best choice.

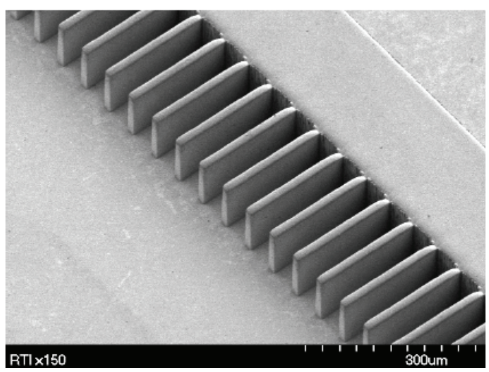


Figure 3.26. Micromachined slow wave structure for producing sub-mm wave oscillator.

The confluence of microfabrication (silicon, MEMS) processing capabilities and faster numerical electromagnetic modeling have now enabled microfabricated VEDs. With no material at all between the anode and cathode, these devices will have even higher frequency responses than the III-V materials, deep into the sub-THz regime, enabling communication at frequencies and bandwidths unthinkable by traditional means.

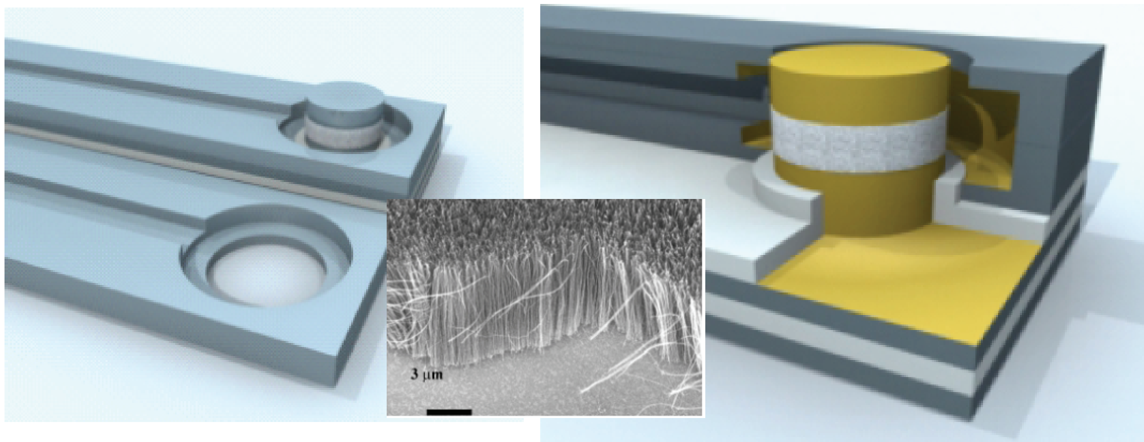


Figure 3.27. Sub-millimeter wave micromachined waveguide, cavity, and magnetron (yellow post) with carbon nanotube cathodes (zoomed in inset)

The first viable versions of these devices are only now being built, leaving considerable basic research to be performed. However, it is the fabrication and integration of these devices into higher level systems that require further work, not the electron transport and electromagnetic propagation physics. In effect, the physics of these devices have been well studied for over 50 years, and, from a performance perspective, they are really incomparable. Microfabrication, however, brings the final piece to the table, enabling mass production with a high degree of control and substantially reduced cost.

3.5.4 Multi-band Tunable Antennas

Future Army communication systems will require access to multiple available services including GPS, personal area sensor networks, wide area information networks, and so forth. The need for a minimal form factor for the whole system drives the push for the smallest antenna designs possible. These requirements illustrate the necessity for the design of a small single antenna capable of accessing multiple frequency bands, which will require the antennas to tune at different frequencies and also alter radiation patterns to communicate on multiple standards. Current research has shown success in generating dual-band antennas with dual-polarization abilities that increase available bandwidth without increasing the size of the antenna. These successes show the need for increased research in the area of producing antennas capable of tuning to an arbitrary number of frequency bands with adequate efficiency and bandwidth. Multi-band antennas allow designers to combine the abilities of multiple communications subsystems into a single architecture and processing unit.

The need for the sensor networks to be able to communicate at various frequency bands, and pass data over various communications media has been covered several times in this paper already. A multi-band antenna becomes a necessary part of the logistics communications architecture to keep monitoring systems small, efficient, and self-automated. They will lower the overhead necessary for providing the data to the numerous sources necessary for processing the prediction algorithms and supplying the necessary information to neighboring supply depots as well as the GIG.

3.5.5 Global Area Network

The IEEE Mobile Broadband Wireless Access (MBWA) standard, or 802.20, will fill the gap between cellular networks (low bandwidth and high mobility) and other wireless (high bandwidth and low mobility) such as Wi-Fi or WiMAX. MBWA will provide seamless integration of current WPAN, WLAN, and mobile cellular networks to allow for a single network connection wherever the user goes. The scope of WBMA is interoperable mobile broadband systems with performance comparable to that of current wired broadband internet connections operating in all licensed bands below 3.5 MHz.

WBMA will essentially make use of a worldwide mesh network as depicted in Figure 3.28. Here towers act the same way as a cell phone tower, taking advantage of large broadcast ranges to allow full mobility to both routers and end user nodes. Furthermore, an IEEE 802.20 mesh network would connect WiMAX, Wi-Fi, PANs, and 3G cellular networks to form a heterogeneous mesh networks. This makes the MBWA network completely accessible by pre-existing wireless networking technologies.

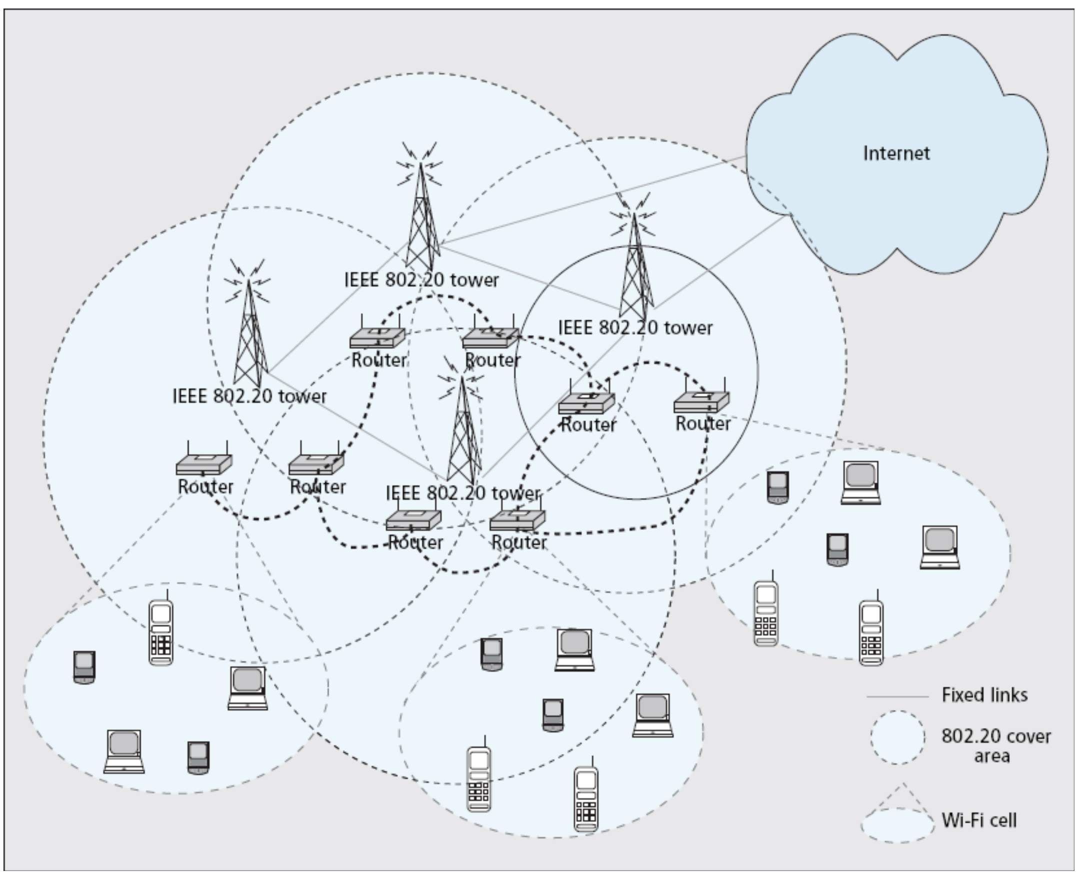


Figure 3.28. IEEE 802.20 mesh network architecture.

Designing to meet the interoperability criterion is one of the main challenges in designing a WBMA standard, along with addressing security issues and ensuring that the performance of a wireless mesh network do not degrade when the number of mobile stations or the size of the network increases significantly. Initial testing of standard attributes shows that velocity of the mobile nodes also causes degradation in the data speed of a WBMA link down to the order of hundreds of Kbps, which is comparable to that of a current broadband internet speed during high user hours. Currently, security is based on a stream cipher which blocks any user until the mobile station verifies a cipher or security key that initiates access to the network. Also, authentication for both base and mobile stations will be based on digital signatures that protect base station from access by rogue mobile stations.

Because of a high return of investment indication, many commercial entities are willing to provide significant funding for the implementation of the 802.20 WBMA standard. This means that funding requirements for Army logistics will be relatively low. However, the mobility of such a network far outstrips that of any other mesh network described thus far because of the incredible ranges achievable by WBMA. Essentially, any location accessible by a cell phone will be accessible to a WBMA user, and this means worldwide access regardless of the service provider. This would enable assets to be instantaneously linked to a network accessible by any other Army entity, making the transfer of data from one area of the world to any other seamless. The only limitation is the low data rates available when the network is overloaded which can be much less than 1 MBps.

3.5.5.1 Multi Platform - Common Data Links (MP-CDL)

The idea of MP-CDL is not based on a specific technology, but rather the integration of previously described elements into an ideal network of seamless fiber-optic, FSO, and RF communication capabilities as depicted in Figure 3.29. The main issues incorporated within the Army concept of MP-CDL is that of interoperable networking for an extremely mobile force. The information passed within the MP-CDL network should also be accessible by all Army entities in real time. The ambition of the MP-CDL requires the combination of most future technologies discussed under both the optics and RF sections of this chapter, including hybrid mesh networks for increasingly mobile and robust PANs, long range and short range optical links with optimum data rates, a global information network that allows instantaneous access to asset information all over the world in real time, and all the underlying sub-technologies that go along with these concepts.

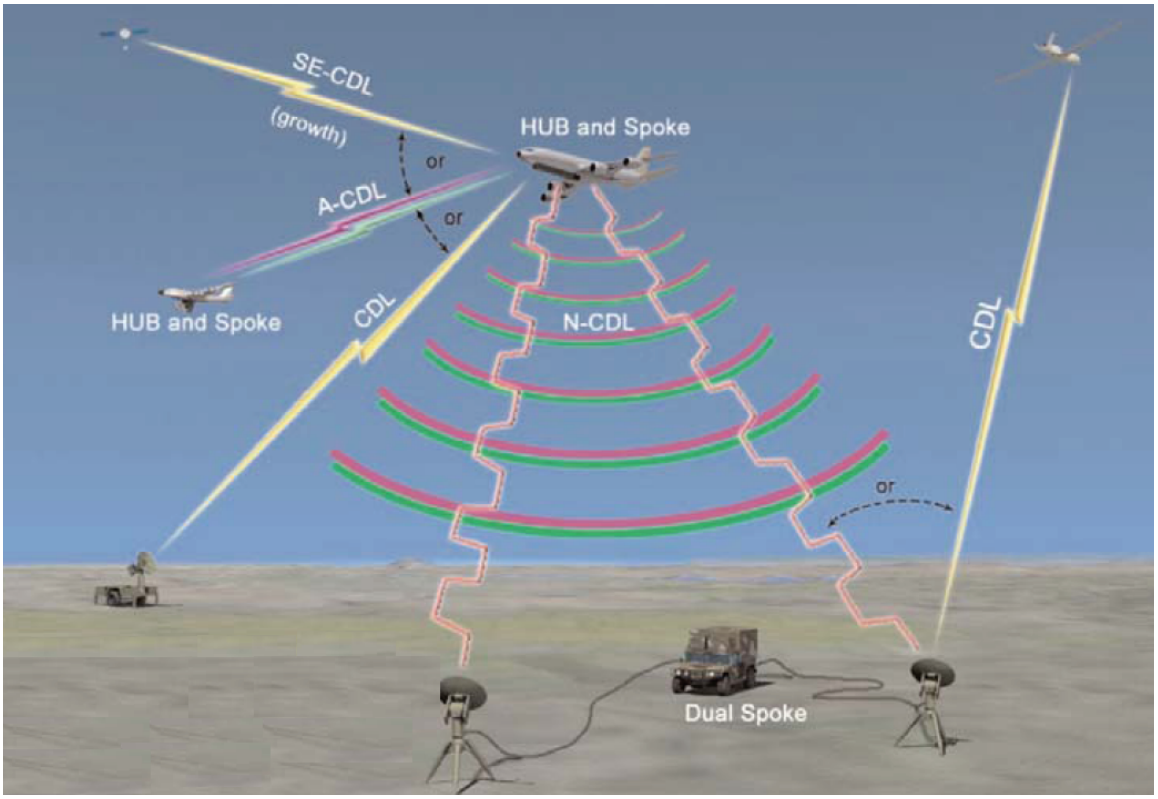


Figure 3.29. An example of potential MP-CDL net-centric operating environment networking topology.

Interoperability will mean that airborne, WAN, LAN, PAN, satellite, and fiber-optic networks can all communicate with each other. This type of connectivity is illustrated in the idea of the Global area network. However, with different standards of operation for each type of network, as well as different waveform and encryption characteristics, this interoperability has to take into account possibly thousands of combinations of frequency spectrum, modulation, SNR power, security encryption, data formatting, and routing algorithms to be fully realizable.

In essence, the idea of the Army MP-CDL is the fruition of all the communication technologies projected through the 2030 timeframe. If proper funding for research is allocated, most of the described future technologies (bridged with existing and emerging technologies) will provide the technical capabilities to implement such an expansive network. Technical capabilities aside, much research will also have to be conducted on how to configure a network topology to support the capabilities desired by the network- centric force of the future Army.

3.6 Essential Data Transmission Technologies: Rankings and Quad Chart

3.6.1 Technology Rankings

The following charts and descriptions are numerical weighting systems that dictate the outcome of the Quadrant Model for ranking technologies based on Probability of Reaching Maturity, Cost, and Benefit to LPPC as described in chapter 1.

For all three parameters, Probability of Reaching Maturity, Benefit to LPPC, and Cost, the numerical results are normalized to the highest scored technology. Hence, *x* and *y* axes range from 1 to 3 (Low to High).

Benefit to LPPC rates each technology based on the following three criteria from the list of 19 events to be preempted given in table 1.1 of chapter 1: Loss of Communications with Log, Intel and Ops; Loss of Common Operating Picture; and Loss of Lines of Communication, and loss of Common Operating Picture. Although these three are the primary ones being evaluated, it is important to realize that loss of communication capabilities affects many of the nineteen events because inability to communicate data, the results of the prognostic algorithms, etc. will disable the preemptive capabilities of logistics leading to loss of supplies in transit, running out of supplies in theater, and the unexpected breakdown of equipment. Furthermore, any of these events could directly lead to Soldiers dying, being wounded, or losing the engagement. The way that loss of communication affects these events is taken into consideration when the ratings are assigned. Here the Weight corresponds directly to the impact of the associated technology on the ability to preempt that event, and the Score corresponds to the overall impact on the logistical enterprise that the preemption of that event will accomplish through the use of that technology.

3.6.1.1 Free Space Optical

FSO communications allow data rates up to 10 Gbps and unlimited bandwidth capabilities. Ideal for sending huge amounts of data accurately and securely, FSO links suffer greatly from atmospheric turbulence and are also dictated by extremely precise and complicated pointing algorithms.

FSO			(1-10)	(1,2,3)=(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			33		2.2
	1	Signal Fading	8	2	0.484848
	2	Pointing System	10	2	0.606061
	3	Atmospheric Turbulence	9	2	0.545455
	4	Vibr remediation	6	3	0.545455
Cost			43		2.4
	1	Raw Materials	10	2	0.465116
	2	Mfr Scalability	9	3	0.627907
	3	Devices	10	3	0.697674
	4	Engr-NRE	7	2	0.325581
	5	Engr-Integration	7	2	0.325581
Benefit to LPPC			87		1.93
	1	Loss of Comms. with Log, Intel, and Ops.	9	2	0.21
	2	Loss of LOC	8	2	0.18
	3	Loss of COP	10	3	0.34
	4	Losing the mission	6	2	0.14
	5	Soldiers dying / wounded	2	1	0.02
	6	Running out of Ammo	4	1	0.05

7	Running out of Fuel	4	1	0.05
8	Running out of Medical Supplies	4	1	0.05
9	Running out of Water	4	1	0.05
10	Running out of Batteries/Fuel Cells	4	1	0.05
11	Breakdown of Equipment	6	2	0.14
12	Meeting w/ Bad Weather	2	2	0.05
13	Encountering Threat Forces	2	1	0.02
14	Loss of Strategic Assets and Cargo	6	2	0.14
15	Loss of Theater Lift Assets and Cargo	6	3	0.21
16	Closure of APODs and SPODs	2	1	0.02
17	Closure of Sea Lanes	2	1	0.02
18	Encountering Inaccessible Terrain	2	3	0.07
19	Untimely Delivery of Parts	4	3	0.14

Signal Fading – In general, signal fading for FSO links is minimal. This is one of the main reasons that they enjoy such large transmission ranges. The only time signal fading becomes a major issue is in the face of atmospheric turbulence or link misalignment, which causes severe range limitations for FSO devices. Several research efforts focus on potential technologies that can help FSO devices in the face of this turbulence (MRRs, hybrid networks, adaptive FSO networks), but these have a long way to go before the Army will see implementation on the battlefield.

Pointing System – Currently, pointing systems on optical devices are complicated and expensive. This is due to the very low tolerance of FSO links to misalignment (less than 0.0057˚ tolerance). Misalignment sensitivity is a major obstacle for the implementation of increasingly mobile networks in a terrestrial environment. Devices such as MRRs will potentially decrease this sensitivity, but at a great sacrifice to range and data rates.

Atmospheric Turbulence – In the terrestrial domain, atmospheric turbulence is the most common cause of link degradation. The nature of the links themselves, due to their dependence on photons, will always make them susceptible to this turbulence. Hybrid networks are showing promise in combating this problem but come with their own drawbacks, and adaptive optical links are far from maturity.

Vibration Remediation – Vibrations leading to potential misalignments are usually due either to atmospheric turbulence or vibrations inherent to the operation of the optical components themselves. This is one of the less significant problems, and can be solved using adequate position lookup tables. Remediation by actually reducing the vibrations of individual system components is a more complicated and arduous task.

Raw Materials – Long range FSO communication devices are relatively expensive ranging from approximately $3,500-$100,000 for a single device (the latter being for satellite communications where the satellites themselves range in the millions of dollars).

Mfr. Scalability – Because manufacturers are not producing FSO links except for specific applications, there is nothing to drive production costs down.

Devices – Current devices, though functional, are costly, and most current research in FSO is ongoing in the area of individual components. Until these emerging new technologies become more scalable (not in the near future), the individual device costs will keep the cost for overall systems high.

Benefit to LPPC – FSO will be extremely important to preempting the loss of the COP because, to have a real time picture of asset status, high data rates and bandwidth will be necessary to transmit the data necessary for the prognostic algorithms in real time. The effect on Loss of LOC and Loss of Comms with Log, Intel and Ops is less dramatic because of the effects of atmospheric turbulence and precise pointing. FSO also impacts losses of assets in transit because faster data transmission means faster, and therefore more accurate, GPS response times.

3.6.1.2 Photon Counting Receivers

Photon counters use streams of individual photons to represent a "1" or "0" in a data stream. Although important for some forms of optical communications, they reduce the data rates achievable by optical communication devices.

PCR			(1-10)	(1,2,3)=(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			27		1.0
	1	Noise Reduction	8	1	0.296296
	2	High Density Absorption	10	1	0.37037
	3	Dark Count Remediation	9	1	0.333333
Cost			33		2.0
	1	Raw Materials	6	2	0.363636
	2	Mfr Scalability	8	1	0.242424
	3	Devices	6	2	0.363636
	4	Engr-NRE	7	3	0.636364
	5	Engr-Integration	6	2	0.363636
Benefit to LPPC			33		1.06
	1	Loss of Comms. with Log, Intel, and Ops.	6		0.00
	2	Loss of LOC	6		0.00
	3	Loss of COP	4	4	0.48
	4	Losing the mission	2	2	0.12
	5	Soldiers dying / wounded	1	1	0.03
	6	Running out of Ammo	1	1	0.03
	7	Running out of Fuel	1	1	0.03
	8	Running out of Medical Supplies	1	1	0.03

9	Running out of Water	1	1	0.03
10	Running out of Batteries/Fuel Cells	1	1	0.03
11	Breakdown of Equipment	1	1	0.03
12	Meeting w/ Bad Weather	1	1	0.03
13	Encountering Threat Forces	1	1	0.03
14	Loss of Strategic Assets and Cargo	1	1	0.03
15	Loss of Theater Lift Assets and Cargo	1	1	0.03
16	Closure of APODs and SPODs	1	1	0.03
17	Closure of Sea Lanes	1	1	0.03
18	Encountering Inaccessible Terrain	1	1	0.03
19	Untimely Delivery of Parts	1	1	0.03

Noise Reduction – Noise in the diodes and amplifiers is caused mainly by current leakages inherent to both devices. Because both of these elements are absolutely critical to the functionality of the photon counter this problem is important, and ties in directly to the reduction of "dark counts" or erroneous detections of photons. Much effort has been invested in recent years to reduce noise in these devices, but because the culmination of these efforts results in devices currently contributing to the noise problem, further improvements will inherently be difficult and potentially costly.

High Density Absorption – Photon counters operate best when lasers of low density photon counts are used. Low density requirements stem from processing delays and the relationship between leakage currents and detection rate. High density detection is paramount for increasing the data rates attributed to photon counters. Increasing the sensitivity of a counter to a greater number of photons is extremely difficult because even with extremely small processing delays, photons approaching at light speed (300,000,000 m/s) will greatly magnify the effects of such delays.

Dark Count Remediation – Elimination of dark counts would greatly cut down on post reception processing allowing photon counters to operate at higher data rates. This makes dark count remediation extremely important, but the technical difficulty is tied in directly to that of the noise reduction problem. In the absence of noise reduction, the only way to decrease dark counts is with complicated filtering schemes which add to the processing delays and help to reduce the data rates supported by photon counting receivers.

Raw Materials – The individual components of photon counters, namely the photodiode and low noise amplifier, are easy to produce and readily available. Therefore, photon counters as they currently stand are not expensive devices. Further noise reductions may greatly increase cost for these devices though because there is a point of diminishing returns for optimization of devices, where smaller gains are attributed to greater complexities and costs at each level.

Mfr. Scalability – Scalability from a cost perspective is not really an issue because the devices themselves are cheap and the photon counting receiver technology is relatively simple.

However, because photon counters are only operable in low data rate applications, their applications are limited. Increasing application scalability will depend greatly on the advances made in the areas of noise reduction, high density absorption, and dark count remediation. As described above, advances in these areas will be difficult and potentially costly.

Devices – As with the raw materials the devices involved are not costly. However, the devices are the main source of limitation for the photon counting technology, and device optimization will require much research and subsequent funding. Also, there is no indication that the improved future devices will be as cheap and easy to manufacture as their predecessors.

Benefit to LPPC – Photon counters will have minimal effects on loss of communication capabilities in general because they do nothing to alleviate any of the connectivity problems of FSO devices. However, by enabling optimal communications for certain types of laser communication, photon counters will help enable the real time dynamics of the Common Operating Picture.

3.6.1.3 Modulating Retro-Reflectors

MRRs use reflective materials to communicate over an FSO link. They are small enough to reduce the size of the overall device, and the variability in the index of refraction of the materials used gives them a broadcasting capability that point to point FSO devices lack. However, their ranges and data payload capabilities are comparable to those of RF devices and eliminate the greatest benefits of an optical link.

MRR			(1-10)	(1,2,3)=(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			26		2.0
	1	Broadcasting	10	2	0.76923
	2	Data rate	8	1	0.30769
	3	Form Factor	8	3	0.92308
Cost			37		1.4
	1	Raw Materials	7	1	0.18919
	2	Mfr Scalability	6	2	0.32432
	3	Devices	7	1	0.18919
	4	Engr-NRE	10	1	0.27027
	5	Engr-Integration	7	2	0.37838
Benefit to LPPC			40		1.78
	1	Loss of Comms. with Log, Intel, and Ops.	10	2	0.50
	2	Loss of LOC	7	2	0.35
	3	Loss of COP	7	3	0.53
	4	Losing the mission	1	1	0.03
	5	Soldiers dying / wounded	1	1	0.03
	6	Running out of Ammo	1	1	0.03
	7	Running out of Fuel	1	1	0.03
	8	Running out of Medical Supplies	1	1	0.03
	9	Running out of Water	1	1	0.03

10	Running out of Batteries/Fuel Cells	1	1	0.03
11	Breakdown of Equipment	1	1	0.03
12	Meeting w/ Bad Weather	1	1	0.03
13	Encountering Threat Forces	1	1	0.03
14	Loss of Strategic Assets and Cargo	1	1	0.03
15	Loss of Theater Lift Assets and Cargo	1	1	0.03
16	Closure of APODs and SPODs	1	1	0.03
17	Closure of Sea Lanes	1	1	0.03
18	Encountering Inaccessible Terrain	1	1	0.03
19	Untimely Delivery of Parts	1	1	0.03

Broadcasting – The ability to broadcast over ranges greater than 4 km makes the MRR an extremely promising addition to FSO links. A broadcast style link makes reconfiguration of FSO network topology feasible without advanced pointing algorithms, and allows a wider range of applications for FSO communication systems. Current MRRs under test have shown this capability, and future research will involve adapting them to a wider variety of systems.

Data Rate – One of the main drawbacks of the MRR is the drastic reduction in data rate to nearly 70 Mbps. Because MRRs continue to cost more than today's best RF links, there is no real drive towards adopting MRR technology on FSO links. While recent advancements have seen the data rate climb from 10 Mbps to 70 Mbps, a more drastic increase in data rate capabilities will have to be obtained before MRRs become an attractive addition to FSO links.

Form Factor – MRRs have the capability to shrink the size of the transmitter/receiver elements of current FSO links. While MRRs reduce characteristics such as range and data rate, for certain applications that require a smaller form factor and can also tolerate these degradations in performance, MRRs may be an ideal solution. Current MRR devices are readily available which have already shown a drastic decrease in size over traditional FSO devices.

Raw Materials – Materials for production of MRRs are readily available, and relatively cheap. The only variable here is that reflective materials with higher indices of refraction become exponentially more costly. These high index materials increase the device's FOV, increasing its broadcasting capability

Mfr. Scalability – Current architectures for MRRs are simple, and because they use common materials, they easily transition to wide-scale production.

Devices – The main devices for the MRR are the quantum well modulator and the optical receiver or photodiode. As with the photon counting receivers, adequate photodiodes are cheap and available, while the modulator design is based on an established quantum-well array method that allows for straightforward and cost effective production.

Benefit to LPPC – MRRs will have a beneficial impact on reliability for FSO devices by allowing them to broadcast and making them comparable to RF devices as far as link reliability. This will help prevent loss of communication with FSO devices and benefits across all three areas of the rankings in this area. However, limited applicability and range capability keep MRRs from achieving a higher ranking.

3.6.1.4 Adaptive FSO Mesh Networks

The adaptive FSO network functions the same way as a hybrid network, but eliminates the need for RF devices. FSO devices form a mesh type network with quick reconfiguration and pointing algorithms with broadcasting capabilities that do not sacrifice the high data rates and bandwidth of optical devices. The only downside is the enormous accomplishments in several areas of FSO communication before this type of network is even feasible.

Adaptive FSO			(1-10)	(1,2,3)=(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			38		1.2
	1	Dynamic link parameters	8	2	0.42105
	2	Movable transceivers	10	1	0.26316
	3	Reconfiguration	10	1	0.26316
	4	Mobility	10	1	0.26316
Cost			45		2.4
	1	Raw Materials	10	2	0.44444
	2	Mfr Scalability	10	3	0.66667
	3	Devices	9	2	0.4
	4	Engr-NRE	7	3	0.46667
	5	Engr-Integration	9	2	0.4
Benefit to LPPC			60		2.20
	1	Loss of Comms. with Log, Intel, and Ops.	10	3	0.50
	2	Loss of LOC	10	3	0.50
	3	Loss of COP	10	3	0.50
	4	Losing the mission	5	1	0.08
	5	Soldiers dying/wounded	1	1	0.02
	6	Running out of Ammo	1	1	0.02
	7	Running out of Fuel	1	1	0.02
	8	Running out of Medical Supplies	1	1	0.02
	9	Running out of Water	1	1	0.02
	10	Running out of Batteries/Fuel Cells	1	1	0.02
	11	Breakdown of Equipment	1	1	0.02
	12	Meeting w/Bad Weather	1	1	0.02
	13	Encountering Threat Forces	1	1	0.02
	14	Loss of Strategic Assets and Cargo	6	2	0.20
	15	Loss of Theater Lift Assets and Cargo	6	2	0.20
	16	Closure of APODs and SPODs	1	1	0.02
	17	Closure of Sea Lanes	1	1	0.02

18	Encountering Inaccessible Terrain	1	1	0.02
19	Untimely Delivery of Parts	1	1	0.02

Dynamic Link Parameters – Adaptive link parameters will play an important role in mitigating atmospheric degradation. Changing things like transmission power, reducing range, or changing modulation schemes can help keep the link quality tolerable. The main technical difficulty will be evaluating how to compromise these changes with desired link effects, and also determining the optimal network topology when incorporating these dynamic link parameters.

Movable Transceivers – The most important aspect of a mesh network is the ability to change transmission paths for a given node. Movable transceivers are essential to this ability, but simply changing the direction of the link is not enough. Precise point-to-point FSO links require difficult and time consuming scanning and processing techniques in the absence of a broadcast ability. MRRs may help in this area, but they will reduce range and by broadcasting the security of FSO point-to-point, links will be reduced.

Reconfiguration – Reconfiguration is the single defining quality of any mesh network. Self-healing abilities make the network more robust both in terms of natural causes of link degradation or enemy jamming techniques. For an all-optical network to be feasible, the reconfiguration must be done in near real time. However, the complicated pointing procedures make this extremely difficult with the aid of RF broadcast ability. This is the main technical challenge standing in the way of realizing an all FSO mesh network.

Mobility – Because of the difficulties in realizing a fast network reconfiguration, the mobility of optical nodes is greatly limited. Again, this will be greatly aided by fast pointing and/or optical broadcast abilities. As of now, even if some optical nodes are mobile they require accompaniment by stationary optical nodes that continue to limit applications where higher degrees of mobility are required.

Raw Materials – Long range FSO communication devices are relatively expensive in comparison with current fieldable wireless communication technologies. Similarly, FSO systems are not produced on a large scale because they have not proliferated to the commercial world and therefore are not produced en masse.

Mfr. Scalability – Because manufacturers are not producing FSO links except for specific applications, there is nothing to drive production costs down. Furthermore, some of the more advanced technologies needed for implementing adaptive FSO links will create higher costs than those for traditional point-to-point FSO links.

Devices – The device cost in and of itself does not differ much from current long range FSO devices. Controlling these devices in such a way as to make them adaptive consists mainly of algorithm developments, which will not add to the inherent device costs. However, FSO devices are costly in and of themselves in comparison to other forms of wireless communication.

Benefit to LPPC – The impact an adaptive FSO network would have on logistics is profound. Adaptive links give FSO devices the same mesh networking abilities as an RF network, but the elimination of a backup RF link means that information can be passed at optical data rates and across large bandwidths all of the time. These effects would reduce loss of communication to all entities and allow for the near real time management of data being transmitted to the GIG, which allows for the availability of an accurate COP including the real time tracking information for assets and cargo in transit.

3.6.1.5 Hybrid RF/FSO Networks

A hybrid network combines the reliability of broadcast and mesh RF capabilities with the high data rates and high bandwidth of an FSO link. The main drawback is in the presence of a link failure, limiting how the system can transfer the huge data payload from the FSO to the RF link.

Hybrid RF/FSO			(1-10)	(1,2,3)=(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			40		2.0
	1	Tx Switching	7	3	0.525
	2	Pointing System	10	2	0.5
	3	Atmospheric Interference	7	2	0.35
	4	Multi-channel	8	2	0.4
	5	Data Rate Scalability	8	1	0.2
Cost			39		2.0
	1	Raw Materials	10	2	0.51282
	2	Mfr Scalability	8	2	0.41026
	3	Devices	9	2	0.46154
	4	Engr-NRE	5	2	0.25641
	5	Engr-Integration	7	2	0.35897
Benefit to LPPC			58		2.17
	1	Loss of Comms. with Log, Intel, and Ops.	10	3	0.52
	2	Loss of LOC	10	3	0.52
	3	Loss of COP	8	3	0.41
	4	Losing the mission	5	1	0.09
	5	Soldiers dying/wounded	1	1	0.02
	6	Running out of Ammo	1	1	0.02
	7	Running out of Fuel	1	1	0.02
	8	Running out of Medical Supplies	1	1	0.02
	9	Running out of Water	1	1	0.02
	10	Running out of Batteries/Fuel Cells	1	1	0.02
	11	Breakdown of Equipment	1	1	0.02
	12	Meeting w/Bad Weather	1	1	0.02
	13	Encountering Threat Forces	1	1	0.02
	14	Loss of Strategic Assets and Cargo	6	2	0.21
	15	Loss of Theater Lift Assets and Cargo	6	2	0.21
	16	Closure of APODs and SPODs	1	1	0.02

17	Closure of Sea Lanes	1	1	0.02
18	Encountering Inaccessible Terrain	1	1	0.02
19	Untimely Delivery of Parts	1	1	0.02

Transmitter Switching – Transmitter switching itself is not difficult, and current technologies allow circuits to do this easily. The only variable is what constitutes a FSO link failure, and this would be evaluated on an application specific basis. The real challenge in this process is the disparate data rates of FSO and RF links.

Pointing System – The complexities of the pointing system for FSO devices will be somewhat alleviated by the broadcasting abilities of RF transmitters, which can search for alternate link paths while the FSO link continues to transmit data. This means the system knows a close approximation to alternate FSO receivers making the FSO link scan over a minimal area.

Atmospheric Turbulence – Atmospheric turbulence is also mitigated by the RF transceiver, which can operate under conditions where FSO links fail or degrade. RF links can also detect surrounding nodes, making the FSO links more adaptive in finding paths around the turbulence.

Multi-Channel – Multi-channel communications are already easily conducted in optical links using the WDM process. Transferring this multi-channel communication to RF requires multiple receivers and transmitters to operate simultaneously. Size and weight limitations will determine the maximum number of channels available per node, where the limitation is induced by the maximum number of RF links.

Data Rate Scalability – This is the main problem in a hybrid network because currently there is no way to transfer the data load from a 10 Gbps FSO link to a 100 Mbps RF link. Currently, the only proposed solution is to make the pointing scan delays for the FSO links as minimal as possible.

Raw Materials – Costs for raw materials will still be high due to the FSO link, but less prohibitive because higher costs may be tolerable when the FSO link maintains operation for a higher percentage of the time as is the case with hybrid links.

Mfr. Scalability – Due to the adaptive nature and increased capabilities of FSO links when paired with RF, a surge in the demand for FSO links may actually drive scalability costs up. The reason is that there is not an established demand for FSO production at either the commercial or military level. This potential surge may be prohibitive at first, but once a steady demand for FSO links is established this will help drive link production costs down in the long run.

Devices – FSO devices are still costly, and will dwarf the costs of adding additional RF devices, though costs of the FSO pointing system may be somewhat lower.

Benefit to LPPC – Hybrid networks have the greatest potential to benefit logistics with a low overall technical risk. By making use of both the characteristics of FSO bandwidth and data rates and RF mesh connection reliability, hybrid network topologies nearly eliminate downtime from loss of link connectivity. Maintaining links has large effects on the loss of communications, but because of the disparity in data payload capabilities between RF and FSO, if an FSO link goes down there is an inability to communicate large amounts of data in real time to preserve an up-to-date COP. Hybrids also incorporate the FSO capabilities of real time GPS information.

3.6.1.6 UAV Networking

UAVs as a mobile communication node add more mobility and satellite communication capability to a remotely operating network. UAVs may also act as remote storage or data processing nodes that would alleviate the data communication requirements of a preemptive network. However, difficult flight patterns algorithms and high costs are the driving factors against widespread integration.

UAV Networking			(1-10)	(1,2,3)=(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			35		1.7
	1	Flight Pattern	10	1	0.28571
	2	On-board processing/memory	8	2	0.45714
	3	Tx Switching	7	2	0.4
	4	Node Reconfiguration	10	2	0.57143
Cost			46		2.7
	1	Raw Materials	10	3	0.65217
	2	Mfr Scalability	10	3	0.65217
	3	Devices	10	3	0.65217
	4	Engr-NRE	8	2	0.34783
	5	Engr-Integration	8	2	0.34783
Benefit to LPPC			65		2.22
	1	Loss of Comms. with Log, Intel, and Ops.	6	3	0.28
	2	Loss of LOC	6	3	0.28
	3	Loss of COP	7	3	0.32
	4	Losing the mission	3	1	0.05
	5	Soldiers dying/wounded	1	1	0.02
	6	Running out of Ammo	1	1	0.02
	7	Running out of Fuel	1	1	0.02
	8	Running out of Medical Supplies	1	1	0.02
	9	Running out of Water	1	1	0.02
	10	Running out of Batteries/Fuel Cells	1	1	0.02
	11	Breakdown of Equipment	1	1	0.02
	12	Meeting w/Bad Weather	8	2	0.25
	13	Encountering Threat Forces	8	3	0.37
	14	Loss of Strategic Assets and Cargo	6	2	0.18
	15	Loss of Theater Lift Assets and Cargo	6	2	0.18
	16	Closure of APODs and SPODs	1	1	0.02
	17	Closure of Sea Lanes	1	1	0.02

18	Encountering Inaccessible Terrain	5	2	0.15
19	Untimely Delivery of Parts	1	1	0.02

Flight Pattern – Flight pattern is critical to UAV networking because it determines how UAVs will not only position themselves for optimal transmission, but also the protocols it must follow to avoid obstacles contributing to link degradation. This has to be evaluated on an application specific basis.

Processing/Memory – Onboard processing would alleviate data transmission requirements and onboard storage capacity allows UAVs to be extremely mobile sensing nodes. Processing and memory abilities will be limited mainly by UAV size and weight constraints.

Transmitter Switching **–** Transmitter switching only becomes an issue when FSO and RF links are incorporated. Clever flight patterns may alleviate the need for FSO links in some applications, and will allow an RF broadcast to quickly obtain new nodes by bringing them closer together. This allows fast FSO link configuration and improves data rate scalability between the two.

Node Reconfiguration – Because UAVs are extremely mobile, node reconfiguration is very important to ensure that the UAV remains available to other nodes in the network. Current reconfiguration schemes involved in mesh networks can serve this purpose. However, because of high UAV speeds, lower latency must be achieved in these algorithms.

Raw Materials – UAVs are very costly ranging on the order of $10,000 and beyond. The addition of high cost FSO links makes mobile UAV nodes more expensive. However, with unique processing capabilities, UAVs that are used in other Army operating environments may double as network nodes. Also, with respect to global networking, erecting the broadcast towers necessary to access an 802.20 network in a remote location would far outweigh the costs of a GIG satellite uplink via a UAV.

Scalability – The scalability issues described for other FSO technologies continues to drive up scalability costs, and because the robotics and aerodynamics of a UAV make it a technical challenge, production costs for UAVs will remain high for the foreseeable future.

Devices **–** To make UAV communication most effective, expensive FSO links must be incorporated, and the expensive autonomous intelligence and onboard processing make UAVs extremely expensive even from the device level.

Benefit to LPPC – UAV transmission will have mild impacts on logistics because its benefits are only realized in specific instances. A UAV can act as a satellite uplink for a network in a remote area without SATCOM capabilities of its own, which helps maintain the COP globally, but only effects loss of communication between nodes or entities if the links are restricted by range. However, UAVs can have great “scouting” capabilities for predicting enemy movements, bad weather, or difficult terrain. These UAVs, performing roles as sensors and communications enablers, will complement other sources of predictive information such as weather forecasting and intelligence operations.

3.6.1.7 Meta-Materials

Meta-materials are characterized by “left-handed” properties. Whereas naturally occurring physical bodies exhibit “right-handed” properties, or those properties that define the make ups of their magnetic and electric field, meta-materials’ fields behave oppositely with beneficial effects. These include smaller form factor and increased gain and also the potential for cloaking abilities. The drawback is that these materials have to be manufactured and few facilities have the equipment or expertise necessary to manufacture these materials even on a small scale.

Meta Materials			(1-10)	(1,2,3)=(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			28		2.3
	1	Scanning	8	3	0.85714
	2	Miniaturization	10	2	0.71429
	3	Tx Power	10	2	0.71429
Cost			43		2.2
	1	Raw Materials	10	2	0.46512
	2	Mfr Scalability	10	3	0.69767
	3	Devices	9	2	0.4186
	4	Engr-NRE	7	2	0.32558
	5	Engr-Integration	7	2	0.32558
Benefit to LPPC			31		1.48
	1	Loss of Comms. with Log, Intel, and Ops.	5	2	0.32
	2	Loss of LOC	5	2	0.32
	3	Loss of COP	5	2	0.32
	4	Losing the mission	1	1	0.03
	5	Soldiers dying/wounded	1	1	0.03
	6	Running out of Ammo	1	1	0.03
	7	Running out of Fuel	1	1	0.03
	8	Running out of Medical Supplies	1	1	0.03
	9	Running out of Water	1	1	0.03
	10	Running out of Batteries/Fuel Cells	1	1	0.03
	11	Breakdown of Equipment	1	1	0.03
	12	Meeting w/Bad Weather	1	1	0.03
	13	Encountering Threat Forces	1	1	0.03
	14	Loss of Strategic Assets and Cargo	1	1	0.03
	15	Loss of Theater Lift Assets and Cargo	1	1	0.03
	16	Closure of APODs and SPODs	1	1	0.03
	17	Closure of Sea Lanes	1	1	0.03
	18	Encountering Inaccessible Terrain	1	1	0.03
	19	Untimely Delivery of Parts	1	1	0.03

Scanning – Meta-materials allow antennas to scan in the backwards direction, whereas traditional antennas allow forward scanning in the direction of propagation. Backwards scanning provides instantaneous 360˚ scanning capabilities that enhance both detection and broadcast capabilities in RF devices.

Miniaturization – Meta-materials are the first technique that allows a shrinking in antenna size while maintaining or even increasing antenna gain. Initial research results prove this, and this is one of the most important aspects for shrinking RF devices that require high antenna gains. Also, smaller antennas mean less obtrusive targets. However, the feasibility of integrating meta-materials into large scale antennas has not been assessed.

Transmission Power – Tied in closely to miniaturization is the fact that using meta-materials requires less transmission power for a given antenna size. This could be an important aspect for costly, power hungry applications or those requiring extremely low amounts of power.

Raw Materials/Processing Cost – Because meta-materials are not naturally occurring, they have to be artificially altered, and this process makes them very expensive. Current research invested in this area hopes to find cheaper and simpler ways to generate these types of materials. The nature of frequency response is such that what might be "invisible" at one wavelength or frequency, is not necessarily true at another. Material processing in one embodiment may be as simple as introducing dielectric elements on the size of a penny (RF meta-materials). For meta-materials at optical wavelengths, substantially higher tolerances are needed in the exact placement of the effecting elements.

Scalability – Currently there are few facilities equipped for the production of meta-materials, and the process is technically tedious meaning that only those well educated in the area of the defining left-handed properties (dielectric permittivity) of meta-materials can do it. This creates considerable obstacles for leveraging the benefits of widespread production for meta-materials.

Devices – The only device involved is the meta-material itself, and as explained above, the production costs for meta-materials are very high.

Benefit to LPPC – Meta-materials will not have a very significant impact on predictive capabilities in general, but have shown the capability to increase RF transmission ranges, increase RF signal strength, and reduce form factors for longer wavelength antennas making them a less visible target for enemies. Increased range and strength also enhances RF reliability and robustness.

3.6.1.8 Multi-Band Tunable Antennas

These are antennas that allow simultaneous RF communications across multiple frequency bands at the same time and on one device.

Multi-Band Tunable Antennas			(1-10)	(1,2,3)=(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			37		1.8
	1	Bandwidth	10	3	0.81081
	2	Size	8	2	0.43243
	3	Tuning Capabilities	10	1	0.27027
	4	Radiation Efficiency	9	1	0.24324
Cost			32		1.2
	1	Raw Materials	5	1	0.15625
	2	Mfr Scalability	6	1	0.1875
	3	Devices	6	1	0.1875
	4	Engr-NRE	7	2	0.4375
	5	Engr-Integration	8	1	0.25
Benefit to LPPC			42		1.88
	1	Loss of Comms. with Log, Intel, and Ops.	6	2	0.29
	2	Loss of LOC	6	2	0.29
	3	Loss of COP	10	3	0.71
	4	Losing the mission	1	1	0.02
	5	Soldiers dying/wounded	1	1	0.02
	6	Running out of Ammo	1	1	0.02
	7	Running out of Fuel	1	1	0.02
	8	Running out of Medical Supplies	1	1	0.02
	9	Running out of Water	1	1	0.02
	10	Running out of Batteries/Fuel Cells	1	1	0.02
	11	Breakdown of Equipment	1	1	0.02
	12	Meeting w/Bad Weather	1	1	0.02
	13	Encountering Threat Forces	5	2	0.24
	14	Loss of Strategic Assets and Cargo	1	1	0.02
	15	Loss of Theater Lift Assets and Cargo	1	1	0.02
	16	Closure of APODs and SPODs	1	1	0.02
	17	Closure of Sea Lanes	1	1	0.02
	18	Encountering Inaccessible Terrain	1	1	0.02
	19	Untimely Delivery of Parts	1	1	0.02

Bandwidth – Access to multiple bands means not only having the ability to communicate between a multitude of standards, but also the ability to increase RF bandwidth for any given standard by using multiple bands for communication simultaneously. Current research has shown the ability to incorporate two bands on a single antenna, but a future multi-band antenna with abilities to access several frequency bands or more still requires significant effort and funding.

Size – Currently, the only way to communicate across multiple bands simultaneously is through the use of a separate antenna for each band. This limits the form factors of some communication devices because additional antennas require a large space relative to the device. Multi-band antennas would allow for this type of communication on a single antenna keeping device size small and applicable to a wider variety of applications.

Tuning Capabilities – Tuning for transmission is relatively straightforward since the frequency band and the wireless standard are known beforehand. Tuning for reception is a more difficult problem because, in order to tune upon reception, the antenna must somehow find this information before it is able to receive a signal of any kind. Random sweeps for signals at given frequency bands has been suggested, but this introduces hypothetical scanning and tuning latencies. However, once more bands become accessible on a single antenna, this problem will be fundamental to the operation of the antenna.

Radiation Efficiency – For a given standard and operational frequency different antenna configurations will yield different results. Each type of communication has its own type of antenna that yields the highest radiation efficiency. For multi-band antennas, a single antenna may operate over different frequency ranges meaning that there will inherently be a tradeoff in performance at some frequency bands. This introduces a unique problem, the optimization of which will be done on an application specific basis.

Raw Materials – Currently, there is no indication that the material structure of a multi-band antenna will differ from that of current antennas. This means that the actual production of antennas should be relatively cheap in comparison to the rest of the communication device.

Scalability – Because there are many commercial entities with the expertise to make antennas, and because they are already produced on a large scale the scalability of multi-band antennas should not be a costly issue.

Devices – The device cost of a multi-band antenna should not differ much from that of today's current antennas.

Benefit to LPPC – Multi-band antennas will mostly have impacts in the areas of RF bandwidth and flexibility, but since RF are already highly reliable and flexible relative to optics, the real benefit comes from increasing the bandwidth capabilities of RF devices. Allowing simultaneous communication across multiple channels or frequency bands helps reduce the load sharing dispute between FSO and RF in hybrid networks. This gives a greater RF capability for maintaining high data rates necessary for sustaining the COP. Also, multi-band communications increase the security by spreading information over a wider variety of sources making it more difficult for enemies to intercept and piece together.

3.6.1.9 Micro-Fabricated Vacuum Electron Devices

uVEDs are components that make up the subsystems of an RF device, and have achieved smaller sizes with greater gains than previously used methods for RF fabrication.

uVEDs			(1-10)	(1,2,3)=(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			34		2.2
	1	Cold Emission Cathodes	10	1	0.29412
	2	Subcomponent integration	8	2	0.47059
	3	Bandwidth	7	3	0.61765
	4	Miniaturization	9	3	0.79412
Cost			34		1.4
	1	Raw Materials	5	1	0.14706
	2	Mfr Scalability	6	1	0.17647
	3	Devices	8	2	0.47059
	4	Engr-NRE	7	2	0.41176
	5	Engr-Integration	8	1	0.23529
Benefit to LPPC			34		1.53
	1	Loss of Comms. with Log, Intel, and Ops.	6	2	0.35
	2	Loss of LOC	6	2	0.35
	3	Loss of COP	6	2	0.35
	4	Losing the mission	1	1	0.03
	5	Soldiers dying/wounded	1	1	0.03
	6	Running out of Ammo	1	1	0.03
	7	Running out of Fuel	1	1	0.03
	8	Running out of Medical Supplies	1	1	0.03
	9	Running out of Water	1	1	0.03
	10	Running out of Batteries/Fuel Cells	1	1	0.03
	11	Breakdown of Equipment	1	1	0.03
	12	Meeting w/Bad Weather	1	1	0.03
	13	Encountering Threat Forces	1	1	0.03
	14	Loss of Strategic Assets and Cargo	1	1	0.03
	15	Loss of Theater Lift Assets and Cargo	1	1	0.03
	16	Closure of APODs and SPODs	1	1	0.03
	17	Closure of Sea Lanes	1	1	0.03
	18	Encountering Inaccessible Terrain	1	1	0.03
	19	Untimely Delivery of Parts	1	1	0.03

Cold Cathodes – The cathode is the portion of the device responsible for emitting the electron beam. The universal challenge of vacuum electronics (micro-scale and otherwise) has been the development of cold emission cathodes. For most devices (operating in continuous wave mode), a thermionic cathode is used, meaning that it is heated up until it readily emits electrons whose flow (beyond the thermal emission) is controlled directly by the bias voltages on the other electrodes. While cold cathodes have been demonstrated for pulsed signals, and some short lifetime experiments, this remains the primary challenge for extending the capability of the microscale versions since the addition of this external heating element does not readily lend itself to microfabrication processing.

Subcomponent Integration – Additional challenges are found in yoking together the remaining components, slow wave structure and beam dump (anode). The slow wave structure is the corrugation or cavities built along the path of the electron beam. Its natural resonances are the component responsible for producing the RF oscillations on the electron beam that in turn amplifies it. (This is directly analogous to blowing across a glass soda bottle. The sound emanates from the natural frequency of the cavity (bottle) and the person's breath serves the same function as the electron beam). Current approaches to solving this more tractable issue involve performing as much holistic device manufacture (contemporaneous integration and fabrication) as possible.

Bandwidth & Miniaturization – Unlike some of the other subcomponents, the bandwidth of these devices is directly related to the ease of fabrication of the slow wave structures. In essence, this is a non issue for 100 GHz to 1 THz geometries. (In fact, micro-VEDS represent one of the most realizable approaches to sub-THz generation). The only significant challenge is to design for historically low frequencies because the geometries tend to involve structures that are larger than typical semiconductor wafers.

Raw Materials/Processing Cost – Raw Materials are a modest issue since many devices can be built with silicon and typical fabrication metals. However, in this case, although some standard materials and techniques can be used, the lower volume and substantial differences in geometry (as compared to mainstream silicon) leave this factor at a relatively higher cost.

Scalability – For most technologies that can be produced via microfabrication, there exist implicit advantages in manufacturing scalability. Several of the remaining on-shore facilities retain the capability to produce these structures, ameliorating the concern for off-shore migration (again as compared to mainstream silicon).

Devices – The device cost of a microfabricated VED, upon reaching mature process, will be no more than an order of magnitude over contemporary transistors filling that same frequency niche.

Engineering (NRE) – Primary cost of the devices will come out of the initial development. Substantial CAD (computer-aided engineering) is required and the type of software used for these devices is both computationally expensive and specialized.

Engineering Integration – Upon demonstration of successful capability at the device level, a substantial amount of infrastructure already exists for integration of micro-VEDS into higher level circuits (amplifiers, oscillators, and transmitter). Primary work effort here would be development of the empirical models to be used in the circuit simulators.

Benefit to LPPC – The overall impact on uVEDs on logistics will be limited mainly by the fact that they will only affect antenna size and transmission frequency for RF devices. While high transmission frequencies inherently mean greater bandwidth for RF communications, this has little to do with link reliability and doesn't affect loss of communications. What uVEDs can do is increase the data payload capability of RF devices when accompanied by an effective multi-band antenna by allowing greater bandwidths. This helps transmit more data to maintain an accurate and available COP.

3.6.1.10 Multi-platform Common Data Link (MP-CDL)

The main issues incorporated within the Army concept of MP-CDL is that of interoperable networking for an extremely mobile force. The information passed within the MP-CDL network should also be accessible by all Army entities in real time. The ambition of the MP-CDL requires the combination of the future technologies ranked in this section; these include hybrid mesh networks for increasingly mobile and robust PANs, long range and short range optical links with optimum data rates, a global information network that allows instantaneous access to asset information all over the world in real time, and all the underlying sub-technologies that go along with these concepts.

MP-CDL			(1-10)	(1,2,3)=(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			40		1.0
	1	Interoperability	10	1	0.25
	2	Mobility	10	1	0.25
	3	Networking	10	1	0.25
	4	Accessibility	10	1	0.25
Cost			48		3.0
	1	Raw Materials	10	3	0.625
	2	Mfr Scalability	10	3	0.625
	3	Devices	10	3	0.625
	4	Engr-NRE	8	3	0.5
	5	Engr-Integration	10	3	0.625
Benefit to LPPC			81		2.35
	1	Loss of Comms. with Log, Intel, and Ops.	10	3	0.37
	2	Loss of LOC	10	3	0.37
	3	Loss of COP	10	3	0.37
	4	Losing the mission	8	3	0.30
	5	Soldiers dying/wounded	1	1	0.01
	6	Running out of Ammo	1	1	0.01
	7	Running out of Fuel	1	1	0.01
	8	Running out of Medical Supplies	1	1	0.01
	9	Running out of Water	1	1	0.01
	10	Running out of Batteries/Fuel Cells	1	1	0.01
	11	Breakdown of Equipment	1	1	0.01
	12	Meeting w/Bad Weather	8	2	0.20
	13	Encountering Threat Forces	8	2	0.20
	14	Loss of Strategic Assets and Cargo	6	2	0.15
	15	Loss of Theater Lift Assets and Cargo	6	2	0.15
	16	Closure of APODs and SPODs	1	1	0.01
	17	Closure of Sea Lanes	1	1	0.01

18	Encountering Inaccessible Terrain	5	2	0.12
19	Untimely Delivery of Parts	1	1	0.01

Interoperability – Like with the JTRS radio effort, interoperability between all military platforms is paramount to a net-centric force. Because different standards, and even different characteristics pertaining to RF and FSO, are best suited in separate applications, interoperability must ensure that all information is accessible to all critical outfits in the Army regardless of location or communication capabilities. Though interoperability between some different platforms has been demonstrated, to achieve full scale interoperability will require significant effort and funding.

Mobility – The future Army network must be able to support the mobility of troops and assets in the arena of combat ensuring that all preemptive information is available regardless of speed, network infrastructure, or communication requirements. While several emerging technologies have shown the ability to operate in a mesh topology for mobile networks, optimal mobility will require investments in technologies such UAV networking, and optimum communication abilities require adapting FSO to a mobile configuration.

Networking – Current network topologies have shown weaknesses in several respects to the types of high volume, long range, and mobile communications necessary for a net-centric Army. Investing in the addition of FSO links to traditional network topologies as well as topologies that support faster, more mobile networks and global networks will all be extremely important to the realization of the Army MP-CDL.

Accessibility – Information needs to be accessible at all echelons of the Army and by all necessary Army personnel to ensure that the best decisions are being made with the most up to date information. The only way to do this is with a unified global network that is accessible anywhere on the globe. This requires the development of a standard (or potentially 802.20) and the implementation of the required infrastructure. Similarly, investment in satellite uplink capabilities in remote locations will also be critical.

Raw Materials – Extremely high costs will be driven by investments in a multitude of FSO links, UAVs, and expensive broadcast towers worldwide for network broadcast capabilities.

Scalability – Scalability will be necessary for implementation on a global scale because large volumes of new technologies will be essential for the efficiency and robustness of a MP-CDL network. This means large investments in the production processes and funding to outside entities to drive the production of new and expensive technologies on a large scale.

Devices – Devices will range from cheap to very expensive. On the whole, an effective globally accessible network will require the investment in both research and production of expensive future technologies.

Benefit to LPPC – The MP-CDL will have a dramatic effect on logistics communication capabilities for preemption in all areas. Adaptable mesh networks ensures that loss of communication will not be an issue, while high speed, high bandwidth data transfer, satellite uplinks, and backhaul communications to the GIG facilitate the real-time prognostic assessment of assets in the COP.

3.6.2 Data Transmission Technology Quadrant Chart

The quadrant chart below summarizes the data transmission technologies in terms of Probability of Maturity, Cost, and Benefit to LPPC. The colors indicate cost and are based upon leveraging efforts within the S&T community i.e., green indicates technologies that are already being researched for other applications would provide

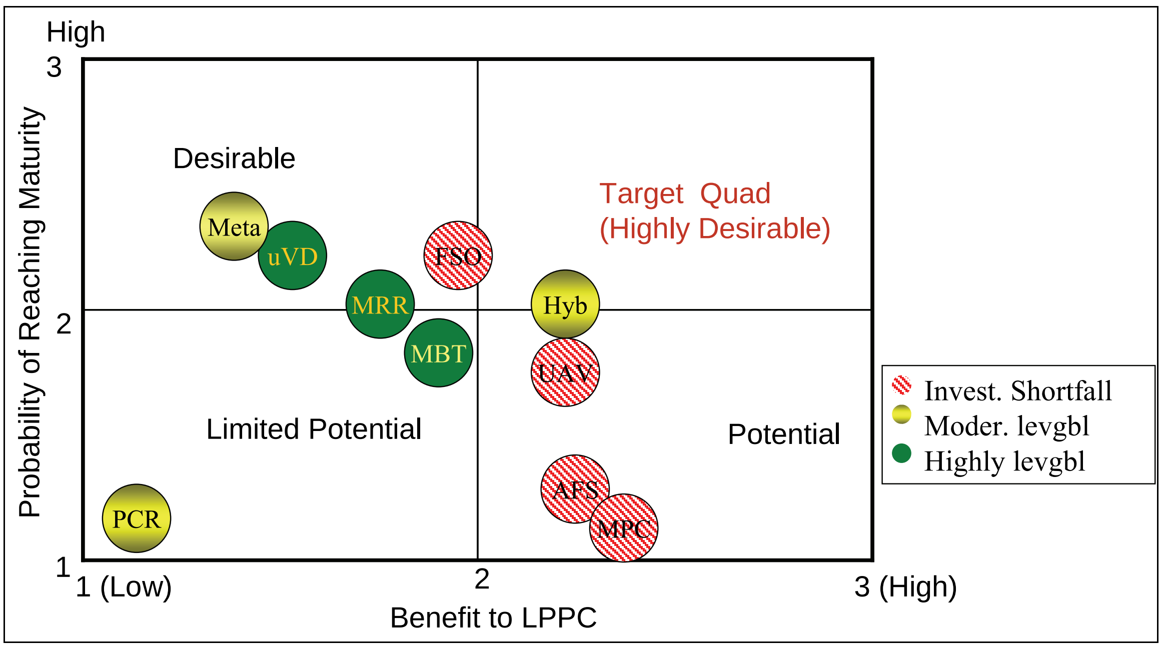


Figure 3.30. Summary of future data transmission technologies, their benefit to LPPC, probability of maturity, and cost. (Red indicates investment shortfall, while yellow and green represent leveraging technologies, meaning that other sectors, e.g., C2 or the commercial sector hold a substantial vested interest in the respective technology.

Symbol	Technology	Section
FSO	Free Space Optical Communication	3.2.1
PCR	Photon Counting Receivers	3.2.2
AFS	Adaptive Free Space Optical Communication	3.2.3
MRR	Modulating Retro Reflector	3.2.4
Hyb	Hybrid RF Optical Communication	3.2.5
UAV	UAV Relayed Communication	3.2.5.3
Meta	Meta-materials	3.5.2
uVD	Microfabricated Vacuum Electronic Devices	3.5.3
MBT	Multi-band Tunable Antennas	3.5.4
MPC	Multi-Platform Common Data Link (MP-CDL)	3.5.5.1

3.7 Conclusions

Data transmission is unique because it is not accomplished at nodes in the prediction and preemption chain such as data collection, fusion and analysis, and assessment and exploitation. Instead data transmission provides the necessary link to facilitate the progression from one stage in the prediction and preemption process to another. This means that a failure in communication links will negatively impact all of the 19 events to be preempted, by any technology, within each of the other three areas of the prediction and preemption process.

This chapter explained current day and emerging communication technologies as a baseline for the development of future technologies, and forecasted technologies with the potential to improve logistics prediction and preemption capabilities in the 2020-2030 timeframe. All forecasted technologies are ranked based on Probability of Maturity, Costs, and Benefit to LPPC. Based on these rankings, we conclude that hybrid networks have the most potential to reach maturity while exerting a large impact on the communications capabilities of a logistics network. By taking advantage of current RF and emerging FSO technologies, projects like ORCLE can demonstrate the feasibility and improvements offered by hybrid communications on a smaller scale. Hybrid networks are also adaptable to new global communication protocols by accessing the internet via backhaul communications if infrastructure is available or through current military SATCOM capabilities in more remote areas. FSO has already shown great promise, and will drastically impact logistics prediction and preemption capabilities by increasing data rates and bandwidth to levels necessary for the high data payloads required by prognostics algorithms. High developmental risks involved in an all-optical adaptive network can be alleviated by incorporating FSO in the aforementioned hybrid configuration. Multi-band tunable antennas are a promising technology that looks to incorporate less investment risk for investment. Multi-band antennas will be widely applicable and will significantly benefit the LPPC communication capabilities by enabling simultaneous communication over parallel channels by the same device.

The high technical risk associated with meta-materials may be alleviated by their significant benefit to form factor for RF devices. However, this is not as widely applicable across all areas of logistics communication. Limited applicability is also the case for MRRs, although they show great potential for increasing mobility for short range and low data rate FSO networks in the near future. These limitations may lower the overall impact that MRRs will have on future logistics capabilities. UAV communications would greatly benefit from the mobility, range, and global networking capabilities of a hybrid network, but their widespread deployment may be limited by their high production costs relative to other communication devices. Photon counting receivers have a high level of maturity because they have already been demonstrated on several test platforms currently. Many laser communications devices require the use of photon counting receivers to optimize performance, but it is unclear that these limited number of FSO devices will greatly benefit the LPPC by themselves.

The final two technologies are the adaptive FSO and the MPCDL global network. These have the potential to greatly benefit logistics prediction and preemption and general communication capabilities, but unfortunately also pose the greatest technical risks because they will be both costly and extremely difficult to realize on a large scale. Adaptive FSO networks would give the benefit of optical data rates and bandwidth to a mobile force, and have the ability to mitigate atmospheric turbulence to keep links active nearly 100% of the time. However, for reasons discussed in the prior section, this would be extremely difficult and costly to implement and produce on even a small scale. The main issue associated with incorporating MP-CDL within the Army's concept for the LPPC is that of interoperable networking for an extremely mobile force. Interoperability will mean that airborne, WAN, LAN, PAN, satellite, and fiber-optic networks can all communicate with each other allowing accessibility to all Army entities in real time. The good news is that a fully realized MP-CDL is the product of realizing many of the technologies described already. Investments in FSO links as they apply to hybrid FSO / RF networks, as well as a heavy investment in UAV production for communication capabilities will go a long way in realizing an MPCDL. Many of the other technologies will have impacts in specific areas, but they will not have the Army-wide applicability necessary for realizing a global MPCDL. A mobile network with high bandwidth and data rate capabilities that has access to the GIG is the basis of the MPCDL, but the other challenging aspect is interoperability not just in the sense of JTRS, but also incorporating optical and satellite communications into the overall communications capability. The MPCDL will greatly enable a fully realized mobile, net-centric force with prediction and preemptive capabilities.

---

[38]Chatterjee, Samir and Pawlowski, Suzanne. "All Optical Networks: Enlightening the Effects and Implications of Nearly Infinite Bandwidth." Communications of the ACM, Vol. 42, No. 6, 2004.
[39]Demi, Alper. "Noise Analysis Fiber Communication Systems". Proceedings of the International Conference on Computer Aided Design, 2003.
[40]Betti, Silvello; DeMarchis, Giancarlo and Iannone, Eugenio. Coherent Optical Communications Systems, John Wiley & Sons, Inc, 1995.
[41]Ibid.
[42]Alwayn, Vivek."Fiber-Optic Technologies". Cisco Press, Apr 23, 2004. http://www.ciscopress.com/articles/article.asp?p=170740&seqNum=6&rl=1.
[43]Betti, Silvello; DeMarchis, Giancarlo and Iannone, Eugenio. Coherent Optical Communications Systems, John Wiley & Sons, Inc, 1995.
[44]Milner, Stewart and Davis, Christopher. "Hybrid Free Space Optical/RF Networks for Tactical Operations". IEEE Military Communications Conference, 2004.
[45]Chan, Vincent. "Free-Space Optical Communications". Journal of Lightwave Technology, Vol. 24, No. 12. 2006.
[46]Leland, Joe and Porsche, Issac. "Future Army Bandwidth Needs and Capabilities". Arroyo Center. Rand Corporation, 2004.
[47]S. and Kopeika, N.S. "The Performance Limitations of Free Space Optical Communication Satellite Networks Due to Vibrations – Analog Case". Ben-Gurion University of the Negev, 1996.
[48]Chan, Vincent. "Free-Space Optical Communications". Journal of Lightwave Technology, Vol. 24, No. 12, December 2006.
[49]Milner, Stuart and Christopher Davis. "Hybrid Free Space Optical/RF Networks for Tactical Operations." IEEE Military Communications Conference. Conference Proceedings, IEEE, 2004.

[50]Ibid.
[51]Ibid.
[52]Cheng, Chen-Mou, Pai-Hsiang Hsiao, HT Kung, and Dario Vlah.. "Performance Measurement of 802.11a Wireless Links from UAS to Ground Nodes with Various Antenna Orientations". IEEE Press, 2006.
[53]Pinkney, F.J., D. Hampel, and S. Diperro. "Unmanned Aerial Vehicle (UAS) Communications Relay". Military Communications Conference. Conference Proceedings, IEEE, 1996.
[54]Ibid.
[55]Milner, Stuart and Christopher Davis. "Hybrid Free Space Optical/RF Networks for Tactical Operations." IEEE Military Communications Conference. Conference Proceedings, IEEE, 2004.
[56] Carr, Joseph. RF Components and Circuits. Boston: Newnes Press, 2002.
[57] Ibid
[58] Carr, Joseph. RF Components and Circuits. Boston: Newnes Press, 2002
[59]Ibid
[60]Griffith, Whitfield B. Radio-Electronic Transmission Fundamentals, 2nd Ed. Atlanta: Noble Publishing Corporation, 2000.
[61]Carr, Joseph J. Practical Antenna Handbook. Blue Ridge Summit, PA: Tab Books, 1989.
[62]Koski, Eric and Charles Linn. "The JTRS Program: Software-Defined Radios as a Software Product Line". 10th International Software Product Line Conference. Conference Proceedings, IEEE, 2006.
[63]Place, J., D. Kerr and D. Schaefer. "Joint Tactical Radio System". JTRS Joint Program Office. 2001.
[64]Koski, Eric and Charles Linn. "The JTRS Program: Software-Defined Radios as a Software Product Line". 10th International Software Product Line Conference. Conference Proceedings, IEEE, 2006.
[65]"AFDX: The Next-Generation Interconnect for Avionics Subsystems". Avionics Magazine Tech Support. IEEE, 2004.
[66]Ibid.
[67]"Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications". LAN MAN Standards Committee of the IEEE Computer Society, Institute of Electric and Electronics Engineers, 1999.
[68]"Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low- Rate Wireless Personal Area Networks (LR-WPANs)". LAN MAN Standards Committee of the IEEE Computer Society, Institute of Electric and Electronics Engineers, 1999.
[69]"Understanding 802.14.4 and Zigbee Networking". Daintree Networks, 2006.
[70]Griggs, Stephen. "Optical and RF Combined Link Experiment for SPIE Conference on Defense Transformation and Network-Centric Systems". Proceedings of SPIE, Vol. 5820, April 1, 2005.
[71]Ibid.
[72]Kshetrimayum, Rakhesh. "A Brief Introduction to Meta-materials." IEEE Potentials, 2004.
[73]Eleftheriades, G.V., M.A. Antoniades and F. Qureshi. "Some Antenna Applications of Negative Refractive Index Transmission Line Metamaterials."
[74]Kshetrimayum, Rakhesh. "A Brief Introduction to Meta-materials." IEEE Potentials, 2004.

Chapter 4. Data Fusion and Analysis

B. Ruth

"We used to think that if we knew one, we knew two, because one and one are two. We are finding that we must learn a great deal more about 'and'."

- Sir Arthur Eddington

4.1 Overview

4.1.1 Operational Context[75]

In the post-9/11 world, the United States needs the capability to counter a non-state threat that is state sponsored and is extremely dynamic in its tactics. The threat's tactics have in large measure morphed into attacking logistics assets and activity. The Army's capability to conduct sustained combat operations is dependent upon the Army's capability to keep its logistics operations functioning. Relevant to extant U.S. warfighting capabilities, this requires strategic and tactical resupply mobility in hours/days, not weeks/months; Joint netted lethality in close combat; Joint netted logistics/supply operations anywhere in the world, and combined and noncombatant survivability in complex terrain. To achieve national security objectives, the suitability of solutions (i.e., total DOTMLPF[9] life-cycle ownership cost) and the time to field capabilities must improve to meet the rapid adaptability of our enemy. Effectiveness, survivability, and sustainability will require unprecedented integration and interoperability across the Joint Commands and Services; operations, intelligence, and logistics down to the lowest echelons.

"The Chief of Staff of the Army says that he would accept a 60% solution to a problem but wants it now."[10] We must be willing to accept a "good enough" solution. Why bring this up at this point? We are all aware that computational power is advancing at what seems to be an ever increasing rate both in storage capacity and computational speed. Today's dialog strongly suggests that we may see teraflop laptops commercially available within the next ten years. That would be an incredible increase in analytical computing power and may easily serve the LPPC "data" fusion and analysis requirements at the combat brigade level and above. There has to be a corresponding will to acquire this analytical capability for the LPPC.

Einstein once said that the "perfection of means and confusion of ends seem to characterize our age." Unfortunately, these words characterize certain DoD transformation initiatives today,

[9]DOTMLPF is military terminology for the collective consisting of doctrine, organization, training, materiel, leadership, personnel, and facilities.

[10]LTG Lovelace-Deputy Chief of Staff Operations G-3, Battle Command Strategic Symposium, 1 Feb. 2007.

where efforts focus largely on the ***materiel***—the physical means needed for successful military prosecution—without adequate consideration for (or linkage to) the ***missions***—the end actions that must be accomplished to meet objectives. To use the terminology of the engineer's maxim, form (the technical and systems architecture) is often not following function (the operational architecture).

Recognizing that the Cold War is past and faced with enemies who are not conventional states and who practice asymmetric warfare through such means as terrorism, assassination, and targeting of civilians, U.S. defense leaders appreciate that they must seek to improve capabilities to predict and preempt such enemy actions. Critical to this mission is the ability to combine operating environment data with Logistics enterprise data gathered from sensor networks and existing business processes into a coherent situational representation, and then analyze the likely evolution of this composite situation through time. And once analyzed, a projected situation that evolves towards conditions undesirable to a military commander must be preempted via a corrective course of action (COA).

Col John Boyd, USAF (Ret), coined the term and developed the concept of the *OODA loop* (i.e., a cycle of observation, orientation, decision, and action processes).[76] Figure 4.1 depicts a flowchart representation of the OODA loop. According to Boyd, decision-making occurs in a cycle of observe-orient-decide-act. An entity (either an individual or an organization) that can process this cycle quickly, observing and reacting to unfolding events more rapidly than an opponent, can thereby "get inside" the opponent's decision cycle and gain a military or business advantage. Boyd developed this concept to explain how to direct one's energies to defeat an enemy and survive, emphasizing that "the loop" is actually a set of interacting loops that are to be kept in continuous operation during a military operation or business enterprise. The OODA loop is now used as a standard description of decision-making cycles in U.S. military services, and has also penetrated into the business community and academia around the world.

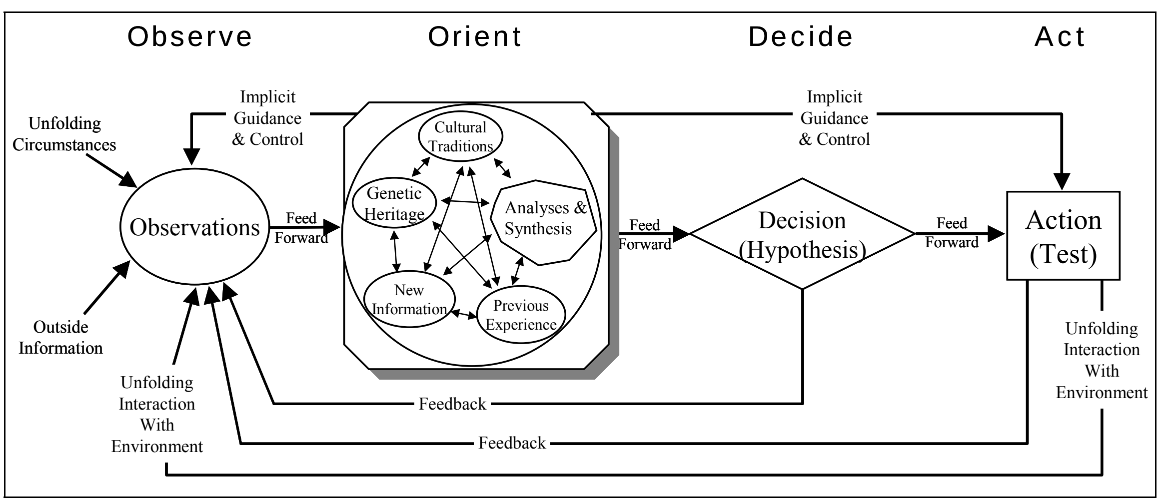


Figure 4.1. Observe-orient-decide-act (OODA) loop paradigm designed by COL Boyd.

The OODA loop is not as simple as "first observe, then orient, then decide, then act." In fact, such a sequential model would be very ponderous and would not well describe how successful warfighters or competitors operate. The key to speed turns out to be the two "implicit guidance and control" arrows at the top. In other words, most of the time people and groups do not employ the explicit, sequential O-to-O-to-D-to-A mechanism. Most of the time, they simply observe and act. Then the question, of course, is "what action?" A thinking opponent does not provide us with a laundry list of his tactics so we can work out responses in advance. The mechanism that handles this uncertainty and makes the loop function in a real world situation is "orientation." As we suck in information via the "observe" gateway, and detect mismatches between what we predict and what actually happens, we have to change our orientation (and hence the "implicit guidance and control" flowing from orientation). Finally, note that "OODA" speed is quite different from the speed of our actions.

Data fusion and analysis is the combination of raw facts gathered from multiple sources. Figure 4.2 illustrates the general data fusion process[77]. Here, individual data sources are sampled from the following domains:

- military intelligence (Red/enemy resources and strategy),
- civilian broadcasting (White/nonmilitary civil affairs),
- local environment (Green/environmental factors such as weather and terrain), and
- military operations (Blue/friendly resources and strategy).

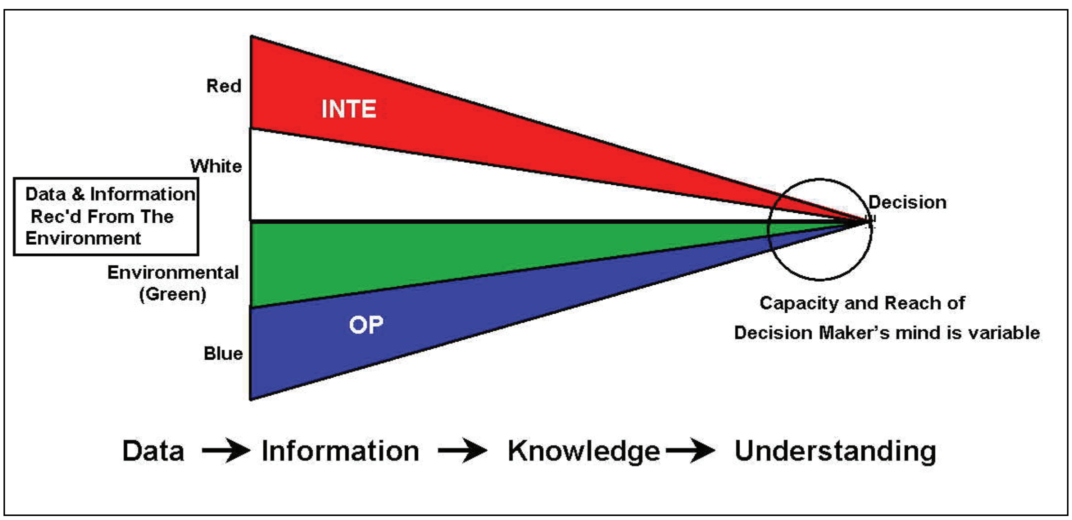


Figure 4.2. Data fusion and analysis provides a critical link between data collection and transmission and actionable exploitation and assessment resulting from those data.

Once the data are fused, they need to be analyzed using qualitative and quantitative measures to yield actionable knowledge. The resulting actionable knowledge is used to develop potential courses of action (COAs). Finally, realistic quantified uncertainties must be provided along with these COAs.

As pointed out by Ferryman[78], the challenge of COA analysis can be viewed as a stage of a scientific decision making process – specifically the *Military Decision Making Process* (*MDMP*) – with a goal to optimize the outcome of a mission. Typically, this translates well to practice if one can specify:

- a list of all possible COAs (or at least an initial list of envisioned COAs),
- a list of all possible outcomes (often quantified in a single or a few characteristics, such as loss of life or some measure of mission success), and
- the probability of each outcome, given the COAs and other factors.

The scientific decision making process provides the defensible and tractable approach necessary to guide the Prediction Project efforts. By using this process, we can create a compelling case for the Army logistics community to develop prediction capabilities and do so in an operational context addressing considerations across logistics, intelligence, and operational domains.

4.1.2 The Data Fusion Process

The hierarchy of progressive inference levels within a generic data fusion process is illustrated in Figure 4.3[79]. Data fusion is an information process that first samples data and information from single and multiple sources, then associates, correlates, and combines these data to estimate the identities and locations of all sensed entities. Once all perceived entities are identified and located, the fusion process produces an assessment of the overall perceived operating environment situation. This assessment serves to address all threats and problems associated with the perceived situation as a function of the former's significance to the military decision maker. Finally, the data fusion process is characterized by continuous refinements of its estimates and assessments – and by evaluation of the need for additional sources, or modification of the process itself – to achieve improved results.

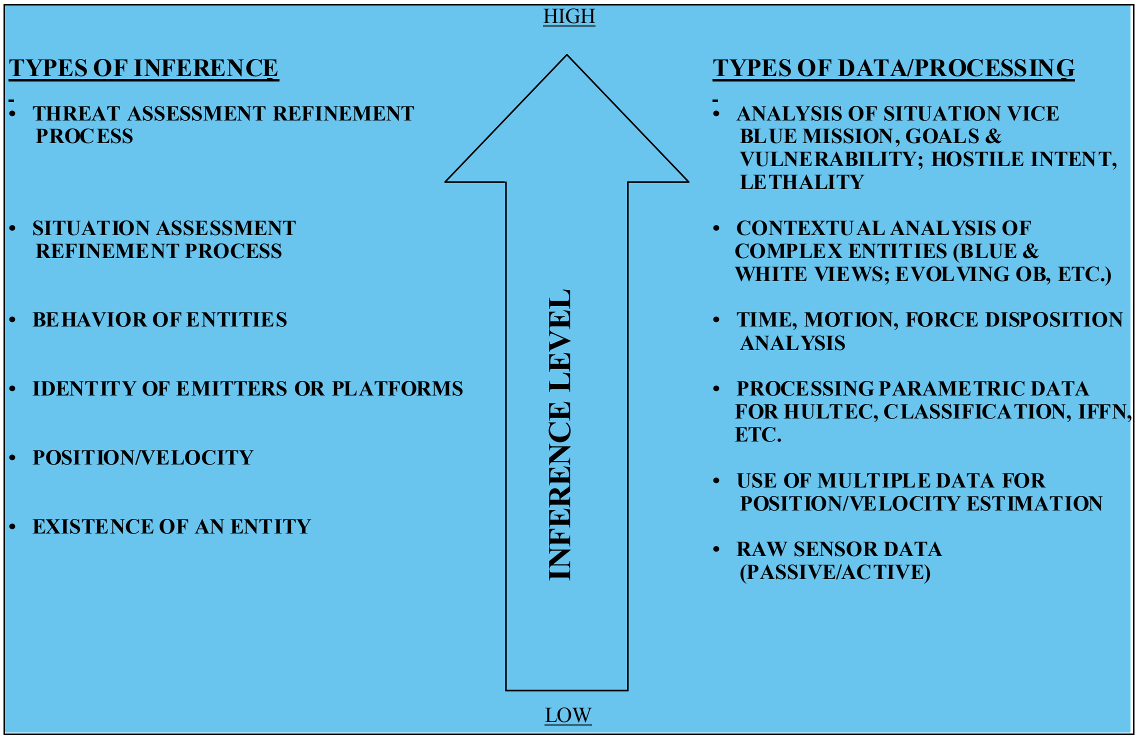


Figure 4.3. Hierarchy of data fusion inferences.

The process of data fusion is a natural extension or application of human cognition. In this context, data fusion is the desire to derive more information about a situation via combining than could be gleaned from the data separately. A number of approaches have been applied to the problem of data fusion, including decision theory, estimation theory, association, and uncertainty management. Other approaches exist, but these appear to be the most significant approaches.

Decision or detection theory is based on the ideas of Bayes. In this approach, measurements are compared with alternative hypotheses in an effort to determine the best match. The process is effective because of the ability to update estimates as more information is gathered on the target. Estimation theory is an extension of decision theory and finds its roots in statistical estimation methodologies. Basically, multiple measurements of a variable or parameter are executed, and estimates of the parameter are made based on these measurements.

Association is a method for dealing with multi-source information in a multi-sensor environment. In this situation, a resolution process must be undertaken in order to associate signal with source prior to making any kind of assessment. In this case, information is gathered, using the Bayesian technologies, in an effort to reduce uncertainty in a decision. This last approach is intended to operate in environments in which complete information is difficult or impossible to obtain.

4.1.3 Ontologies for Knowledge Management[80]

Military commanders at all levels and types of military organizations require timely and accurate situational awareness of the operating environment as well as prediction of likely intentions of the participants. The techniques being developed for data fusion and analysis in military decision support systems are becoming increasingly more sophisticated, particularly through the incorporation of algorithms for high-level decision-making processes. A fundamental component of these processes is a support database (or databases) containing *a priori* knowledge defining

- expected objects and entities within the operating environment,
- expected behaviors of these objects and entities, and
- specific relationships between different objects and entities.

Information sources supporting data fusion processes refer to different aspects such as political and geographical knowledge, platform/dismount characteristics, mission guidelines, weapon characteristics, corridors and flight paths, lethality, emitter characteristics, doctrine, etc.

Such a support database containing this relevant *a priori* knowledge is formally known as an *ontology*: a data model that represents a domain and is used to reason about the objects/entities within that domain and the relations between them. In general, ontologies describe

- *atoms*: the basic or "ground level" objects;
- *individuals*: the basic or "ground level" entities;
- *classes*: sets, collections, or types of objects or entities;
- *attributes*: properties, features, characteristics, or parameters that objects/entities can have and share;
- *relations*: ways that objects/entities can be related to one another.

Ontologies have received increasing interest in the computer science community and their benefits have been recognized in many areas such as knowledge management or electronic commerce. Experts agree that there are two essential components of any ontology:

- a *vocabulary of terms*, and
- a *specification of meaning* for these terms grounded in some form of logic.
- A fundamental distinction between different types of ontologies is the manner in which the necessary relationships among terms is specified. Finally, Figure 4.4 depicts a visual representation of a data ontology reflecting the political situation in Bosnia in the mid-1990's [81].

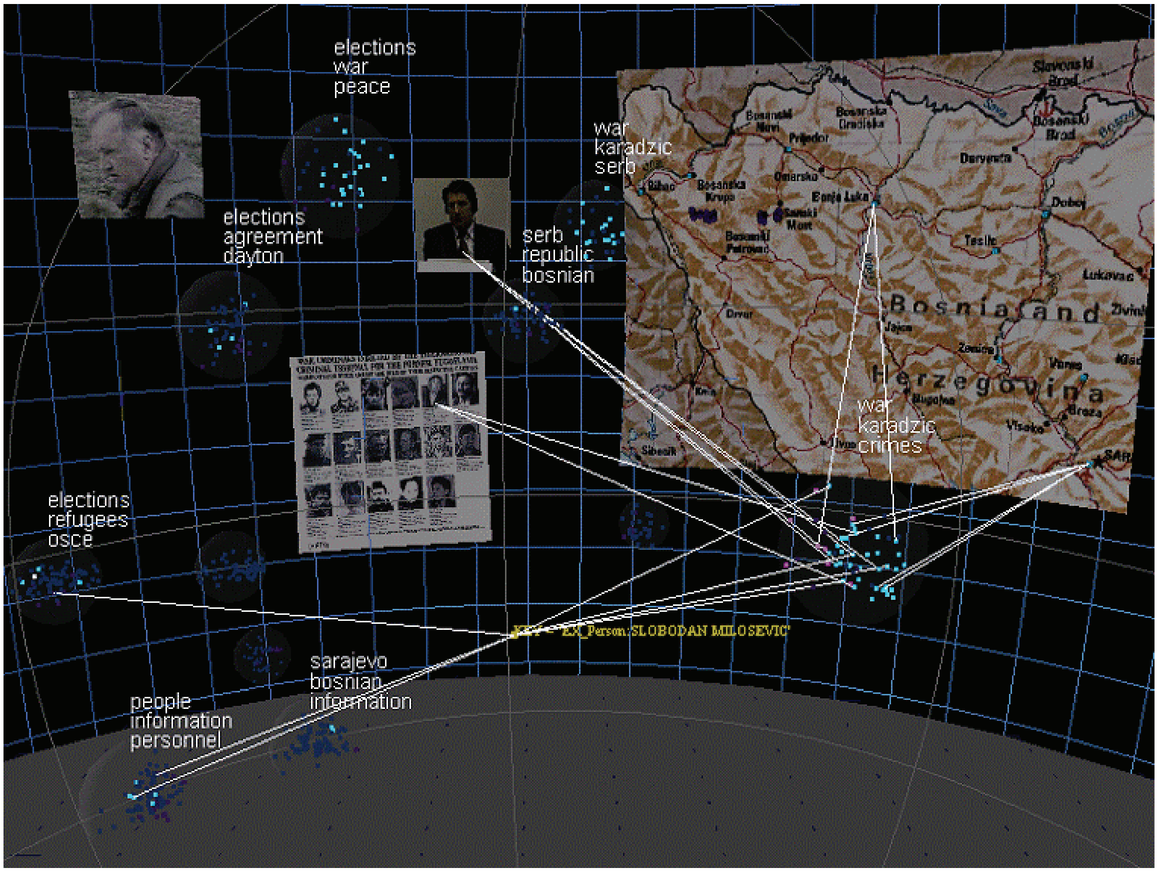


Figure 4.4. A data ontology provides a framework for concurrent information analysis.

In the artificial intelligence community, ontologies constitute the foundation for the design of knowledge-based systems. One of their main roles is to enable the building of knowledge models that can be reused in a wide range of applications. By doing so, they facilitate knowledge sharing and reuse. Moreover, ontologies facilitate information integration and interoperability between heterogeneous knowledge sources at a high level of abstraction. For example, Internet search engines use domain-specific ontologies to organize information and guide search processes.

Information integration from heterogeneous sources can be addressed at the structural, syntactic or semantic levels. In this context, ontologies are used to describe the semantics of the information sources in order to make their content explicit. Mechanisms are required to provide mappings between ontologies and to connect ontologies with information sources. There are several possible approaches to achieving information integration.

- *Single ontology approach*: One global ontology provides a shared vocabulary for the specification of the semantics. In this case, all information sources are related to the global domain ontology. The global ontology can be a combination of several ontologies.

- *Multiple ontologies approach*: the semantics of an information source is described by its own ontology. There is no common vocabulary, so inter-ontology mapping is needed to identify semantically corresponding terms of different source ontologies, taking into account different views within a domain (for example, different aggregation and granularity of the ontology concepts).
- *Hybrid approach*: information sources are described by local ontologies that are built from a global shared vocabulary that contains basic terms of a domain.

The *single ontology approach* is the simplest one. The drawback of the *multiple ontologies approach* is the lack of a common vocabulary that requires inter-ontology mapping. The advantage is that it facilitates the adding and removing of information sources more easily. The *hybrid approach* constitutes a good compromise.

The development of ontologies is a modeling activity that is complex and time-consuming. Therefore, methodologies have emerged based on experiences gained in the construction of large ontologies[82]. These aim at turning the development of ontologies into a formal engineering process. The main stages that can be derived from these methodologies consist of the following:

- definition of the requirements for the ontology: purpose and scope;
- building an informal specification of concepts;
- encoding: formal representation of the concepts and axioms in a language;
- evaluation of the ontology.

After determining the purpose and scope of the ontology, the next step in the process is to identify the most important concepts in the domain, build a lexicon for these terms, and then derive a comprehensive taxonomy of terms of the domain. The use of a mixed top-down and bottom-up approach to ontology development is recommended. The top-down mode may extend the definition of concepts from an existing upper-level ontology, i.e., establish links to upper-level categories that have already been defined within large ontologies (e.g., CYC) or relevant military models (e.g., NATO C2IEDM data model). The bottom-up approach adds more specific concepts from additional reference sources (e.g., glossaries, terminology or domain databases, etc.).

The semantics of new concepts within an ontology is specified through their definition, their properties, relations with other concepts, and eventually axioms that formally specify definitions and constraints of terms in the domain. Usually, an ontology is decomposed into sub-domains organized into different hierarchies of concepts. Top-level concepts being at the top of class hierarchies are sometimes called micro-theories (e.g., military equipment). An important aspect in the ontology development process is to explicitly establish relationships that exist between concepts. Some of the relations that can be defined between concepts are:

- relations that link a concept with more specific concepts (e.g., a UAV – unmanned aerial vehicle – *is a type of* robotic platform);
- relations that link a complex object to its constituents (e.g., a digital radio *contains* circuit cards, software, a power supply, and an antenna);
- Any variety of relations that should be specified.

These relations can be causal, functional, or temporal in nature (see Figure 4.5).

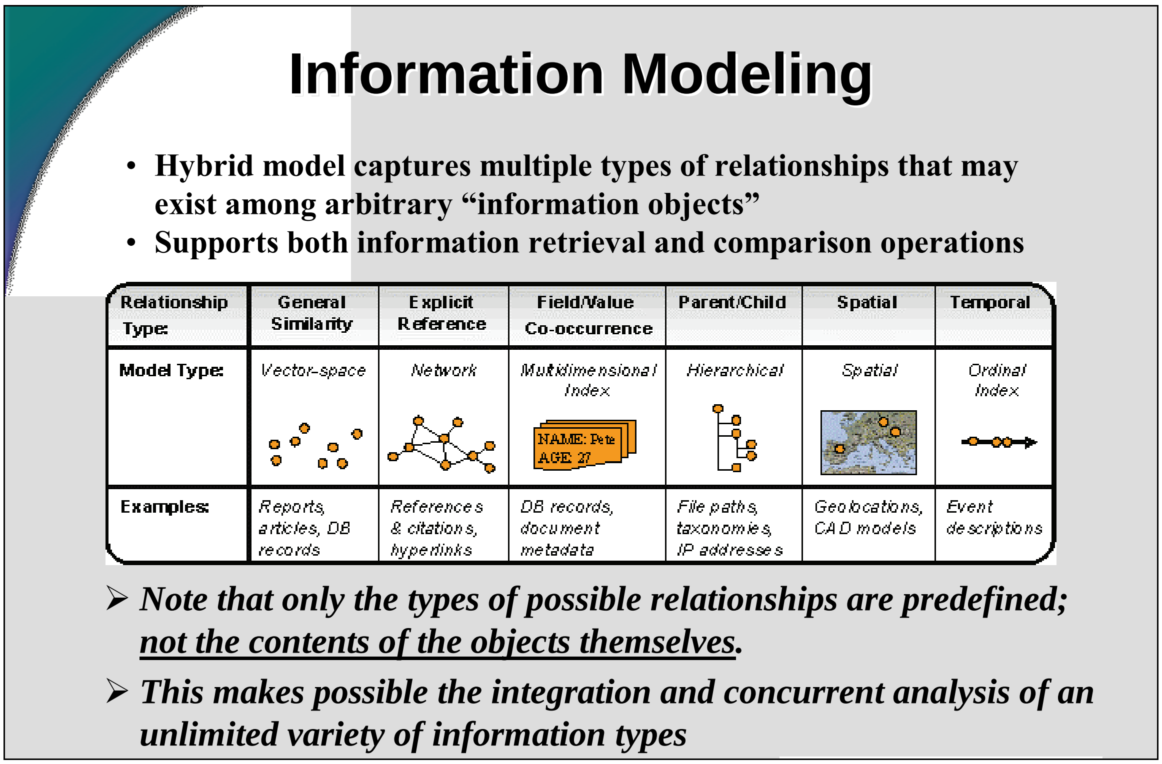


Figure 4.5. Data relationships within an ontology provide context.[83]

4.1.4 Types of Corrective Strategies for COA Adjustment[84]

(Course-of-Action)

Once operating environment data have been integrated and fused within a contextual ontology, there is still the inherent problem of uncertainty. We can characterize this uncertainty in terms of probability measures, but there are different types of uncertainty that are associated with such measures. There are temporal uncertainties, locational uncertainties, uncertainties in identities of sensed objects, and there are combinations of the three uncertainty types that can mix together. These uncertainties will greatly influence how a decision-maker both formulates and then adjusts COAs during different stages of a military mission.

There are three types of strategies for formulating and adjusting a COA.

- *Reactive*: once there is a problem (i.e., enemy attack resulting in friendly force losses, equipment failures due to intense operational tempo, etc.), how is it handled?
- *Anticipatory*: what are the procedures when we are expecting a problem?
- *Proactive*: given the current situation, what problems are likely to arise in the future (so that they can be prevented)?

Reactive strategies are typically cast as production rules (i.e., *if* a certain type of problem occurs, *then* we execute a specific response). Anticipatory strategies can also be cast as production rules combined with event expectation probabilities (e.g., we know with high confidence that somebody is going to attack our troop convoy – we *don't* know when and where exactly, but we are prepared for it and know what to do when it occurs). In a proactive strategy, models and simulations are created and run to create virtual future situations that can potentially evolve from a current situation. In this last approach, production rules and expectation probabilities are combined with a set of decision-making processes associated with entities within a simulated operating environment. Proactive strategies help identify the things that influence our decisions, as well as the actionably events—e.g., the things we can do. We can also "propagate forward" to see how well we're doing in reaching the desired outcomes, and test the outcomes' sensitivities to what happened at key spatial locations and points in future time along the way.

4.2 Data Fusion and Military Domain Ontologies

4.2.1 Existing Data Fusion Frameworks[85]

Measurements are taken which, when analyzed, enable decisions to be made based on condition. These measurements can produce data that are either very similar, often from the same sensor, or completely different from different techniques. Experienced engineers and analysts have traditionally undertaken the analysis of these data. However, with the increased computer power and development of new and novel detection systems, the data produced can be handled in a robust and logical manner. Analytical systems have been developed that are capable of extracting meaningful information from the recorded data.

Before undertaking a data fusion project, a strategy needs to be established that can facilitate the solution of the problem in a robust and organized manner. Since the applications of data fusion are disparate, it is impossible to build a one-fits-all framework. A number of data fusion frameworks have been developed both within the research and commercial environments. These frameworks have been used in numerous projects to aid the development of fusion systems by identifying the optimum solution set or algorithms. In the following sections, each of these data fusion frameworks will be described.

4.2.1.1 Joint Directors of Laboratories (JDL) Data Fusion Framework

One of the most widely used frameworks is the *JDL Data Fusion Framework*. The Joint Directors of Laboratories (JDL) data fusion sub-panel within the U.S. Department of Defense originally defined this system in the early years of data fusion. This framework was primarily developed to facilitate various military applications (and thus it should be of great interest in the area of Predictive and Preemptive Logistics). Llinas and Hall describe a number of levels at which data fusion could be undertaken[86]:

- *Fusion Level 0*: sub-object data association and estimation. This preliminary step works to associate sensor signal levels into a common, shared context. Numerical and statistical estimation techniques are frequently used at this stage.
- *Fusion Level 1*: object refinement, attempts to locate and identify objects. For this purpose, a global picture of the situation is reported by fusing the attributes of an object from multiple sources. The steps included at this stage are:
    - data alignment,
    - prediction of an entity's attributes (i.e., position, speed, type of damage, alert status, etc.), association of data to corresponding entities, and
    - refinement of a specific entity's identity.
- *Fusion Level 2*: situation assessment attempts to construct a picture from incomplete information provided by Fusion Level 1. In other words, an attempt is made to relate all reconstructed entities with an observed event (e.g., aircraft flying over hostile territory).
- *Fusion Level 3*: threat assessment interprets the results from Fusion Level 2 in terms of the possible opportunities for operation. An analysis is made of the advantages and disadvantages of taking one course of action over another.

A process refinement, sometimes referred to as Fusion Level 4, loops around these three levels to monitor performance, identify potential sources of information enhancement, and optimize allocation of sensors. Other ancillary support systems include a data management system for storage and retrieval of pre-processed data and human–computer interaction. The layout of the JDL process model is depicted in Figure 4.6.

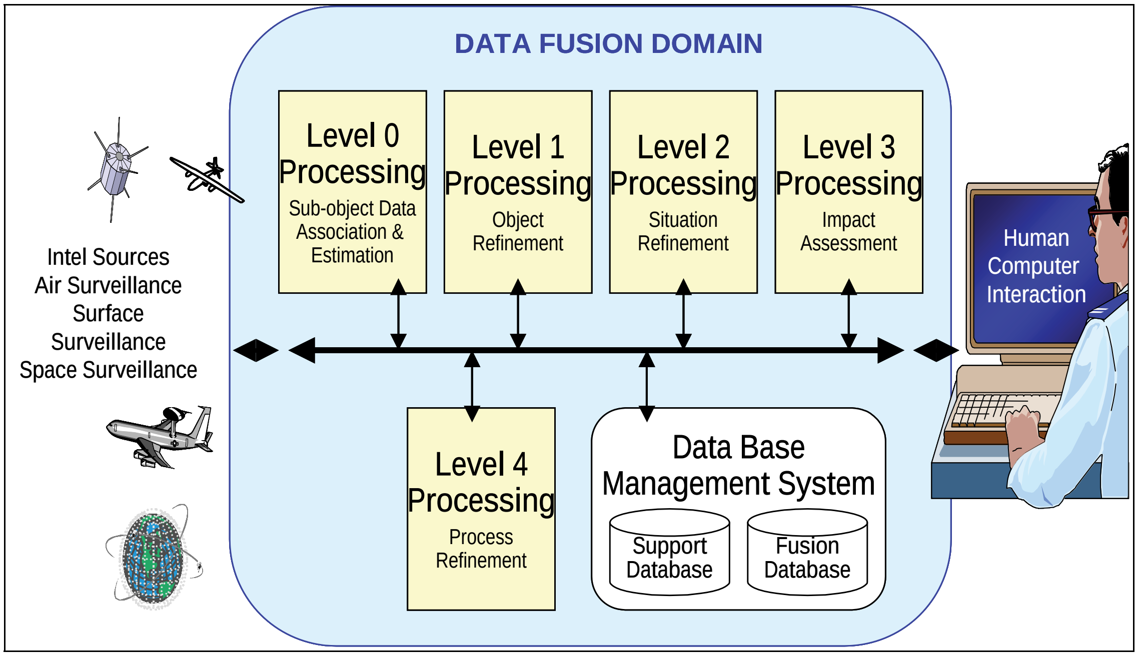


Figure 4.6. The JDL data fusion framework.

The hierarchical distribution of the JDL model allows for the different levels to be broken down into sub-levels. In this manner, Fusion Level 1 could be further divided into four processes: data alignment, data association, object estimation, and object identity.

- At the data alignment stage, the data are processed to attain a common spatial and time frame.
- The data association could be further divided as association performed among data units of the same variable and between data units of different variables. At this stage, the degree of proximity among the variables is measured.
- Object estimation, on the other hand, could be subdivided in terms of the processing approach taken (sequential or batch), parameter identification and estimate equations available, best-fit function criteria, and the optimization of best-fit function approach sought. At this stage the data fusion center estimates the object's position, velocity, or attributes.
- The object identity stage could be subdivided into feature extraction, identity declaration, and combination of identity declarations. At this stage, a prediction of the object's identity or classification is declared.

At each of these lowest sub-levels, the mapping of different types of techniques could be easily allocated, and selected according to the case at hand. Fusion can be performed on raw data in the fusion center (centralized process) or on pre-processed locally fused data (decentralized process). A hybrid data fusion system, consisting of the integration of both raw and pre-processed data, could also be considered. The combination of the first three JDL levels into a blackboard data structure has been proposed by Paradis[87]. This framework is further integrated with a process refinement via fusion agents, which act as fusion centers.

4.2.1.2 Thomopoulos Architecture

Thomopoulos proposed an architecture for data fusion consisting of three modules, each integrating data at different levels[88].

- *Signal level fusion*, where data correlation takes place through learning due to the lack of a mathematical model describing the phenomenon being measured.
- *Evidence level fusion*, where data are combined at different levels of inference based on a statistical model and the assessment required by the user (e.g., decision making or hypothesis testing).
- *Dynamics level fusion*, where the fusion of data is done with the aid of an existing mathematical model.

Depending upon the application, these levels of fusion can be implemented in a sequential manner or interchangeably. If continuous health monitoring of a military platform is the objective, the combination of data could be done at the signal level, while higher order fusion (e.g., evidence fusion) would need to be applied if a wide range of decisions needed to be made from the signals.

An illustration of the Thomopoulos architecture is presented in Figure 4.7. Thomopoulos stressed the point that any data fusion system should consider three essential criteria to achieve the desired performance.

- Monotonicity with respect to the fused information.
- Monotonicity with respect to the costs involved.
- Robustness with respect to any a-priori uncertainty.

In addition, factors such as the delay in the transmission of data, channel errors, and other communication aspects, described in chapter 3, as well as the spatial/temporal co-alignment of the data should also be taken into account in the data fusion system.

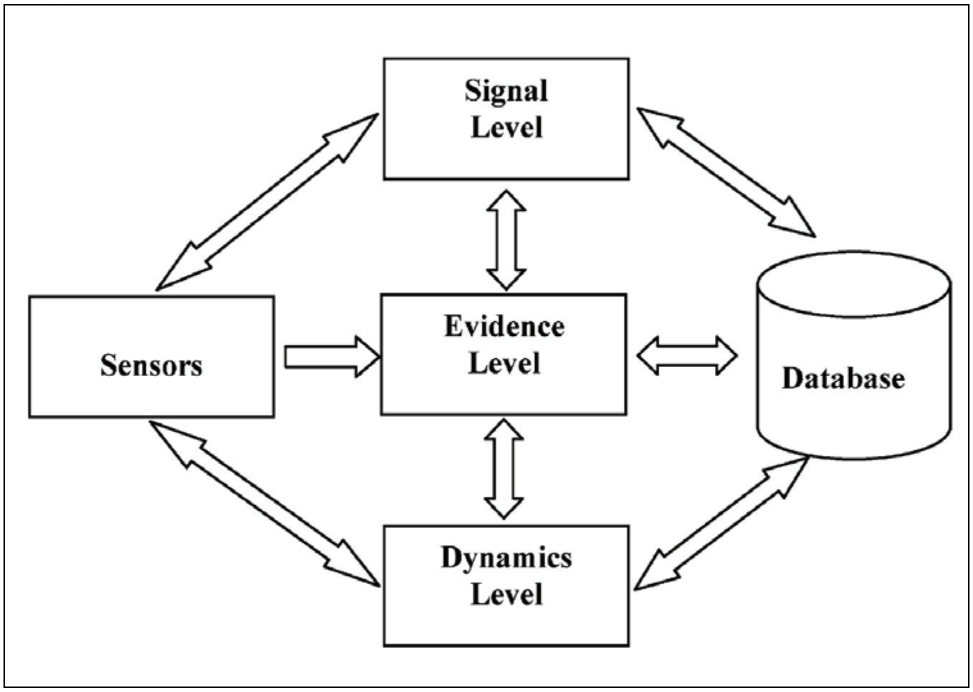


Figure 4.7. Thomopoulos' data fusion model.

4.2.1.3 Multi-Sensor Integration Model

Luo and Kay introduced a generic data fusion structure based on the concept of multi-sensor integration[89]. In this structure, data from various sources are combined within embedded fusion centers in a hierarchical arrangement. A clear distinction is made between *multi-sensor integration* and *multi-sensor fusion*; the former refers to the use of multiple–sensor information to assist in a particular task, while the latter refers to any stage in the fusion process where there is any actual combination of data.

Figure 4.8 portrays a diagram of Luo and Kay's framework representing simultaneous multi-sensor integration and fusion. As shown in the diagram, the data collected at sensors S_1, S_2, S_3, …, S_n (i.e., X_1, X_2, X_3, …, X_N, respectively) are transferred to the fusion centers, where the data fusion process takes place in a hierarchical and sequential manner (i.e., the fused data block iteratively grows according to the sequence $X_1 \rightarrow X_{1,2} \rightarrow X_{1,2,3} \rightarrow \ldots \rightarrow X_{1,2,3,\ldots,N}$). The entire framework shown in Figure 4.8 is a representation of multi-sensor integration. A description of the measured phenomenon is obtained after the outputs of sensors S_1 through S_n are processed with the aid of the information system whenever appropriate (where this information system is comprised of relevant databases and software libraries). Finally, as the information is combined at the different fusion centers, the level of representation needed is increased from the raw data or signal level (e.g., platform fuel level) to more abstract symbolic representations of the data (e.g., readiness of the platform to perform mission-oriented tasks).

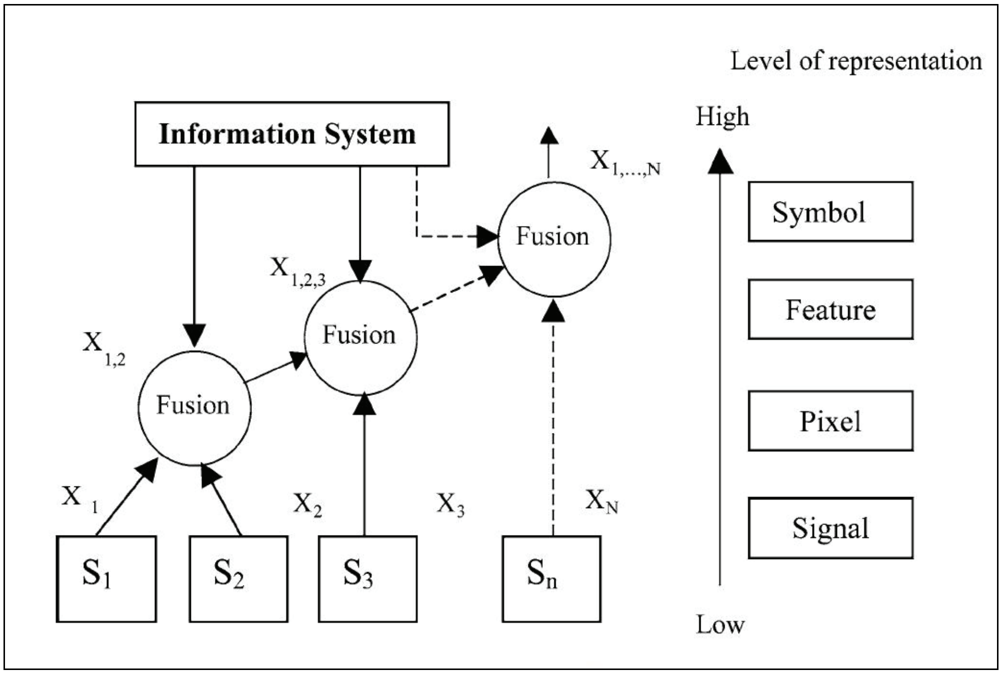


Figure 4.8. Luo and Kay's multi-sensor data integration architecture.

4.2.1.4 Waterfall Model

Another example of a hierarchical architecture commonly used by the data fusion community is the *Waterfall model*[90]. A representation of this model is shown in Figure 4.9. It can be seen from this figure that the "flow" of data cycles from the sensor level up to the decision-making level and then back. This means that the sensor system is continuously updated with feedback information arriving from the decision-making module. The feedback element controls and guides the multi-sensor system on issues of sensor recalibration, sensor reconfiguration, and data gathering.

There are three levels of representation in the Waterfall model, as shown in Figure 4.9.

- At level 1, the raw data are properly transformed to provide the required information about the environment. To achieve this task, computational models of the sensors and (whenever possible) of the measured phenomena are necessary. These models could be based on experimental analysis or on physical laws.
- Level 2 is composed of feature extraction and fusion of these features. These processes are executed to obtain a symbolic level of inference about the data, where the goal is to minimize data content while maximizing information delivered. The output of this level is a list of estimated situational conditions with associated probabilities.
- Level 3 relates objects to events. Possible courses of action are assembled according to the information that has been gathered, the libraries and databases available, and the degree of observed human interaction.

It should be noted that while the Waterfall model places primary emphasis on data processing at the lower levels (i.e., Level 1 and Level 2 in Figure 4.9), the feedback controller connecting Level 3 with Level 1 is not explicitly defined in the model.

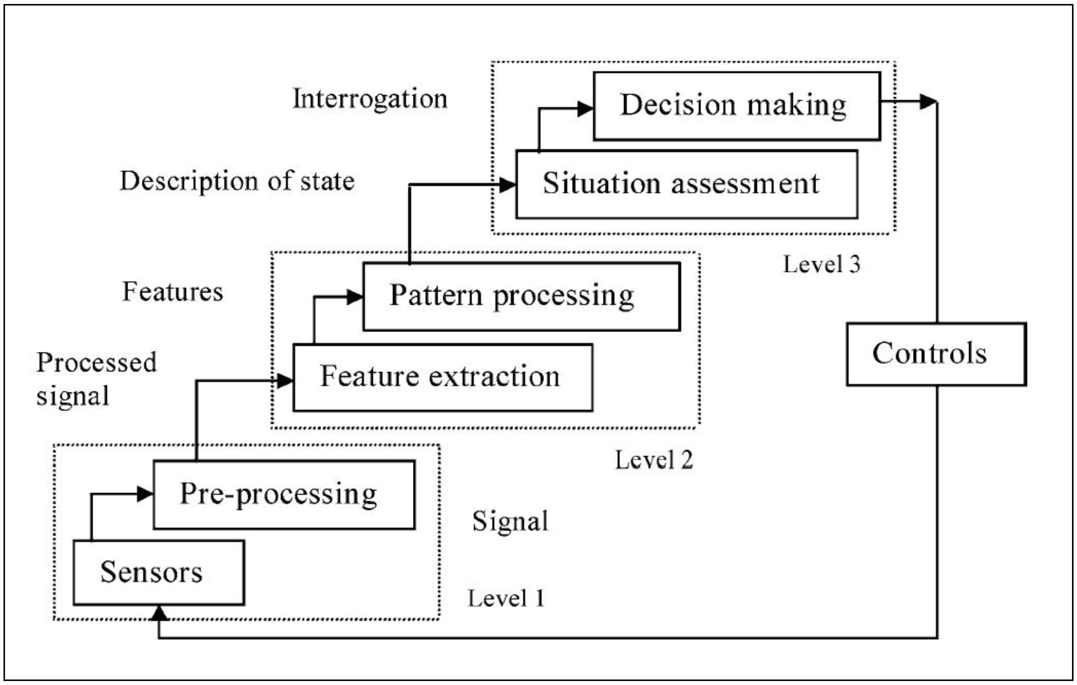


Figure 4.9. Harris's waterfall data fusion model.

4.2.1.5 Behavioral Knowledge-Based Fusion Model

Pau describes another type of data fusion framework based upon a behavioral knowledge formalism[91]. It can be seen from Figure 4.10 that the framework consists of a number of basic fusion stages that must be completed before the overall output is established. A feature vector is first extracted from the raw data collected by sensors $S_1, S_2, S_3, \ldots, S_n$. This vector is then aligned and associated to predefined features of expected objects and entities within the operating environment. Fusion is then undertaken at the sensor attribute and data analysis levels. The final step is the generation of a set of behavioral rules, which can be extracted in terms of the final representation of the fused output.

Rather than assuming the blackboard architecture[11] typically found in knowledge-based systems, this process model uses a hierarchical approach containing three levels of representation.

- The lowest level contains, for each sensor $S_1, S_2, S_3, \ldots, S_n$, a vector space with coordinate dimensions and measured parameters.
- The next level extracts relevant features from these vectors, and attaches labels to them.

[11] In this context, a blackboard represents a software-based knowledge system's beliefs about a specific domain of interest. In the military domain, the blackboard typically contains information about sightings and hypothesized locations of enemy combat units, locations of mission-relevant terrain, and hypotheses concerning enemy tactics and strategy.

- The third level contains a set of formal rules about the operating environment that relate feature vectors to specific events.

This type of data fusion model is frequently used in the field of human detection and identification (e.g., intelligent buildings, security control, monitoring).

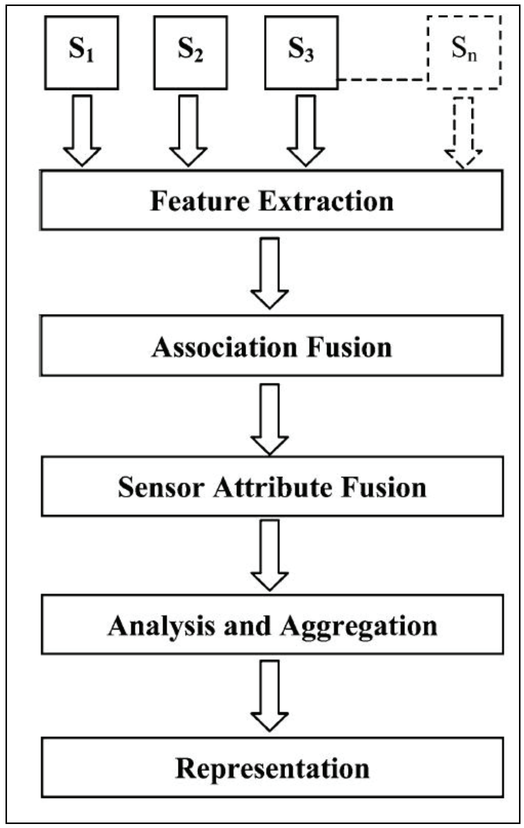


Figure 4.10. Pau's sensor data fusion process.

4.2.1.6 Distributed Blackboard Fusion Architecture

Schoess and Castore describe the distributed blackboard data fusion model, a simple example of which is depicted in Figure 4.11[92]. In this example of the model, the sensors S_1 and S_2 are each connected to a set of transducers T_1, T_2, T_3, …, T_n (where a *transducer* can be broadly defined as any device that converts a signal from one form to another). These sensors also have a supervisory controller that resolves how conflicting sensor measurements are handled by the data fusion system. This controller is often based upon confidence levels assigned to each sensor. The set of transducers are used to acquire as much information as possible from the physical system under analysis (e.g., engine temperature, fuel level, etc.). The fusion algorithm produces a value F, which is dependent upon the data available to the two sensors. Confidence in the measurements is assigned to each of the sensor readings by the supervisory controllers. In the example, confidence levels C_1 and C_2 are assigned to sensor/transducer value pairs (S_1, T_1) and (S_2, T_2), respectively. Then, a production rule (i.e., IF → THEN → ELSE) using these data is defined and stored in the shared memory that assigns a value to *F*. This method could be defined as a database that contains sensory information and operates the communication channels available among the knowledge sources.

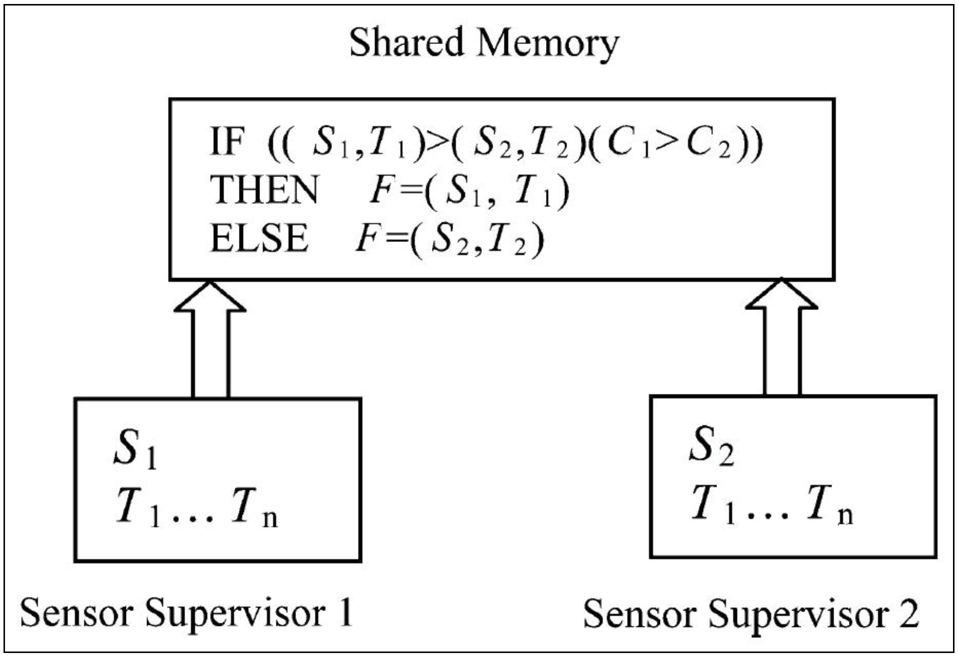


Figure 4.11. The distributed blackboard fusion architecture.

4.2.1.7 Omnibus Fusion Model

Bedworth and O'Brien describe another data fusion framework called the Omnibus model[93]. This framework is a hybrid of Boyd's OODA loop (see section 3.1.1) and the Waterfall data fusion model (see section 4.2.1.4). Figure 4.12 illustrates the general layout of this framework, which consists of four primary modules. These modules are used to address the various tasks in data fusion and its functional objectives. Note that the Omnibus model combines the iterative OODA process with the three basic levels of data fusion: data, feature, and decision.

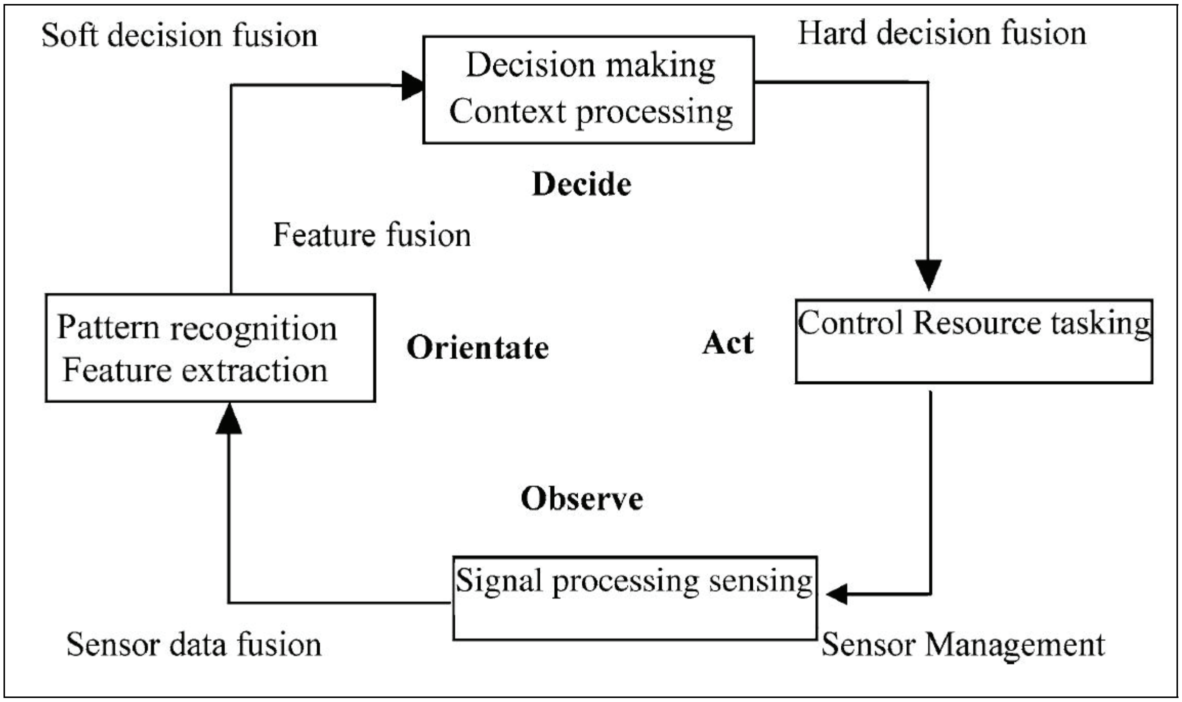


Figure 4.12. The Omnibus data fusion model.

4.2.2 Formal Concept Analysis and Partially-Ordered Sets

Formal concept analysis is a method of data analysis that takes an input matrix specifying a set of objects and the properties thereof, and finds all the "natural" clusters of *attributes* or properties and all the "natural" clusters of *objects* in the input data, where

- an object cluster is the set of all objects that share a common subset of attributes, and
- an attribute cluster is the set of all properties shared by one of the object clusters.

Attribute clusters correspond one-for-one with object clusters, and a *concept* is a pair containing both an attribute cluster and its corresponding object cluster. The family of these concepts obeys the mathematical axioms defining a lattice, and is thus called a *concept lattice*. As we will demonstrate, formal concept analysis provides a very powerful methodology to facilitate the construction of data ontologies.

From a philosophical point of view, a concept is a unit of thoughts consisting of two parts, the extension and the intension. The extension covers all objects belonging to this concept, while the intension comprises all attributes valid for all those objects (Wagner 1973). Hence, objects and attributes play a prominent role together with several relations (e.g., the hierarchical "subconcept-superconcept" relation between concepts, the implication between attributes, and the incidence relation "an object has an attribute.")

It was the idea of Wille[94] to combine objects, attributes and the incidence relation in a mathematical definition of a formal context as a tool for the description of those very elementary linguistic statements of the form “an object *X* has an attribute *Y*.” The second and crucial step was then the definition of a formal concept for a given formal context. We describe this using the following example.

Table 4.1 describes, for a simple set of consumer types, which of a second set of supplies a particular consumer type is required to support its continued functionality. In this table, consumer types (i.e., objects) are listed in the left-most column, while consumables (i.e., attributes) are listed in the top row. Then, the statement “a consumer type *X* requires the consumable *Y*” is encoded by the presence of a cross within the table cell (consumer, consumable). An empty cell in the table indicates that the corresponding object doesn’t have the corresponding attribute. In other examples, an empty cell might also mean that it is not known whether this object has the attribute or not.

Table 4.1. A formal context of consumers.

	Fuel	**Water**	**Food**	**Electricity**
Vehicle	X	X		X
Human		X	X	
Computer				X

A table of crosses represents a very simple and often used data type. The mathematical structure that is used to formally describe these tables of crosses is called a *formal context* (or, more concisely, a *context*). To explain the notion of a formal concept of a context, we look at the attributes of the object “human,” and then ask for all objects (of this context) which of them share one or more of the attributes of a human consumer. Hence we get the set Φ consisting of “human” and “vehicle.” This set Φ of objects is closely connected to the set ψ consisting of the single attribute “water”: Φ is the set of all objects having all the attributes of ψ, and ψ is the set of all attributes which are valid for all the objects of Φ. Each such pair (Φ, ψ) is called a *formal concept* (or more simply a *concept*) of the given context. The sets Φ and ψ are called the *extent* and *intent* of the concept (Φ, ψ). Within the context of consumers shown in table 4.1 the pair (Φ, ψ) serves to efficiently encode the relational information “both vehicles and humans require water in order to maintain functionality.”

It must be noted that the extent of a concept determines the intent and the intent determines the extent. Hence, the notion of a formal concept contains some redundant information. This is very useful since one can choose which of both parts of the concept should be used in a given situation. Between the concepts of a given context there is a natural hierarchical order, the “sub-concept/super-concept” relation. Referring back to table 3.1, we can see that the encoded statement “a human requires water” describes a sub-concept of the concept “a human requires both food and water.” The extent of this sub-concept consists of “human consumer,” while the intent consists only of the attribute “water.” However, while the extent of the given super-concept again consists of “human consumer,” the intent consists of the consumable types “food” *and* "water." In general a concept β is a sub-concept of a concept α (and α is called a super-concept of β) if the extent of β is a subset of the extent of α (or equivalently, if the intent of β is a superset of the intent of α).

A *concept lattice* is a directed graph (or *digraph*) that indicates, for a particular formal context, which concepts are strict sub-concepts of which other concepts. The nodal ordering in this type of lattice is such that an attribute (a gray box) is associated with an object (a white box) if there is a solid arc linking the attribute downward to a subordinate object. Or, more formally:

- an object *g* has an attribute *m* if and only if there is an upwards-leading path from the graph node identified as "*g*" to the node identified as "*m*."

Figure 4.13 presents a concept lattice representation of the formal context *consumers*. In this representation, objects (consumers) are associated with the lower black half of two-color blue/black nodes (which themselves represent a zero-length arc between one-or-more objects and one-or-more attributes). On the other hand, attributes (consumables) are associated with either i) the upper blue half of blue/black nodes or ii) small circular nodes that lack associated objects. For example, the concept "a vehicle requires fuel, water, and electricity" has the extent "vehicle" and the intent "fuel, water, and electricity." This can be read directly from the concept lattice by first noting the clustering of "vehicle" and "fuel" at the lower right-hand blue/black node, then tracing upward arcs to the upper right-hand blue/black node and the small node on the upper left-hand side. We can also extract the concept "a human requires food and water" from the lattice in a similar arc-tracing fashion. Note that we *cannot* extract the false concept "a human requires food, water, *and* electricity" due to the lack of a continuous upward-leading path from the lower left-hand node to the upper right-hand node. Finally, the small empty nodes at the top and bottom of the graph are present in order to create a fully connected lattice (although they convey no information in this context).

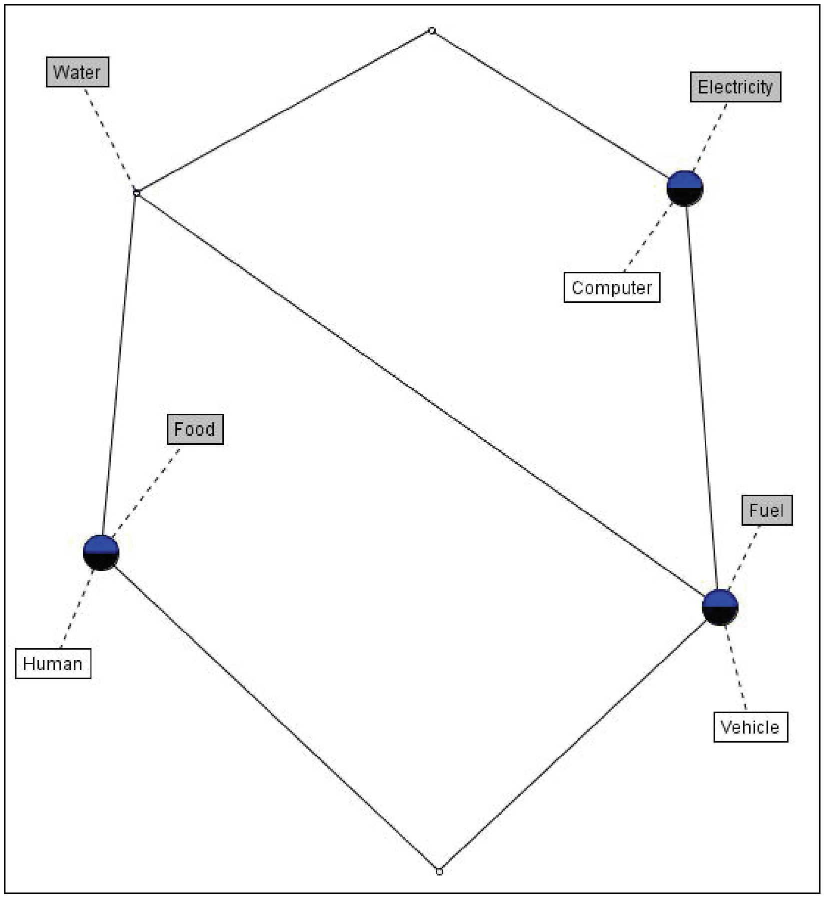


Figure 4.13. Concept lattice displaying the formal context of consumers.

Formal concept analysis is also very applicable to graphical categorization of operating environment data. As an example, table 4.2 presents the (object, attribute) incidence matrix for a formal context representation of U.S. Army vehicle types. Within this context are five objects representing vehicle types: a notional micro-scale unmanned aerial vehicle (Micro UAV), a small unmanned ground vehicle (SUGV), an armed reconnaissance vehicle (ARV), a Black Hawk helicopter, and a manned combat system (MCS). There are also six attributes that describe vehicle categories in an either/or fashion: airborne versus ground-based, manned versus robotic, and "lightweight" versus "heavy." Figure 4.14 depicts the concept lattice that emerges from this context of vehicles. Here, two-color white/black nodes are associated only with objects (vehicles) while attributes (categories) are again associated with small nodes. As before, an attribute is associated with an object if there is a solid arc linking the attribute downward to a subordinate object. Note that this figure is a 2D representation of a 3D lattice, so that crossing arcs do not actually intersect except at the aforementioned small nodes.

Table 4.2. A formal context of U.S. Army vehicles.

	Airborne	Ground-ba…	Manned	Robotic	“Lightweig…	“Heavy”
Micro UAV	X			X	X	
SUGV		X		X	X	
ARV		X		X		X
Black Hawk	X		X			X
MCS		X	X			X

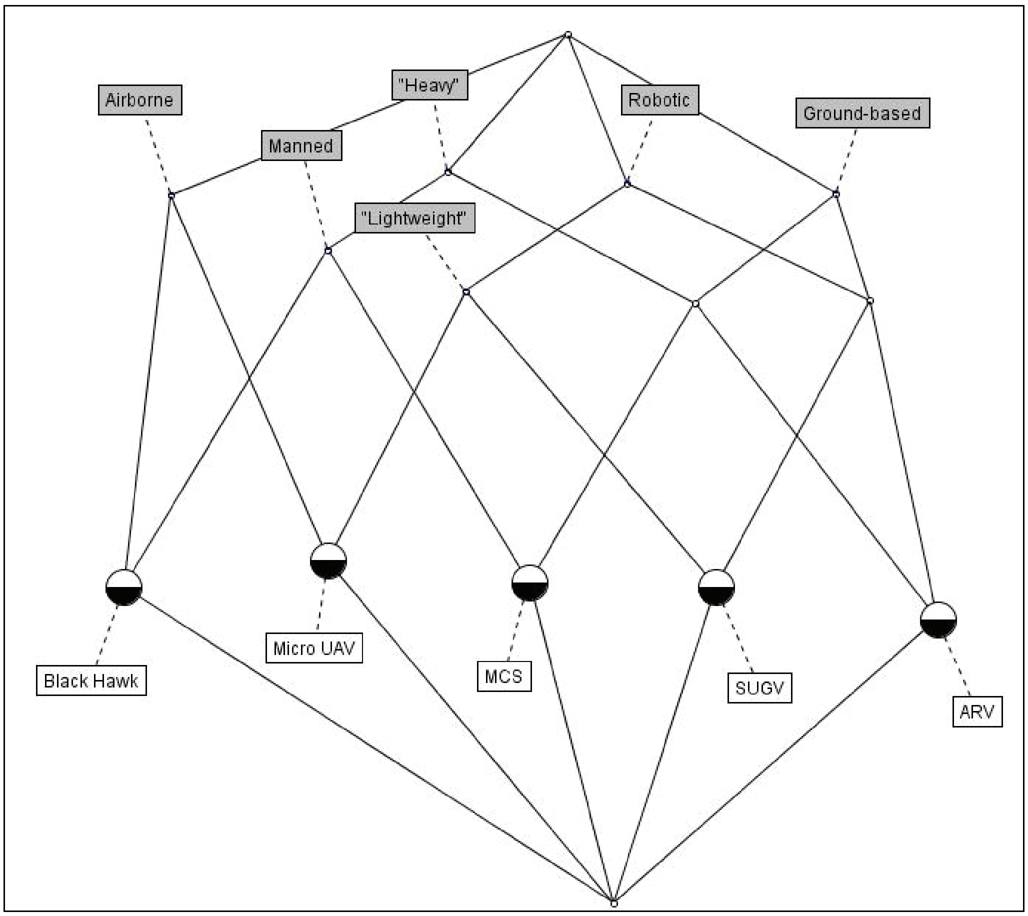


Figure 4.14. Concept lattice displaying the formal context of U.S. Army vehicles.

What is immediately striking about the concept lattice in Figure 4.14 is the obvious categorical separation between the five concepts depicted in the graph. In other words, each of the five white/black nodes in the lattice has exactly one associated vehicle type *and* a unique set of category memberships.

- The Micro UAV is i) airborne, ii) robotic, and iii) “lightweight.”
- The SUGV is i) ground-based, ii) robotic, and iii) “lightweight.”

- The ARV is i) ground-based, ii) robotic, and iii) "heavy."
- The Black Hawk helicopter is i) airborne, ii) manned, and iii) "heavy."
- The MCS is i) ground-based, ii) manned, and iii) "heavy."

In this case, there are no instances of sub-concept/super-concept relations between any of the five concepts described in the above bullets. From a logistical planning perspective, this might indicate the existence of a maximally-complex situation given five possible vehicle types that can be partitioned according to these six categories.

To illustratively confirm the categorical separation in the first example of a vehicle context, an incidence matrix and concept lattice associated with a counter-example are next presented in table 4.3 and Figure 4.15, respectively. In this revised U.S. Army vehicles context, the vehicle types Micro UAV, SUGV, and ARV have been replaced with Stryker, Longbow Apache, and non-line-of-sight (NLOS) Cannon. Inspection of the data in table 4.3 readily indicates that all vehicle types in this revised context are both "manned" and "heavy," and that only their airborne versus ground-based natures serve to differentiate them. This same information is graphically encoded in Figure 4.15, where a quick visual inspection can efficiently reveal to the potential logistics planner the bi-modal categorical nature of the associated concepts. Finally, note that the category attributes "robotic" and "lightweight" are attached to the bottom-most node since these categories are unused in this revised vehicle context (i.e., there are no subordinate objects that are either robotic or lightweight).

Table 4.3. An alternate context of U.S. Army vehicles.

	Airborne	Ground-ba…	Manned	Robotic	"Lightweig…	"Heavy"
Stryker		X	X			X
Longbow A…	X		X			X
NLOS Can…		X	X			X
Black Hawk	X		X			X
MCS		X	X			X

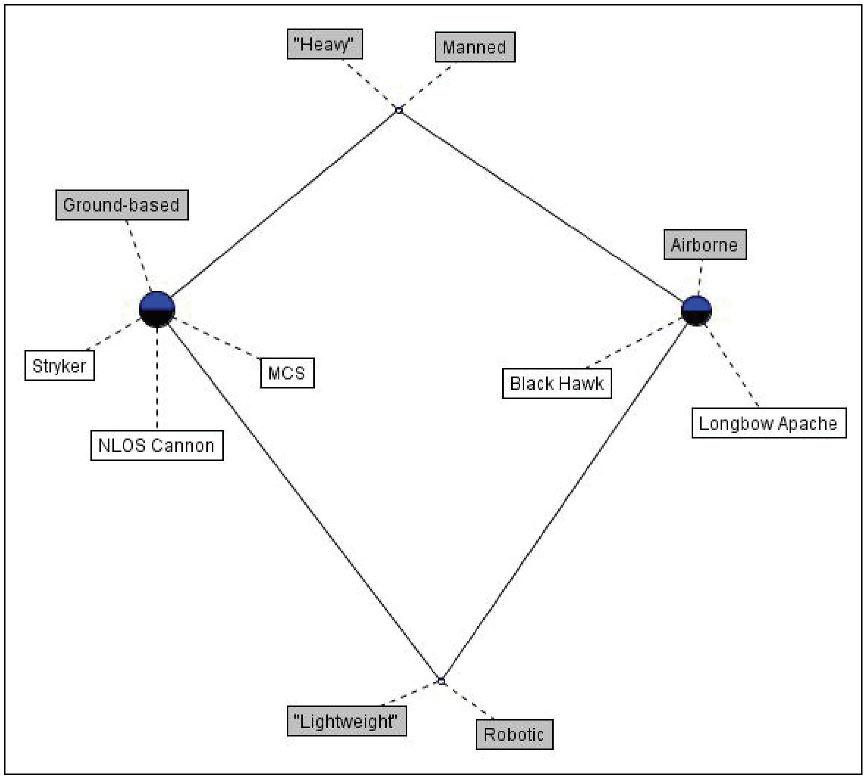


Figure 4.15. Concept lattice displaying an alternate context of U.S. Army vehicles.

In mathematics, especially order theory, a *partially ordered set* (or *poset*) is a set equipped with a partial order relation. This relation formalizes the intuitive concept of an ordering, sequencing, or arrangement of the set's elements. Such an ordering does not necessarily need to be total, that is, it need not guarantee the mutual comparability of all objects in the set, but it can be. (In mathematical usage, a total order is a kind of partial order.) A poset defines a poset topology.

4.2.3 Renormalization Group Theory

The renormalization group is a formalism for studying the scaling properties of a system. It starts by assuming a set of equations or rules that describe the behavior of a system. We then change the characteristic length and time scales at which we are describing the system. In other words, we "coarse grain" the granularity of our system behavior model by losing some of the micro-details. At the new scale, we assume the same set of equations or rules can be applied, but with different scaling coefficients. The objective is to relate the equations/rules at the finer scale to the equations/rules at the coarser scale. Once this is done, the scale-dependent properties of the system under analysis can be inferred[95].

4.3 COA Simulation and Analysis

4.3.1 Missions & Means Framework and Application to Decision Theory & Practice

4.3.1.1 Fundamental Concepts[96]

A disciplined procedure is required to explicitly specify the mission, allocate means, and assess mission accomplishment. In a procedural sense, the connection between a military mission with the means required for its execution is formally expressed via the *mission-to-materiel trace* (Figure 4.16). Using this process, a warfighter designing a mission can describe (i) how a particular mission is comprised of tasks (assigned to units, platforms, and dismounts), (ii) how each task is enabled by a set of one or more capabilities, and finally (iii) how each capability is supplied by the functioning of a set of materiel elements or components. Once the mission has been designed, the mission-to-materiel trace can also describe (i) how materiel elements/components collectively provide capabilities, (ii) how capabilities collectively provide a means to perform tasks, and finally (iii) how tasks collectively provide a means to accomplish the intended mission. Once a set of capabilities is proven to exist, the warfighter knows which tasks are enabled and which materiel properly contributes to mission success. Additionally, knowing the standards to which tasks must be accomplished assists in driving appropriate performance requirements to ensure that materiel provides capabilities in an operationally realistic environment.

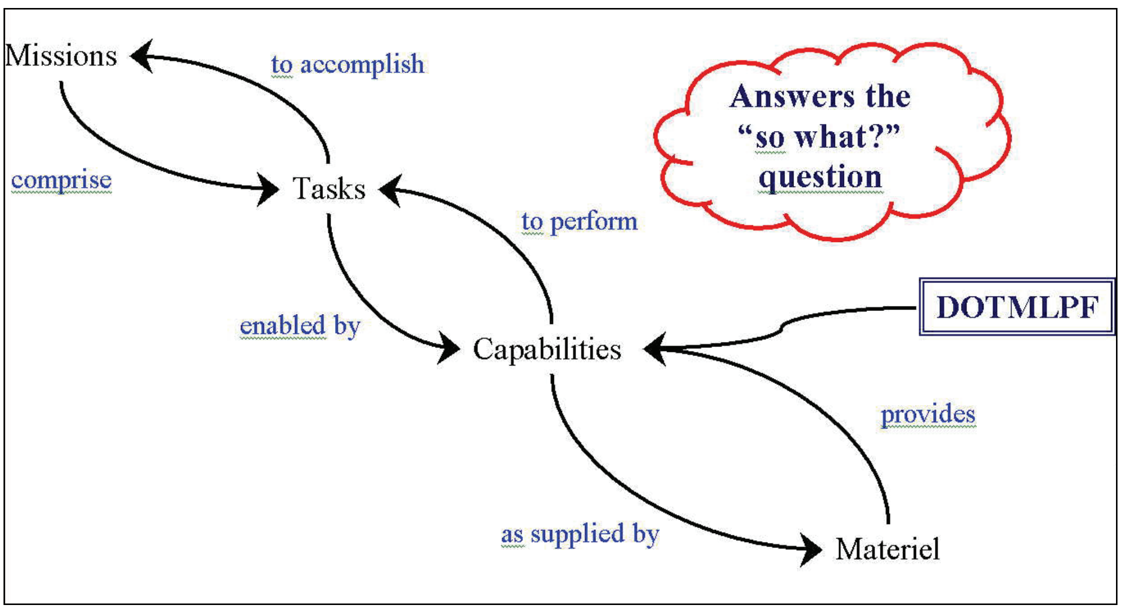


Figure 4.16. The mission-to-materiel trace that associates the mission-to-task decomposition process with supporting capabilities and materiel.

In a doctrinal sense, the association of a military mission with the means required for its execution is expressed via Tactics, Techniques, and Procedures (TTP). Historically, these TTP will evolve from limited operational testing as new military technology becomes available.

Testing and experimentation conducted in a constructive or virtual environment (or even in some combination with a live environment) do not fully explore possible TTP. Most, if not all, training and testing events are artificially constrained such that partial degradation of platforms or systems is unaccounted for. The determination of aggregated capability status is most often based solely on the complete loss of platforms or systems, with remaining systems treated as though available capability always equals full capability. If one is trying to evaluate and assess the contribution of components/platforms/systems/systems-of-systems to mission accomplishment in the context of an operational scenario, then it is essential to be able to model elements of degraded capability of selected platforms/systems and relate the impact of the reduced capability through affected tasks to operations and ultimately the mission.

Once the process of combat adjudication has commenced, it is useful to associate the mission-to-materiel trace with the logical structure that has evolved in the domain of ballistic survivability (and dually, lethality) analysis of materiel. Developed in the mid/late 1980's by Deitz and others[97,98], the so-called *Vulnerability/Lethality (V/L) Taxonomy* addressed a previous generation of longstanding methodological shortcomings (Figure 4.17). This V/L Taxonomy formally defines the elements of the V/L analysis process as a set of four spaces (and the inter-spatial mappings that serve to connect points between them): (1) specification of the interaction conditions between combat entities, (2) post-interaction functional status of materiel/components, (3) system capability status resultant from materiel/component functional status, and (4) task-success status resultant from a system's capability readiness to execute the task. Finally, by combining and integrating the complementary processes that make up the mission-to-materiel trace and the V/L Taxonomy, we logically arrive at the *Missions and Means Framework* (MMF): a methodology for explicitly specifying a military mission and for quantitatively evaluating the mission utility of alternative warfighting DOTMLPF services/products.

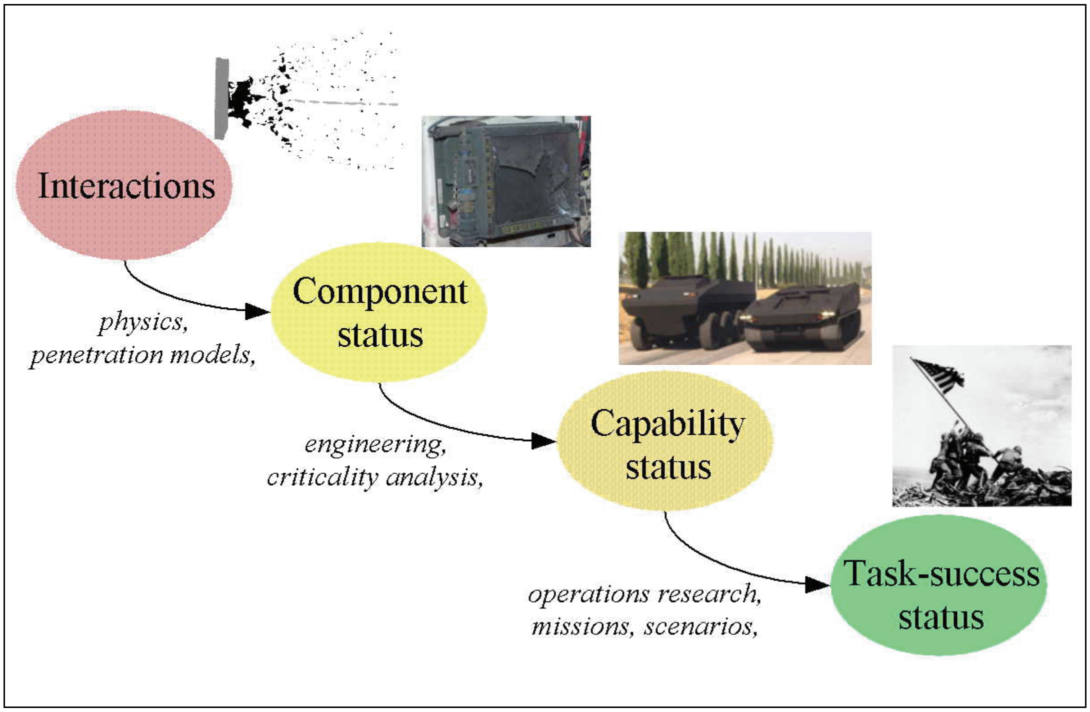


Figure 4.17. The vulnerability/lethality (V/L) taxonomy.

Figure 4.18 illustrates the elements that collectively define the MMF. To specify the mission, the MMF first employs a top-down *planning* process (i.e., the dashed blue arrows in the figure) that begins with an analysis of the operational mission to be performed by the system or the system-of-systems under study. The analysis results in the identification of key elements at several levels. They are:

- *Level 7* – the task, purpose and desired end state of the mission;
- *Level 6* – the operational context (i.e., civil/political, military, and environmental conditions) within which the mission is to be conducted;
- *Level 5* – the space/time index within which the mission is conducted (i.e., the interval of time extending from the initial road-to-war to the conclusion of all operating environment activities);
- *Level 4* – the operations and tasks that must be performed in order to accomplish the mission;
- *Level 3* – the capabilities and functions that contribute to the successful performance of the operations and tasks identified above;
- *Level 2* – the materiel/components that deliver the associated functions and capabilities identified above;
- *Level 1* – the interactions that must be generated in order to achieve the desired effects.

Ideally, this planning process results in an executable *mission thread* of task/component combinations that are sequenced and inter-related from the planned start of the mission to its successful completion (achieving the desired end state). These mission threads represent a model of the warfighter's concept of the operation and/or concept of support that would normally be captured in the form of an execution or synchronization matrix. Finally, it must be critically noted that the planning of mission threads within the MMF is a dual process, with BLUFOR mission planning competitively counter-balanced by OPFOR planning.

To execute and assess the mission threads, the MMF also provides for a bottom-up *employment* process (i.e., the solid red arrows in Figure 4.18) that complements the top-down planning process. This second MMF process facilitates combat adjudication once mission threads have been configured for all battlefield entities, resulting in the observation and capture of information at five different levels. This level-specific information is:

- *Level 1* – interactions between operating environment entities (combatants, logistics support, and indigenous noncombatants if present) and the resulting effects achieved;
- *Level 2* – state changes in components and forces resulting from these interactions;
- *Level 3* – residual levels of function and capability available to operating environment entities as a result of changes in component/force state;
- *Level 4* – follow-on task/capability pairing selected by comparing the perceived effects achieved to those desired and comparing the required capabilities to those perceived available;
- *Level 7* – comparison of perceived operating environment conditions to desired mission end state.

Once key information residing in Levels 4 and 7 is assessed by a force commander, the MMF employment process finally produces the critical $O_{4,1}$ mapping for all operating environment entities. This mapping is a decision-making process (DMP) that guides an entity towards execution of subsequent interactions with other entities within the operating environment. Finally, as with mission planning, it must be noted that the employment of mission threads within the MMF is a dual process, with BLUFOR employment again competitively counter-balanced by OPFOR employment.

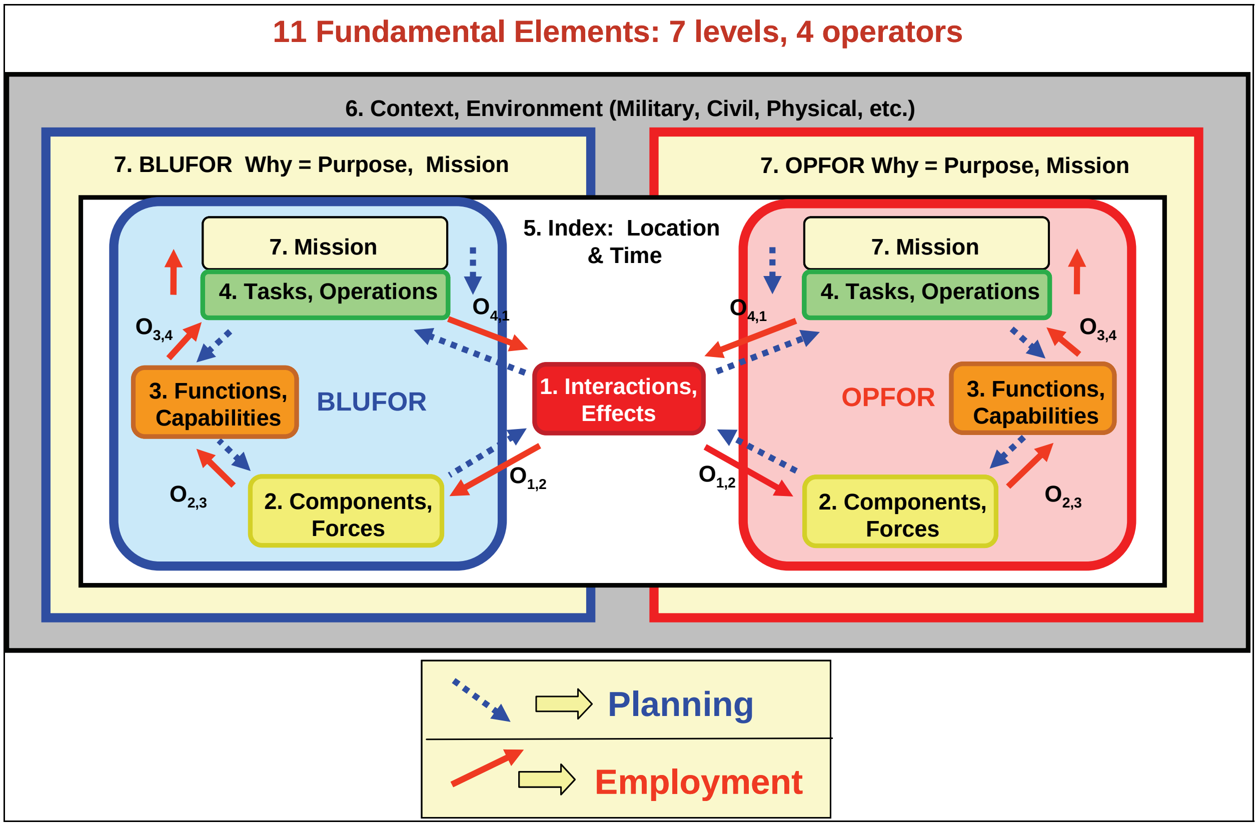


Figure 4.18. Two-sided MMF model of interactions between entities within an operating environment.

The two–sided MMF provides a structured way to describe key elements of military operations that are essential to understand in order to successfully model and simulate those operations. The framework provides the necessary structure to support a disciplined, repeatable procedure to explicitly specify the mission and assess mission accomplishment. Because tasks, which are the building blocks of missions, are pulled from authoritative sources such as the Army Unified Task List (AUTL) and the Universal Joint Task List (UJTL) (Joint Chiefs of Staff 2002), commonly accepted terminology and definitions are built into the framework methodology. Components, which represent the means used to execute tasks, are similarly derived from authoritative sources. Further, task lists such as the UJTL are deliberately designed to facilitate the ability to associate mission specific conditions and standards. Conditions and standards for specific tasks are established based on the results of mission analysis and course of action (COA)[99] development and wargaming during the planning process. These standards may be structured to provide quantitative metrics in the form of measures of performance (MOPs) that describe system functions relative to minimum acceptable levels of capabilities in terms of time, distance, accuracy, etc. Standards may also be structured to provide more qualitative metrics in the form of measures of effectiveness (MOEs) that describe the success of current task performance relative to the desired end state or purpose of the task as specified by the commander in his statement of intent.

4.3.1.2 Nesting and Scalability[100]

The concepts of *nesting* (the recursive combination at different military echelons of individual equipment/personnel into complimentary task-oriented networks) and *scalability* (the span of the nesting construct across one or more echelons with respect to the analysis being conducted) are important in conducting MMF analysis because they help to frame the problem. Understanding nested constructs and the scale at which they apply is important in linking Level 1 interactions/effects to the Level 7 purpose/mission. When applying nesting and scalability to other levels of the MMF, the context of the problem grows in complexity. As in three-dimensional chess, the relationships and interactions within and among the various MMF levels are extensive. At higher echelons in a nested construct, task-oriented networks at a lower n^{th} echelon can be viewed as individual "components" and thus be combined with other complimentary "components" to form a task-oriented network relative to the commanding $n+1^{th}$ echelon.

As an example of a nesting construct using MMF Level 2 components, consider the hierarchical organization of military personnel across multiple echelons. An individual Soldier is a single personnel component within an Army Force at the lowest level in a nested construct. Nine Soldiers as individual component parts with like characteristics, Military Occupational Specialty (MOS) or rank, combine to form a task-oriented network – a squad. At a higher echelon within this nesting hierarchy, the squad can be considered as an individual component part and, when combined with other like squads, forms another task-oriented network of complimentary parts – a platoon. Continuing on up the hierarchy, the platoon can be viewed as a component within a task-oriented company, the company as a component within a task-oriented battalion, and so on and on. This nesting example could continue up through the highest levels within the Army or a Joint Task Force and illustrates the reach and scale at which the nesting could occur.

Applying this nesting principle to other levels within the MMF reveals the scope an analysis effort could take and the multitude of relationships to be expected within and among the levels. Content in one MMF level affects content in another level, and the scope of analysis becomes more complex in comparison with the degree of scale within each level. In order to conduct analysis to this degree of detail, it is imperative to be able to explicitly describe the relationships of the elements at each level. Level 1 interactions involving Level 2 components within a nested construct may affect the actions of other Level 2 components at higher or lower echelons. These interactions may influence the availability of Level 3 capabilities at the various nested echelons that in turn influence the performance of Level 4 tasks. From an aggregated point of view, the effects of Level 1 interactions influence Level 2 forces (i.e., organized networks of equipment and personnel) that in turn provide Level 3 network-centric capabilities to execute Level 4 operations. The conduct of Level 4 operations ultimately affects whether the Level 7 purpose/mission is achieved. Analyzing mission content thus requires breaking the problem apart bit by bit during the planning process, and then tracing the effects of an interaction up through the nested constructs of each level to determine the result on the overall mission. The scale of the analysis effort could be far reaching and yield countless permutations of interactions and results.

In the example depicted in Figure 4.19, capabilities are broken down into individual functional elements. As illustrated in the figure, Fire Support as a higher-level capability is broken down and described by analyzing its parts, i.e., what makes up the capability of Fire Support. Field Manual 3-90 (Doctrine for Fire Support) describes what individual functions contribute to providing a Fire Support capability. Based on this doctrine, the functions that combine to form a Fire Support capability include Target Acquisition, Command and Control, and Attack Resources. After the concept of nesting is applied, any one of these individual functions can be described as a coordinated network of finer-detailed functions. Thus, Target Acquisition can be broken down further into individual cooperating functional elements that describe what makes up the Target Acquisition capability. These functions include Detect, Locate, Identify, Track, and Classify. Taking this deconstruction a step further, each of these individual functions can be considered a capability in itself and broken down further to describe each in more detail (e.g., the ability to Locate might require the functions of See, Hear, Taste, Smell, and Feel). *It is through this nesting process that an audit trail tracing higher-level capabilities to equipment-level functions can be developed*. And once a list of mission-critical equipment and personnel has been identified, the necessary re-supply and maintenance tasks making up the coordinated Combat Service Support mission can be planned.

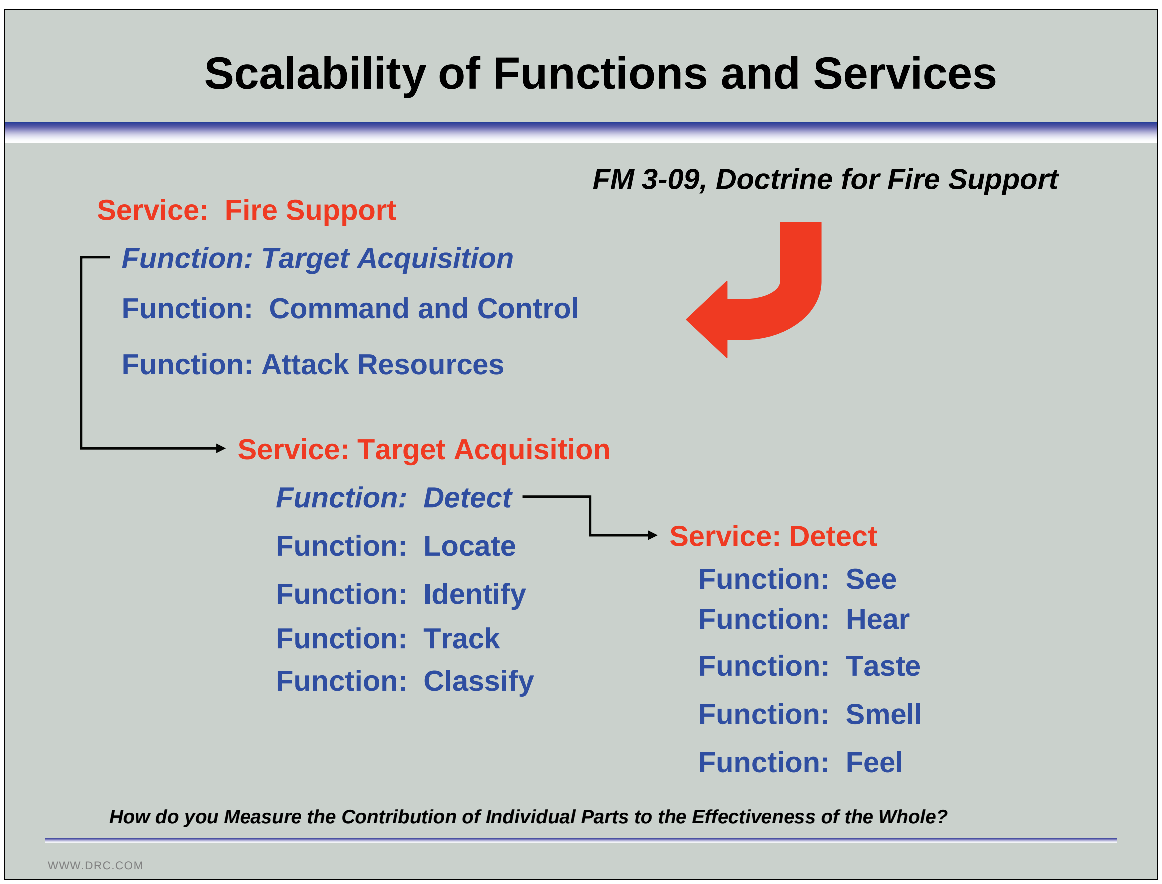


Figure 4.19. Scalability of functions and capabilities for notional fire support mission

4.3.1.3 Analysis of Collective Tasks[101]

The crux of the MMF in the materiel domain lies in the combined process of comparing the entity-level tasks at the leaves of the mission-to-task decomposition (i.e., the planning process) to the capabilities the entity (be it a combat platform, a dismount, or a re-supply vehicle) can currently provide (i.e., the employment process), where the context in which to decide the adequacy of these capabilities is found in the conditions and standards associated with each task. The benefits of MMF, however, are fully realized only by unwinding the recursive decomposition involved in mission planning and determining the success or failure of each higher-level task based on whether its subtasks were performed successfully. This unwinding allows us to move beyond the entity level and assess the performance of the system-of-systems in terms of the success of the so-called *collective tasks*. Having already bridged the gap between the V/L Taxonomy and the mission decomposition by comparing tasks to capabilities, we can now apply the established logic of the military decision-making process (MDMP) to work our way back up through the collective tasks and finally evaluate the success or failure of the entire mission. This evaluation considers the status of the subtasks and whether any is critical to the proper execution of the collective task. If the system failed at any critical subtask, we consider whether the risk incurred by that failure is acceptable in the current mission context and, if not, whether there is a possible adjustment of resources or an alternate course of action that will address the problem. If no such options exist, we conclude that the mission cannot succeed.

Figure 4.20 illustrates how the status of a notional platform-level task T_p can affect the readiness of a combat or re-supply unit to execute an associated collective task T_C. Comparing the residual platform capability (after interaction with one or more other operating environment entities) to the capability required for prosecution of T_p provides an overall *task readiness* status of green (task is executable at design optimal level of performance), amber (task is executable at a non-optimal degraded level) or red (task is *not* executable given residual platform capability). As an example, consider a notional command and control vehicle (C2V) that has lost its external digital communications capability due to radio frequency jamming. This capability loss in turn changes the status of the "disseminate common operational picture (COP)" task assigned to the C2V to red, since without that communication capability, the COP can be neither received from higher echelons nor transmitted laterally or to subordinate echelons. Finally, the flow chart shown in Figure 4.20 portrays the decision process that would typically be used to assess the impact of the C2V's inability to perform that platform-level task on the collective task "manage tactical information" assigned to the company to which the C2V belongs.

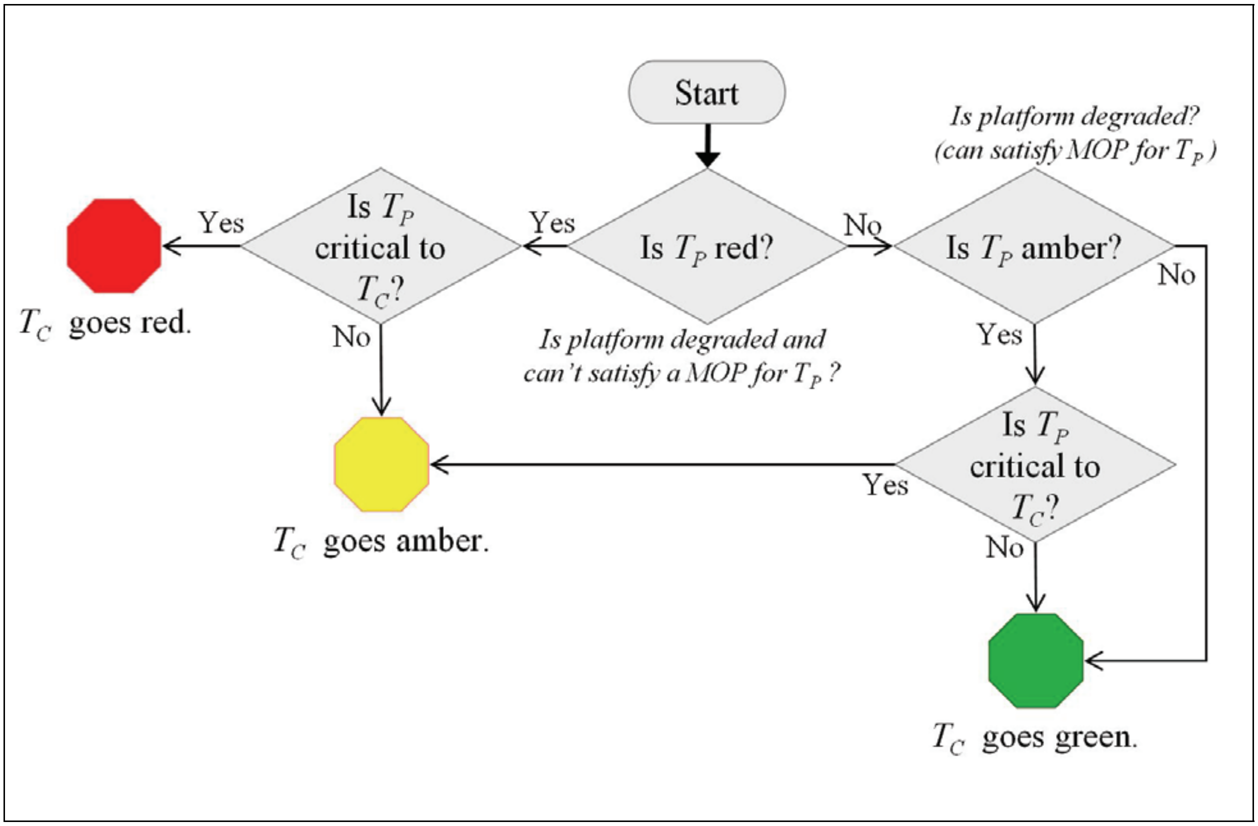


Figure 4.20. The effect of degradation to platform task TP's readiness status on collective task TC readiness.

Shifting our focus from a platform to a combat unit containing that platform, Figure 4.21 depicts the status of collective tasks assigned to a combat unit. In this case, mission readiness status is critically dependent upon

- the risk incurred when the readiness status of collective task T_C (possibly one of a set of collective tasks) goes red,
- the ability of the military force commander to adjust to the loss of T_C readiness (i.e., provide a network-centric system-of-systems solution), and
- the ability of the recommended system-of-systems solution to meet the force commander's intent.

In the context of the example from the previous paragraph, the decision process illustrated in Figure 4.24 would doctrinally guide the force commander to determine whether failure to execute the essential collective task "manage tactical information" would jeopardize successful execution of the mission (and, if so, how well some alternative COA would salvage the mission).

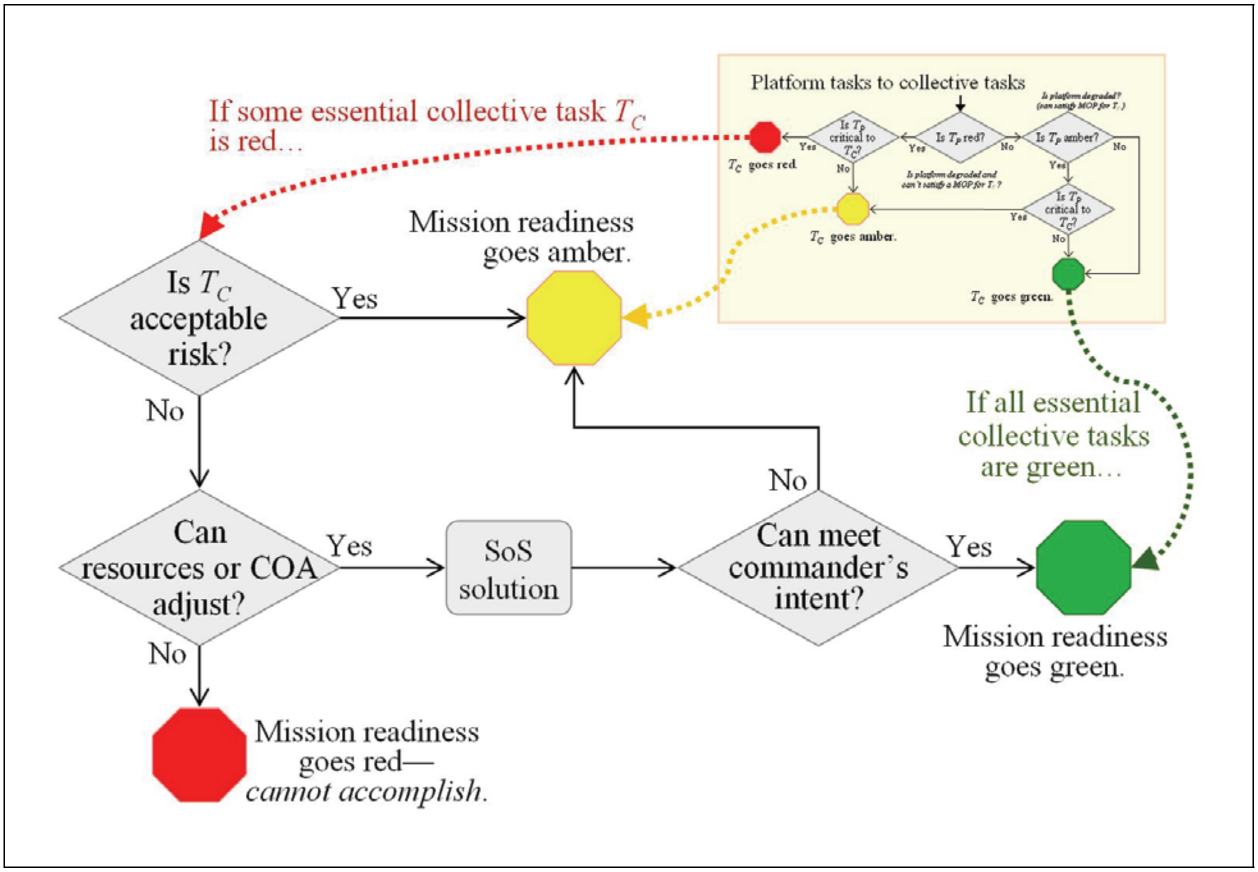


Figure 4.21. The effect of degradation to collective task TC's readiness status on unit-level or force-level mission readiness.

JTIMS:

Challenges- The Joint staff needed an automated system to manage large military training exercises and operations that take place throughout the world. This management system needed to be accessible to users all over the globe. In addition, the automated system needed to manage training exercises in a manner that was congruent with the new task-based Joint Training System (JTS) methodology. The JTS methodology is being used by the Joint Staff and Combatant and Component commands to guide the conduct of all large scale, military training exercises and operational events.

Solutions- The Joint Training Information Management System (JTIMS), developed by Dynamics Research Corporation (DRC), is a Web-based system designed to provide automated support to the JTS. JTIMS directly supports the task-based, closed-loop features of the JTS by facilitating the development of an integrated task-based thread to guide all JTS phases.

JTIMS incorporates the Universal Joint Task List and all associated service task lists, making it an ideal tool for mission/task decomposition in support of joint and service training. The system features easy to understand user interfaces such as the schedule de-confliction screen that automatically highlights conflicts in red in the GANTT chart associated with an exercise. JTIMS functionality associated with the schedule de-confliction screen enables users to explore “what-if” options to get rid of “the red” and thus avoid event scheduling and resource conflicts.

Benefits/Achievements- Ensures that all joint and service component training is mapped to the mission essential task list, making JTIMS an integral element of DoD’s Training Transformation initiative. Provides the framework for implementing task-based training. Can be used directly to support training readiness assessments.

Receipt of the Defense Modeling and Simulation Training Functional Area Award presented to DRC for the successful reengineering of JTIMS into a web-based client/server architecture to support distributed military training management.

For the purposes of the demonstration, mission tasks identified during the analysis process were described as tasks from the AUTL, LSI FCS task list and selected MTP tasks and captured in a mission-specific file using the Joint Training Information Management System (JTIMS), a GOTS tool used to support the Joint Training System. Shown here is a screen-shot capture of a portion of the mission analysis conducted for the demonstration. The mission thread is assembled from the mission tasks.

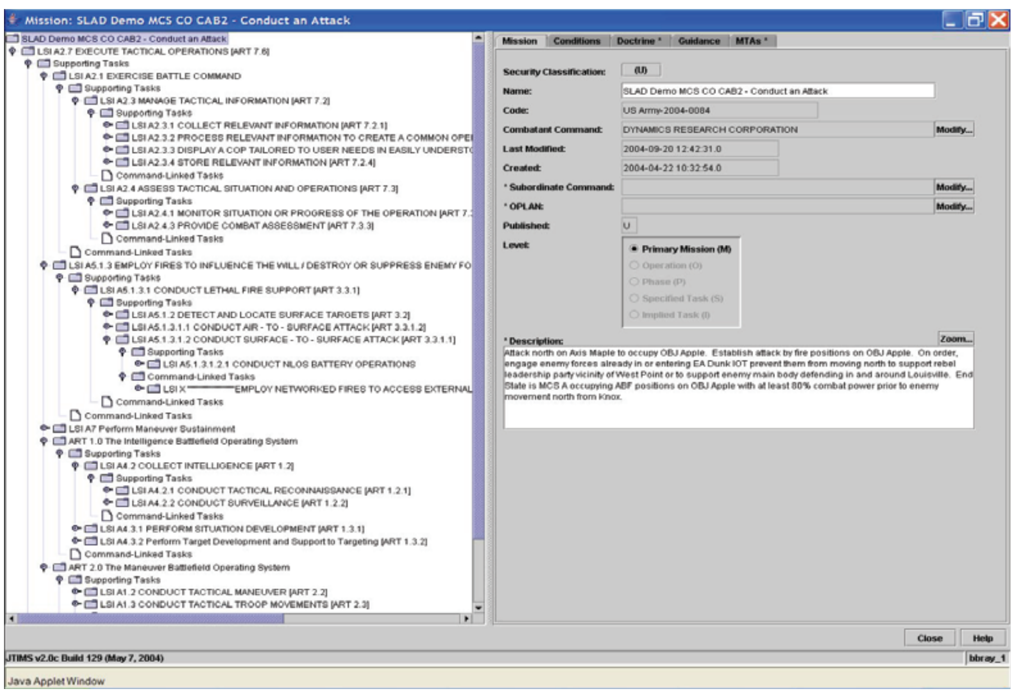


Figure 4.22. The joint training information management system (JTIMS).

4.3.2 Theory of Dynamical Processes

Process Dynamics is an approach to understanding the behavior of (often complex) business-oriented systems over time. It grew from the area of Systems Dynamics, which was founded in the early 1960’s by Jay W. Forrester of the MIT Sloan School of Management with the establishment of the MIT System Dynamics Group. At that time, Forrester began applying what he had learned about systems during his work in electrical engineering to everyday kinds of systems (and the processes that drive them to operate forward through time).

In the domain of military logistics, the theory of dynamical processes can be used to anticipate the future re-supply or maintenance requirements of military entities functioning within situations such as sustainment missions. Let $\mathbf{P}_{\text{logistics}}\,(U_{resources}, U_{COA}, E_{resources}, E_{COA}, Env, t_0)$ represent the state of a military logistics process, where:

$\mathbf{P}_{\text{logistics}}$	denotes logistics process
$U_{resources}$	denotes resources of the U.S. (and allied) force,
U_{COA}	denotes U.S. force course of action (COA),
$E_{resources}$	denotes resources of the enemy force,
E_{COA}	denotes enemy COA,
Env	denotes environment (including weather, terrain, etc.), and
t_0	denotes time of analysis.

Note that, from a technical perspective, $\mathbf{P}_{\text{logistics}}(U_{resources}, U_{COA}, E_{resources}, E_{COA}, Env, t_0)$ is a state vector reporting the status of measurable quantities such as location, speed, and capacity of re-supply vehicles, capacity of re-supply and maintenance depots, and so on.

This military logistical process dynamically evolves in time according to the coupled equations

$$\mathbf{P}_{\text{logistics}}(t_0+\Delta t) = f\begin{pmatrix} \mathbf{P}_{\text{logistics}}(t_0), \Delta U_{resources}(t_0 \rightarrow t_0+\Delta t), U_{COA}(t_0 \rightarrow t_0+\Delta t), \\ \Delta E_{resources}(t_0 \rightarrow t_0+\Delta t), E_{COA}(t_0 \rightarrow t_0+\Delta t), Env(t_0 \rightarrow t_0+\Delta t) \end{pmatrix}$$

$$\mathbf{S}_{\text{logistics}}(t_0) = g\left(\mathbf{P}_{\text{logistics}}(t_0), \delta\mathbf{P}_{\text{logistics}}(t_0)\right)$$

where

$\mathbf{P}_{\text{logistics}}\,(t_0+\Delta t)$	denotes the future state of the logistics process at time $t_0+\Delta t$ (i.e., this is a state vector),
$\Delta U_{resources}(t_0 \rightarrow t_0+\Delta t)$	denotes the change in U.S./allied resources from t_0 to $t_0+\Delta t$,
$U_{COA}(t_0 \rightarrow t_0+\Delta t)$	denotes the unfolding U.S./allied COA from t_0 to $t_0+\Delta t$,
$\Delta E_{resources}(t_0 \rightarrow t_0+\Delta t)$	denotes the change in enemy resources from t_0 to $t_0+\Delta t$,
$E_{COA}(t_0 \rightarrow t_0+\Delta t)$	denotes the unfolding enemy COA from t_0 to $t_0+\Delta t$,

Env ($t_0 \rightarrow t_0+\Delta t$)	denotes the operating environment as it exists from t_0 to $t_0+\Delta t$,
$\mathbf{S}_{logistics}(t_0)$	denotes fused data representing the <u>*sensed*</u> state of the logistics process at time t_0 (i.e., this is a composite *data* vector),
$\delta\mathbf{P}_{logistics}(t_0)$	denotes *uncertainty* implicit within the sensed state of the logistics process at time t_0[12], and
$f(x_1, x_2,\ldots, x_n)$	denote that something is a function of a set of variables (the
$g(y_1, y_2,\ldots, y_m)$	sets $x_1, x_2,\ldots, x_n$ and $y_1, y_2,\ldots, y_m$ in the first and second cases, respectively).

These equations illustrate that 1) the future state of a military logistics operation "grows" from the current state of that operation, 2) the time-evolution of the operation depends upon factors that U.S./allied forces can directly control (i.e., use and expenditure of U.S./allied resources; unfolding U.S./allied COA), as well as other factors currently beyond direct U.S./allied control (i.e., use and expenditure of enemy resources; unfolding enemy COA; operating environment), 3) the perceived current state of the operation (i.e., $\mathbf{S}_{logistics}(t_0)$) will directly influence any changes made to the U.S./allied COA at that time, 4) the future state of the operation is thus a function of uncertainties within the current data-fused picture of the operation.

The evolving logistics process described in the above coupled equations is depicted in Figure 4.23. Here, we see "snapshots" of the real logistics process $\mathbf{P}_{logistics}$ (represented by the clear circles) as sampled at mission times $t_0-\Delta t$, t_0, and $t_0+\Delta t$. This real process dynamically advances through time via the function *f*, which serves to iteratively map the state of the process across successive points in time. Evolving concurrently along with $\mathbf{P}_{logistics}$ is the warfighter's sensed perception of the logistics process, which we have previously identified as $\mathbf{S}_{logistics}$ (represented by the dark gray circles). It is this perceived process, iteratively mapped from the data collection and transmission stages to the fusion stage via the function *g*, that can supply the multivariate time series data used in predictive analytics (see next section).

[12]This uncertainty reflects both i) aspects of the logistics process that cannot be perceived using available sensing technology and ii) sensor measurement noise that might be embedded within the fused data.

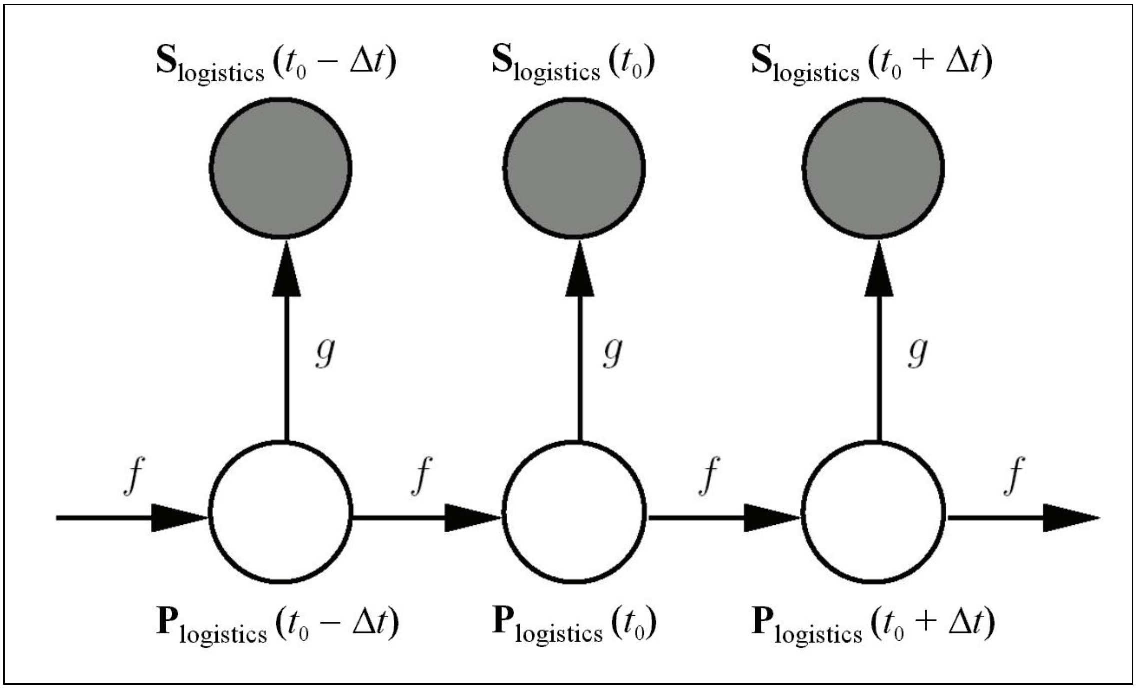


Figure 4.23. An actual logistics process $P_{logistics}$ co-evolving with the sensed operational picture of that process $S_{logistics}$

Finally, we must address the issue of nonlinear dynamical processes. In a linear dynamical process, the collective behavior of a unit of entities is just the sum of the contributions from each individual entity. As a simple example of a linear logistics process, consider a fleet of re-supply vehicles moving supplies during a calm springtime day in peacetime. If we double the number of re-supply vehicles in the fleet, then (barring unexpected vehicle maintenance problems) the volume of delivered supplies is also doubled. However, if we add hostile enemy insurgents and bad weather to this scenario, the logistics process could readily move into the nonlinear regime.

In practice, most dynamical processes in the military operations domain are nonlinear. Control of nonlinear dynamical processes is one of the biggest challenges in modern control theory. While linear control system theory has been well developed, it is the nonlinear control problems that present the most headaches. Nonlinear processes are difficult to control because there can be so many variations of the nonlinear behavior due to extreme sensitivity to the initial conditions of the process. Thus, a nonlinear logistics process resists analysis by using a standard axiomatic (i.e., rule-based) approach. In order to predict the future state of a nonlinear logistics process, one needs to first run a simulation of the process (see Agent-Based Modeling in section 3.3.4).

4.3.3 Predictive Analytics

Predictive analytics encompasses a variety of techniques (from statistics and data mining) that process current and historical data in order to make "predictions" about future events[102,103]. Such predictions rarely take the form of absolute statements, and are more likely to be expressed as values that correspond to the odds of a particular event or behavior taking place in the future. In business applications, models employing predictive analytics process historical and transactional data to identify the risk or opportunity associated with a specific customer or transaction. These analyses weigh the relationship between hundreds of data elements to isolate each customer's risk or potential, which guides the action on that customer.

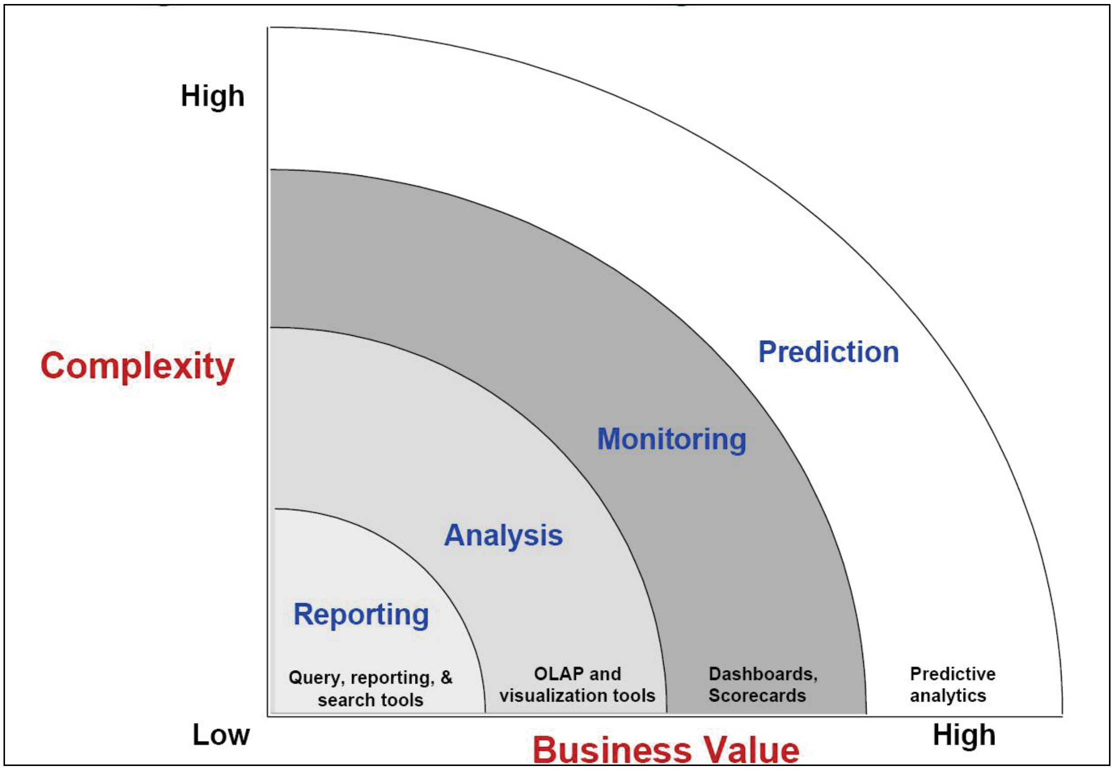


Figure 4.24. Predictive analytics facilitates prediction in highly complex business environments, which in turn provides high value[102,103].

A plethora of tools such as multivariate statistics, neural networks, Bayesian networks, self-organizing maps, CART (Classification and Regression Trees) etc. are available at present to convert data into useful process knowledge (models, rules etc.).

4.3.4 Agent-Based Modeling

4.3.4.1 Fundamental Concepts

One approach to predicting future events is to make a model that explains relationships between observations made in the past, and then use that model in a simulation to make predictions of the future. Such a predictive simulation would 1) first specify a set of differentiated scenarios in terms of initial conditions at time T_0, and then 2) record important attributes of the simulation state as it dynamically progresses through "future" times T_1, T_2, T_3, …, T_{final}. The output of this prediction would be a time series that models the multi-dimensional simulation state as a trajectory moving forward through a multi-dimensional state or phase space – i.e., a response hyper-surface.

Structurally, a military system-of-systems collective can be broken down into a set of simulation agents interacting with one another in a coordinated fashion. A *simulation agent* is an autonomous computational entity with a perpetuated internal state and associated decision-making process (DMP) or set of rules governing behavior (Figure 4.25). In this context, simulation agents are meant to represent *real-world* decision-making entities (e.g., platforms with a human crew, robotic platforms, dismounts, a functioning supply depot, etc.). The agent's state is usually represented as a dynamic vector describing metrics such as agent position, identity, current functionality, and so on. A colony of simulation agents can interact with one another by passing messages between themselves, which can represent communication, cooperative actions, or conflict. Given these elements, a military-domain *agent-based model* is then a collection of interacting simulation agents instantiated within a virtual simulated operating environment that contains a terrain-based environment within which the agents function as well as other hostile simulation agents with which the first group of agents must contend.

If a simulation agent is purely reactive by nature, then the DMP it uses is composed of what are called *stimulus-response rules* in the field of psychology (also known as condition-action rules and production rules in the fields of artificial intelligence and mathematical logic, respectively). A stimulus-response rule is defined by its form: *if* some condition is true, *then* execute some action. Though stimulus-response rules by themselves are limited in scope, they can effectively be organized into rule clusters that can generate any type of behavior that can be computationally described[13]. Within the tactical military domain, there are four specific behavioral classes of stimulus-response rules governing (i) how an agent senses its environment, (ii) how an agent moves within its environment, (iii) how an agent engages other hostile agents, and (iv) how an agent communicates and interacts with other friendly agents. In a properly designed military agent-based model, these four domains structure the atomic behaviors for each agent.

[13] The field of artificial intelligence also uses the term "production rule," but as an implementation of this concept rather than a formal definition of it.

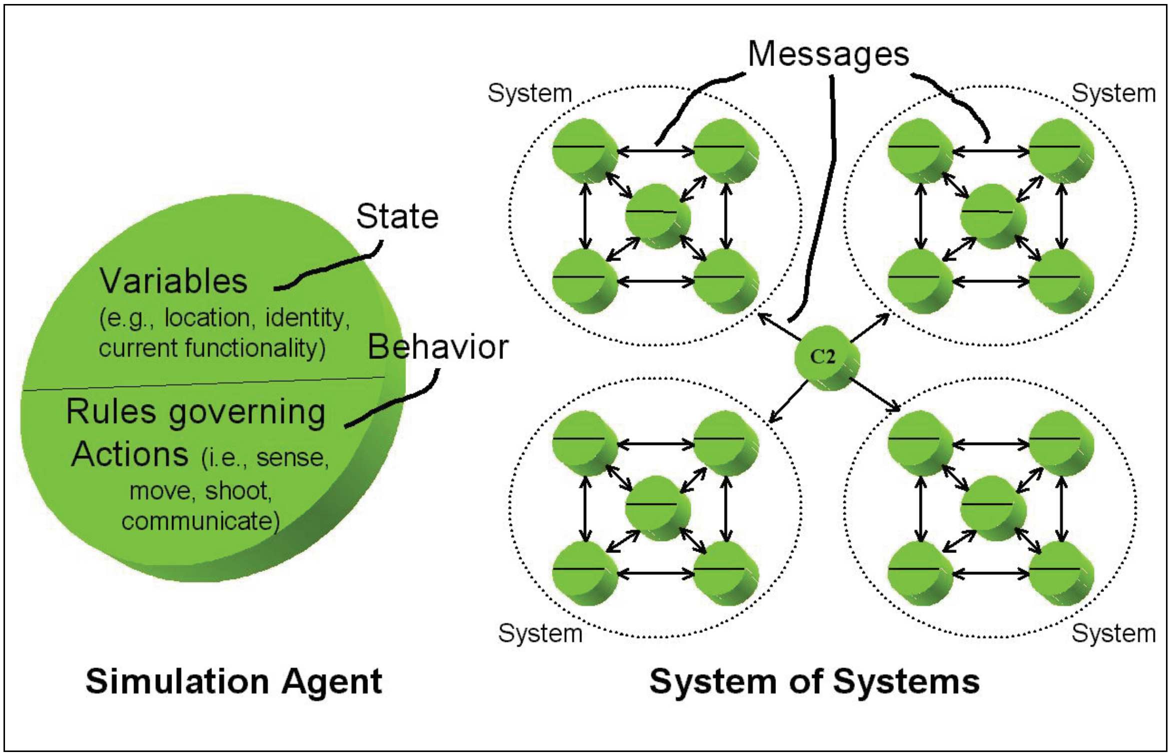


Figure 4.25. Representation of a generic military simulation agent and a military system of systems composed of multiple agents.

4.3.4.2 Cougaar

An *agent architecture* provides a high-level view of the subsystems that make up an agent-based system-of-systems, the interactions between the subsystems, and the flow of control and/or information among the subsystems. The *Cognitive Agent Architecture* (Cougaar) is a Java-based architecture for the construction of highly scalable distributed agent-based applications[14]. Cougaar is the product of a multi-year DARPA research project to develop an open-source agent-based architecture that supports applications ranging from small-scale systems to large-scale highly survivable distributed systems.

Cougaar started in 1996 as the Advanced Logistics Project (ALP), which was a DARPA funded project to model military logistics planning and execution using distributed agent technologies. BBN was the primary contractor and continues as a key Cougaar developer. The Cougaar software is now "open source" (i.e., available for free download over the Internet), and has been applied in non-military applications ranging from sensor data fusion to project planning using business intelligence.

The Cougaar agent framework provides a hierarchy of modeling entities that can be used to effectively represent the hierarchy of business process elements in the military logistics domain. These three infrastructure entities are the *agent* (at the lowest level; equivalent to a simulation

[14]Note that, in this case, the entirety of the supply depot was modeled as a single decision-making agent.

agent as previously described in section 3.3.4.1), the *community* (containing multiple agents), and the *society* (containing either multiple communities or an organized mixture of communities and agents). In the following paragraphs, each of these infrastructure entity types will be further described.

Individual agents in a Cougaar simulation are typically used to model either individual organizational entities or functional entities. Cougaar agents are able to communicate directly with other Cougaar agents over direct links established using agent-specific identifiers. Agents contain *assets*, which can be either physical or conceptual entities managed by a particular agent. In a military logistics application, an agent could represent a re-supply vehicle, while the agent's assets would then include both its own consumables (e.g., fuel, water, electric power) as well as the supplies the agent is transporting.

From a software design perspective, each Cougaar agent has two main components: plug-ins and a blackboard.

- *Plug-ins* are software components that provide behavior and business logic to the agent's decision process. Depending on the functionality that an agent wants to achieve, it can initialize a certain set of plug-ins. Plug-ins are self-contained elements of software and are not dependent on other plug-ins.
- A *blackboard* is a type of memory warehouse that resides internally within an agent. Each Cougaar agent has exactly one blackboard. An agent's plug-ins can communicate with other internal plug-ins only through the agent's blackboard. Plug-ins can publish decision-making results to the agent's blackboard, and can also react to decisions made by other plug-ins that appear on the blackboard.

Figure 4.26 illustrates the organization of plug-ins and the blackboard within a Cougaar agent. If the agent represents a single Soldier, then the blackboard would represent the Soldier's mind, while the plug-ins could represent the different types of decisions that the Soldier would make when executing tasks within a mission.

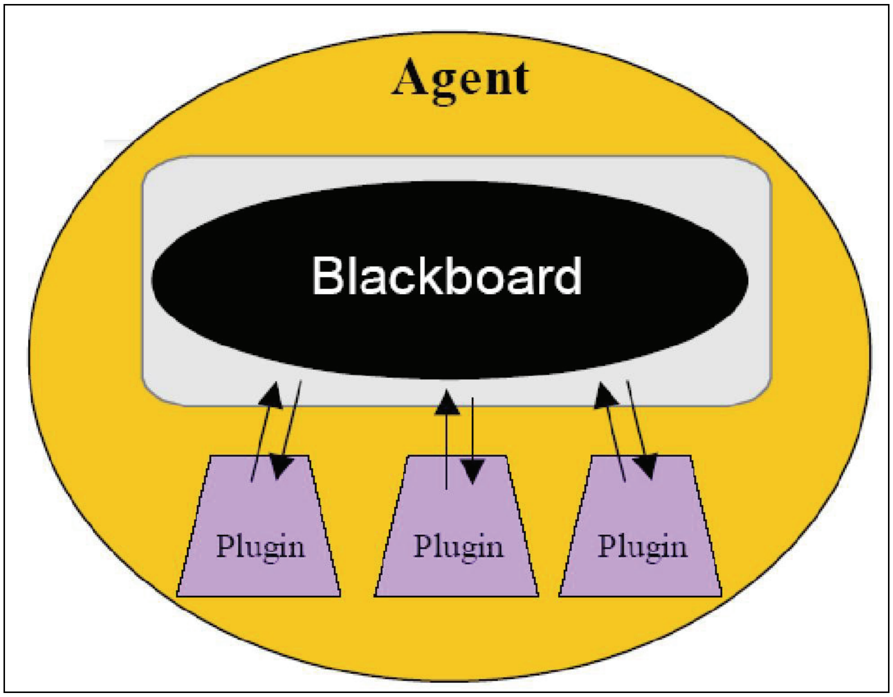


Figure 4.26. A generic Cougaar agent with a blackboard and several plug-ins.

Cerys, Rozga, and Berliner have designed an interesting suite of agent plug-ins to model the logistics activities within a notional military system-of-systems construct. In this model, Cougaar agents were designed to represent combat vehicles, re-supply vehicles, or a supply depot[15]. The different plug-in types are the following.

- The *Demand Forecaster* plug-in exists in all of the agents that consume materiel. This plug-in generates time-phased forecasts of demand throughout the time range of the mission. Individual demand forecasts are generated for each unique item consumed by an agent. Forecasts are based on the detailed time-phased, per-organization, per-vehicle activities specified in the Cougaar operational plan (OPLAN).
- The *Demand Generator* plug-in is similar to the Demand Forecaster plug-in, except that it generates actual supply demand, as opposed to forecasts. So while the demand forecasts for the entire mission time duration are generated when the Cougaar society is instantiated, the actual demand is generated based on the advancement of Cougaar simulation time.
- The *Inventory Manager* plug-in implements the business process of managing materiel inventory quantities at any level of the supply hierarchy. In an agent community representing a battalion, an Inventory Manager plug-in was used to manage the time-phased fuel inventories of each combat vehicle on the battalion, i.e., the amount of fuel in each combat vehicle's fuel tank. The plug-in is general, allowing it to manage inventory

[15]Note that, in this case, the entirety of the supply depot was modeled as a single decision-making agent.

levels for an arbitrary number of managed items belonging to an arbitrary number of vehicles. The Inventory Manager plug-in integrates the total demand forecasts and actual demand from the consumers with the total demand forecasts and actual demand sent from the agent with the Inventory Manager to its suppliers. The result is a time-phased inventory.

Note that the Inventory Manager plug-in was possessed only by the supply depot agent.

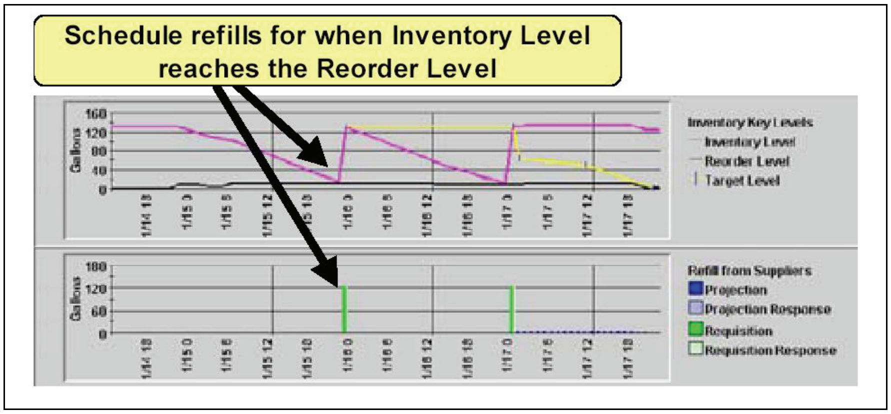


Figure 4.27. The Inventory Management refill scheduling plug-in designed for the supply depot agent.

A Cougaar community is a notional concept and refers to a group of agents with some common functional purpose or organizational commonality. Each community in turn can have separate individual sub-communities, where each sub-community must coordinate with other sub-communities to perform a particular task towards a common goal. In military logistics, a supply transportation unit can be modeled as a community. But the transportation community can in turn be further divided into sub-communities representing air transport units, sea transport units, and ground transport units. Depending on the application domain, communities can be a useful abstraction, allowing the Cougaar user to treat a collection of agents as a single organizational entity.

Finally, the entire simulated world of plug-ins, agents, and communities in a given Cougaar-based application is called a society. For a notional military logistics simulation, the focus might be on creating a society of agent communities, where each community might represent a different type of Combat Service Support unit. Here, all agents and communities within the society would share a common goal of service support. Given that the operational range and uncertainty inherent in military operations requires logistics units to deal with changing distribution schemes, new alignment of organizations, and unexpected fluctuations in demands, a Cougaar-based simulation of military units and their assets can provide valuable predictive utility to an analysis.

4.3.4.3 CoRBCAM

The *Complex Reactive Behavior Combat Agent Model* (CoRBCAM) is an agent-based model developed by the Survivability/Lethality Analysis Directorate (SLAD) of the U.S. Army Research Laboratory (ARL)[104]. A CoRBCAM simulation can model the interactions of two or more adversarial units of simulated tactical entities that engage in quasi-scripted combat by employing a variety of "complex reactive behaviors." Such behaviors reflect the execution of pre-defined military tasks in a manner consistent with the Missions and Means Framework (MMF). Through the use of novel visual programming technology, the software developed in this project allows a military subject matter expert (SME) to construct task-oriented behaviors that are executed by tactical *combat agents* (i.e., simulation agents representing military platforms and infantry) during the course of a simulation. This approach allows the user to demonstrate the emergence of a combat-effective collective unit via the mapping of individual tactical-agent behaviors to collective-unit measures of performance (MOPs) and measures of effectiveness (MOEs).

Once one or more tactical units of combat agents have been defined, the next step is to assign sets of tactical behaviors to each agent. This is accomplished through the use of *ShapeUp,* a visual language toolkit designed to capture domain-specific behaviors for simulated agents. ShapeUp allows a user to define agent behaviors (for specific simulated situations) via the construction of behavior networks. Once constructed, these behavior networks are then stored as Extensible Markup Language (XML) files for CoRBCAM simulation purposes. The design of ShapeUp was explicitly guided so to allow military domain users to construct behavior networks which facilitate the simulated execution of UJTL tasks. For example, Figure 4.28 depicts a notional ShapeUp behavior network that models a "negotiate a tactical area of operations" task. Finally, these task-oriented behavior networks can further be constructed as a function of MMF level 3 degraded capability elements associated with a combat agent.

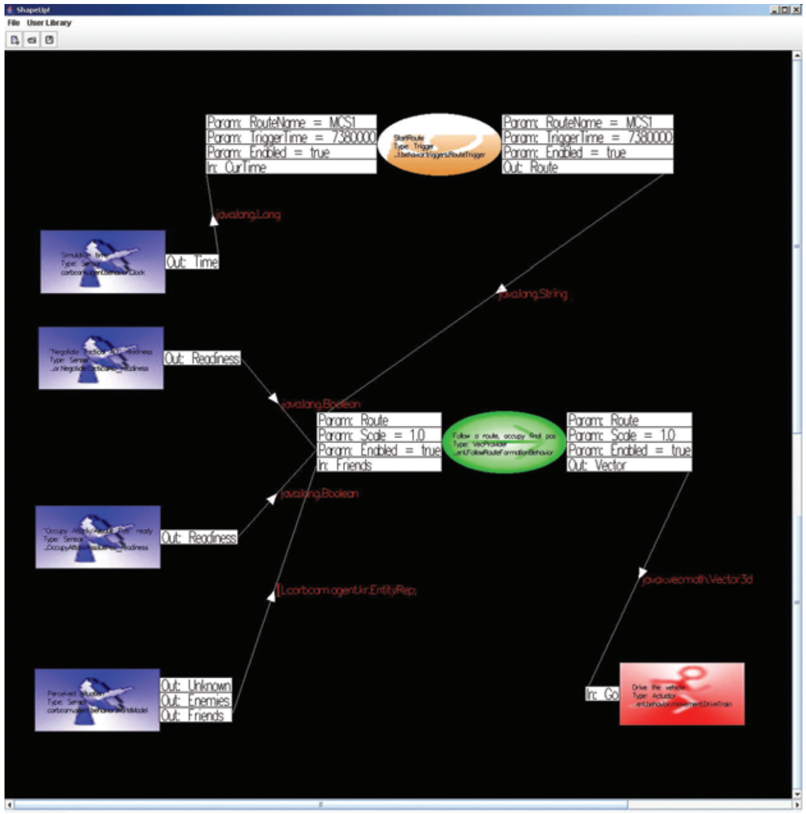


Figure 4.28. ShapeUp behavior network modeling a "negotiate a tactical area of operations" task.

A CoRBCAM simulation of a notional re-supply company executing a sustainment mission was designed. This company consists of three platoons (plus a company commander and XO), where each platoon is made up of four ground vehicles (making a total of 14 BLUFOR combat agents). Agents in the company execute the following tasks.

- **Provide Subsistence (CLASS I)**. Provide food in bulk or prepackaged rations and bottled water. This task is executed by all agents in the 1st and 2nd platoons.
- **Provide Clothing, Individual Equipment, Tools, and Administrative Supplies (CLASS II).** Provide clothing, individual equipment, tentage, organizational tool sets and kits, hand tools, geospatial products (maps), administrative and housekeeping supplies and equipment. This task is executed by all agents in the 1st and 2nd platoons.
- **Provide Petroleum, Oil, and Lubricants (CLASS III B/P).** Supply bulk fuel and packaged petroleum products. This task is executed by all agents in the 1st and 2nd platoons.
- **Repair Equipment.** Restore an item to serviceable condition through correction of a specific failure or unserviceable condition. These items include tactical and combat

vehicles, aircraft, marine equipment, and command and control systems. This task is executed by all agents in the 3rd platoon.

In addition, there is a cluster of parked civilian vehicles that combat agents in the re-supply company must navigate through. Within this cluster of parked vehicles are several terrorist suicide bombers that are visually indistinguishable from other civilian vehicles.

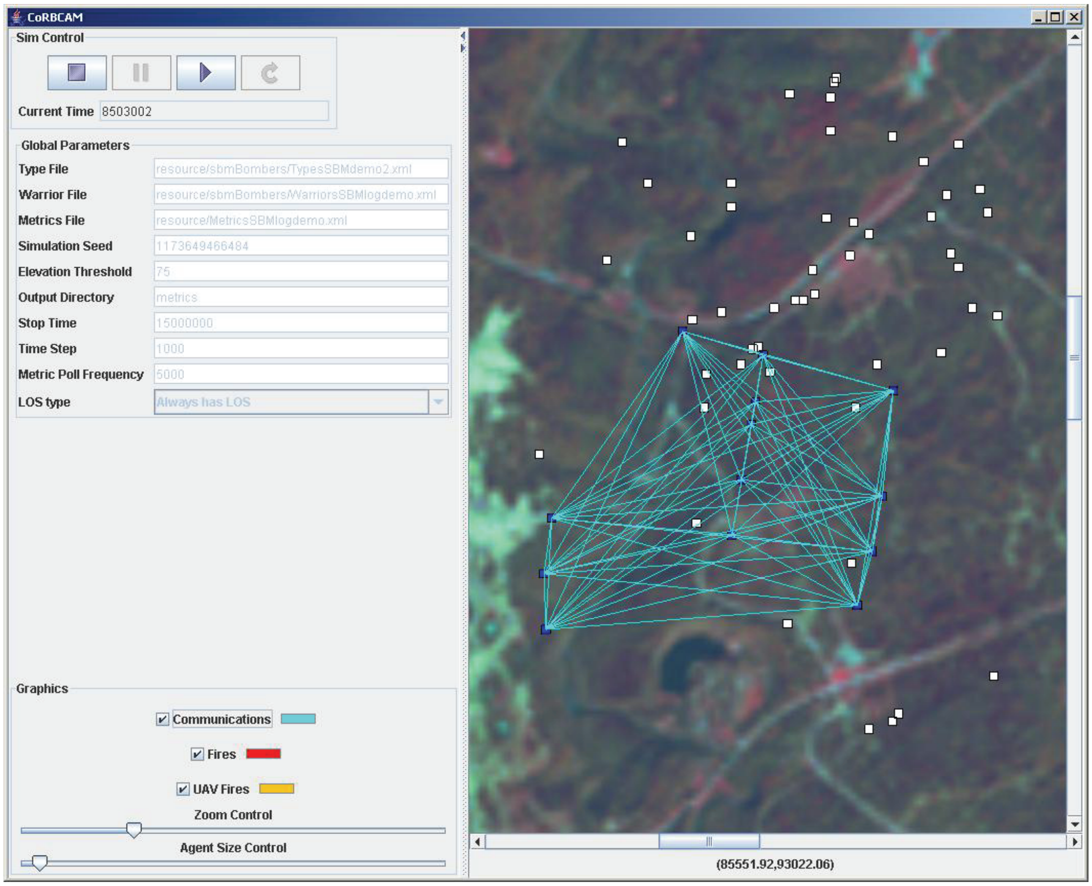


Figure 4.29. CoRBCAM simulation output window: operating environment terrain map.

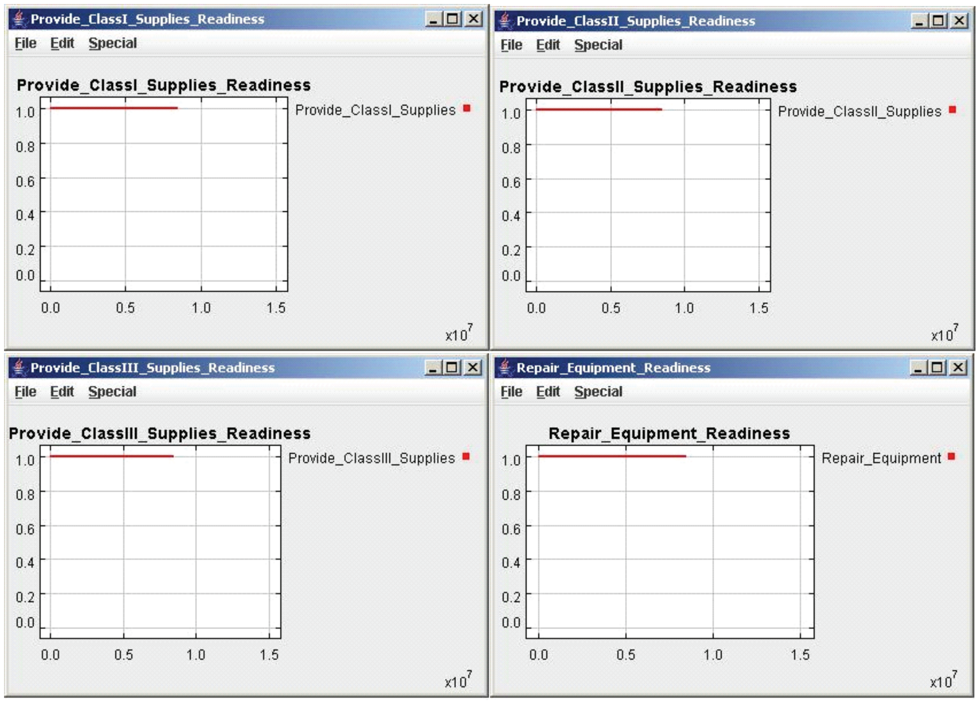


Figure 4.30. CoRBCAM simulation status of a re-supply company mission just prior to a terrorist attack.

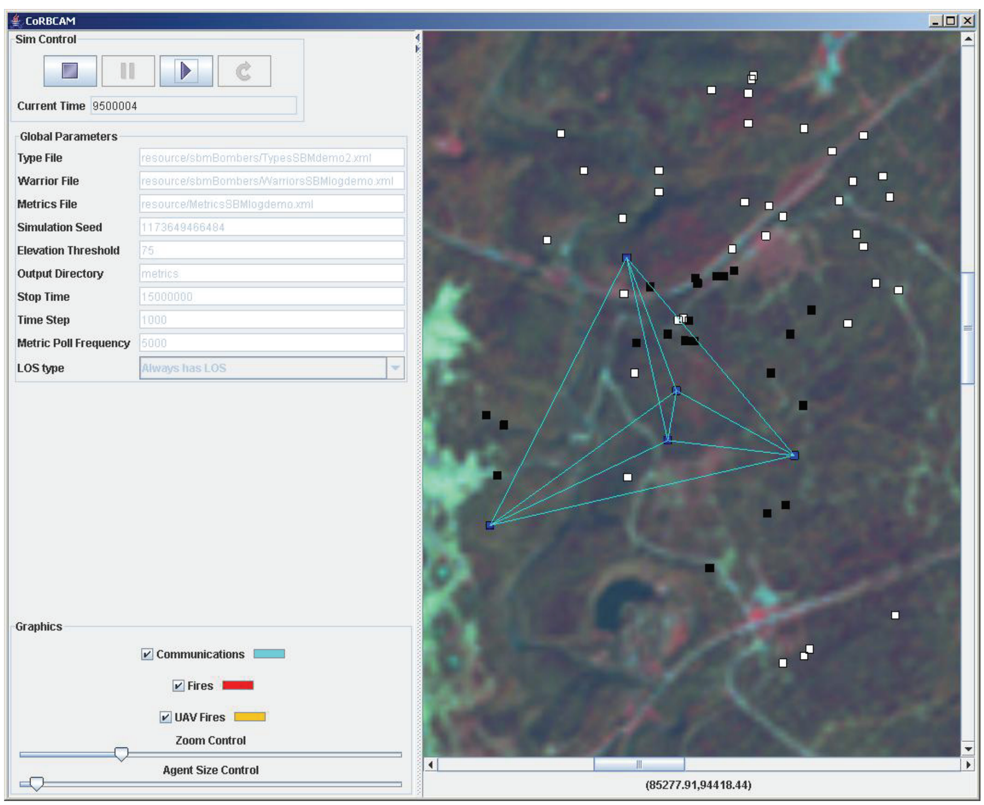


Figure 4.31. CoRBCAM simulation output window: operating environment terrain map during re-supply company mission shortly after the terrorist attack

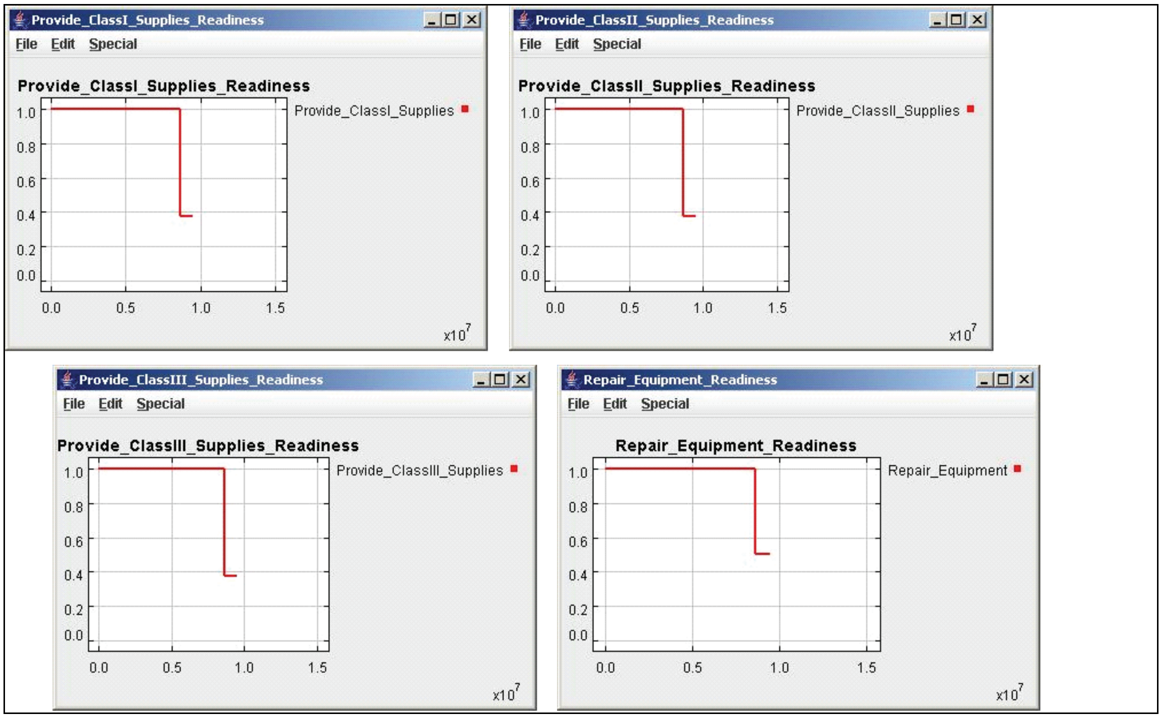


Figure 4.32. CoRBCAM simulation status of a re-supply company mission shortly after the terrorist attack.

4.3.5 Reflexive Theory[105]

In order to model the dynamical evolution of situations for prediction purposes, we must first address how decision-making agents within that model might perceive a simulated situation. Reflexive theory, developed by Lefebvre in the early 1960's and used by the Soviet defense establishment, is a branch of mathematical psychology in which agents do not necessarily act rationally (as is generally assumed in game theory). Instead, an agent will act according to its internal perception or image of the world as well as its image of another agent's image of the world (where that other agent can be either a friend, an adversary, or a neutral). It thus plays a similar role with respect to the discussion of *values* that Boolean algebra has played with respect to the discussion of truth. For the sake of convenience, we use algebraic notation to describe terms that are laden with meaning in natural language, such as "positive" or "negative," without, however, making any value judgments as to the *actual* goodness or evil of the "ethical" objects considered.

The model under consideration here is based on the assumption that the subject possesses an inborn mechanism capable of "computing" the choice leading to a particular action by exploiting internal rules of behavior in conjunction with a perceived situation. The scheme for such a mental computational process is illustrated in Figure 4.33 Agent X_2 perceives an external independent reality (T – the true state of a situation), and then internally stores this perceived truth as $T(X_2)$. In addition, agent X_2 also models its own perception of how a second agent X_1

perceives that same external reality – i.e., $\Omega(X_2(T(X_1)))$, then stores this internally as well. Thus, any decision made by X_2 involving X_1 will be contingent on both $T(X_2)$ and $\Omega(X_2(T(X_1)))$.

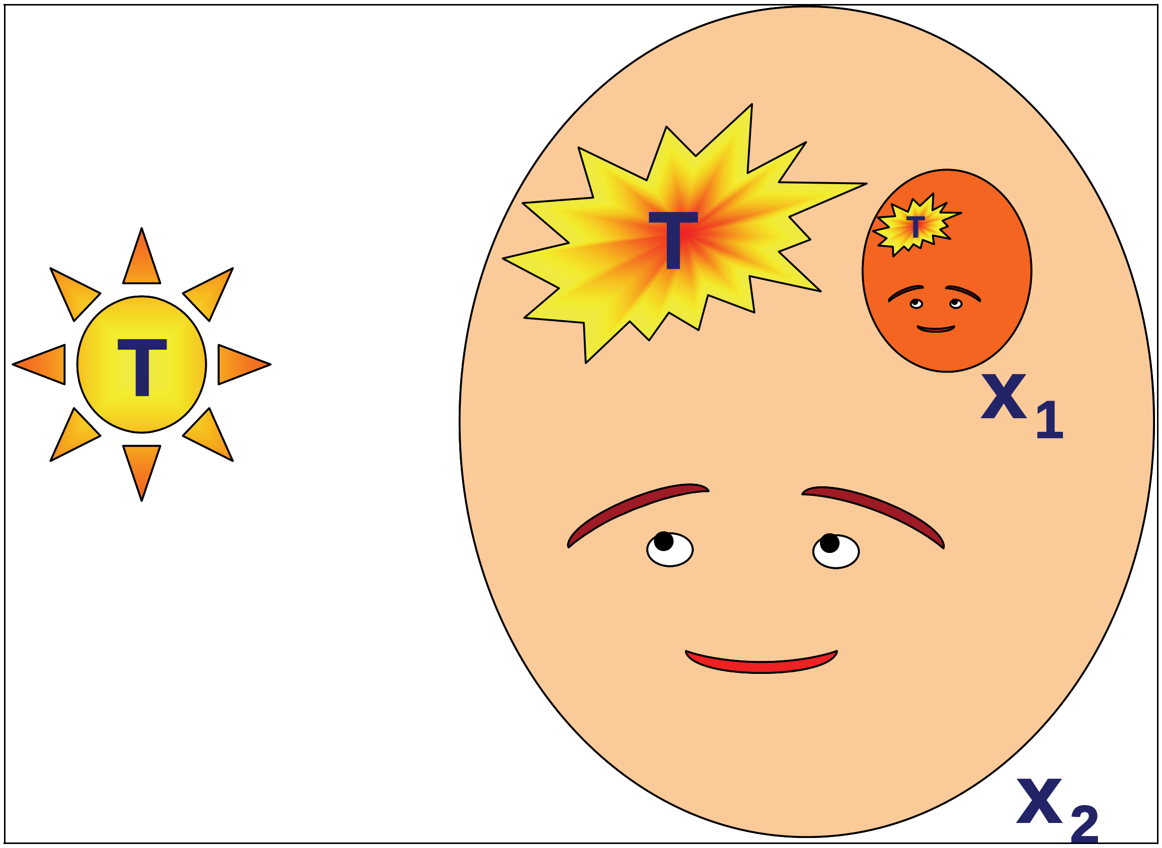


Figure 4.33. Example of a reflexive model. An agent X2 constructs an internal reflexive model of a perceived true situation T plus another agent X1's perception of T.

4.3.6 State/Phase Space and World Lines

The most useful view of equilibrium is as follows. We represent the evolution of the system in a space spanned by the state variables (*phase space*). An instantaneous state of the system is thus represented in phase space by a point. As the system evolves over time, a succession of such states is produced, giving rise to a curve in phase space, which is called a *phase space trajectory*. In a dissipative, dynamical system, as time progresses, the phase space trajectory will tend to a mathematical limit. We call this regime the *attractor*. The attractor representing an equilibrium position is unique and describes a time-independent situation. This gives a phase space point towards which all possible histories converge monotonically. The state of equilibrium is therefore a *universal point attractor*. The goal of *self-organization* is thus the search for new attractors that arise when a system is driven away from its state of equilibrium. By allowing the intrinsic nonlinearity to be manifested in the regime of detailed balance, nonequilibrium can also lead to the coexistence of multiple attractors in state space. The state space can then be carved up into a set of basins. Each of these corresponds to the set of states that, if the system were to start from there, would evolve to a particular attractor. These are known as the *basins of* *attraction*. The ridges separating these basins of attraction are called *separatrices*. The coexistence of multiple attractors constitutes the natural mode of systems capable of showing adapted behavior and of performing regulatory tasks. We would thus expect to see the system staying within one basin of attraction (corresponding to resistance to change) and then at some point switching between different attractors (corresponding to a change in the long-term mode of behavior) as we further vary the initial state of the system. The existence of one-dimensional attractors (points and circles) suggests the possibility of higher dimensional attracting objects in phase space. This model multi-periodic and chaotic behavior is observed under appropriate experimental conditions.

In general, a *world line* is the sequential path of personal human events (with time and place as dimensions) that marks the history of a person—perhaps starting at the time and place of one's birth until their death. The logbook of a ship is a description of the ship's world line, as long as it contains a time tag attached to every position. The world line allows one to calculate the speed of the ship, given a measure of distance (a so-called metric), appropriate for the curved surface of the Earth.

A one-dimensional line or curve can be represented by the coordinates as a function of one parameter. Each value of the parameter corresponds to a point in spacetime and varying the parameter traces out a line. So in mathematical terms, a curve is defined by four coordinate functions x^a(\tau),\; a=0,1,2,3 (where x0 usually denotes the time coordinate) depending on one parameter τ. A coordinate grid in spacetime is the set of curves one obtains if three out of four coordinate functions are set to a constant.

Sometimes, the term world line is loosely used for any curve in spacetime. This terminology causes confusion. More properly, a world line is a curve in spacetime which traces out the (time) history of a particle, observer or small object. One usually takes the proper time of an object or an observer as the curve parameter τ along the world line.

We can use the concept of world lines to represent the history of a simulated object within an N+1 dimensional state space (or phase space). In this mathematical space, there are N degrees of freedom defining scalar attributes associated with an object (e.g., latitude location, speed, weight, residual amount of fuel, etc.) and one degree of freedom associated with a time axis.

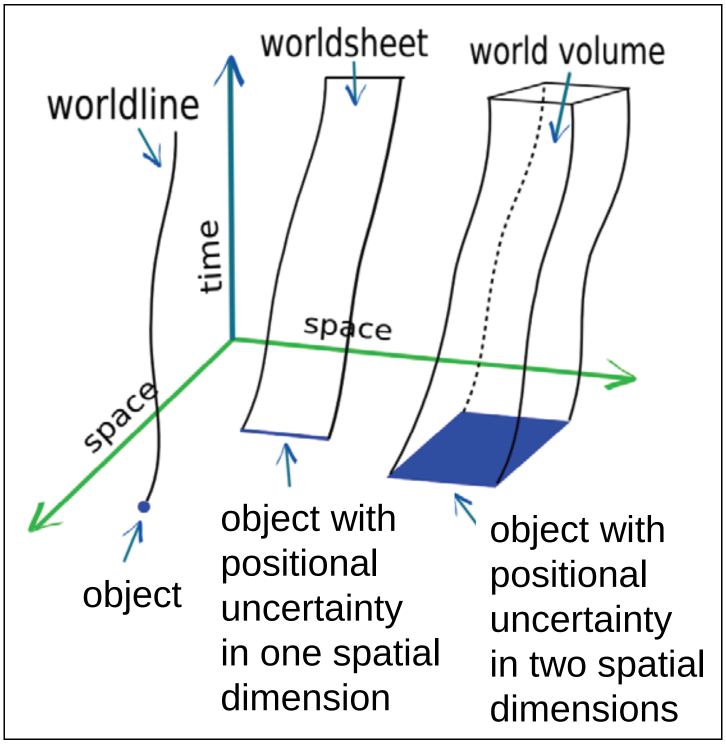


Figure 4.34. Worldline, worldsheet, and world volume as they are derived from the time-evolved states of objects with different degrees of positional uncertainty.

4.4 Emerging Trends in Computational Hardware

4.4.1 Future Trends of Moore's Law

On 27 January 2007, Intel demonstrated a working 45 nm (nanometer) personal computer (PC) processor chip which they intend to begin mass-producing in late 2007. A decade ago, such PC chips were built using a 500 nm process. Companies are working on using nanotechnology to solve the complex engineering problems involved in producing chips at the 30 nm and smaller levels – a process that will postpone the industry meeting the limits of Moore's Law[16].

Recent computer industry technology "roadmaps" predict (as of 2001) that Moore's Law will continue for several chip generations. Depending on the doubling time used in the calculations, this could mean up to a 100x increase in transistor counts on a processor chip by the year 2020. The semiconductor industry technology roadmap uses a three-year doubling time for microprocessors, leading to about nine-fold increase in a decade.

[16]Author's Note: The definition of certain consumer recognized terms such as Moore's "Law" and "clock speed" have been adapted with great liberty over the years by the semiconductor industry. One form of Moore's Law references the increasing number of transistors per wafer; yet if one changes the wafer from 6 inch diameter to 12 inches, this is equivalent to changing the size of the ruler. Nonetheless, for the purposes of this paper, we will concede that overall computational power does continue to increase with the industry's efforts.

In early 2006, IBM researchers announced that they had developed a technique to print circuitry only 29.9 nm wide using deep-ultraviolet (DUV) optical lithography. IBM claims that this technique may allow chipmakers to use current methods for seven years while continuing to achieve results predicted by Moore's Law. New methods that can achieve smaller circuits are predicted to be substantially more expensive.

Since the rapid exponential improvement could (in theory) put 100 GHz (gigahertz) personal computers in every home and 20 GHz devices in every pocket, some commentators have speculated that sooner or later computers will meet or exceed any conceivable need for computation. This is only true for some problems – there are others where exponential increases in processing power are matched or exceeded by exponential increases in the complexity of some problems. These types of complex problems are very common in applications such as scheduling of massively-large simulations of the type previously discussed in section 4.3.

The exponential increase in frequency of operation as the only method of increasing computation speed is misleading. What matters is the exponential increase in useful work (or instructions) executed per unit time. In fact, newer processors are actually being made at lower clock speeds, with focus on larger caches and multiple computing cores. This occurs because higher clock speeds correspond to exponential increases in temperature, making it possible to have a central processing unit (CPU) that is capable of running at 4.1 GHz for only a couple hundred dollars (using practical, yet uncommon methods of cooling), but it is almost impossible to produce a CPU that runs reliably at speeds higher than 4.3 GHz or so.

On 13 April 2005, Gordon Moore himself stated in an interview that his law may not hold for too long, since transistors may reach the limits of miniaturization at atomic levels.

"In terms of size [of transistor] you can see that we're approaching the size of atoms that is a fundamental barrier, but it'll be two or three generations before we get that far – but that's as far out as we've ever been able to see. We have another 10 to 20 years before we reach a fundamental limit. By then they'll be able to make bigger chips and have transistor budgets in the billions."

While this time horizon for Moore's Law scaling is possible, it does not come without underlying engineering challenges (such as increased parameter variation and leakage currents, issues both associated with integrated circuits with nanoscale transistors).

4.4.2 Kryder's Law

In a manner similar to Moore's Law, computer engineer Dr. Mark Kryder has observed that since the introduction of the computer disk drive in 1956, the density of information such a drive can record has swelled from a paltry 2,000 bits to 100 billion bits (gigabits), all crowded in the small space of a square inch. This represents a 50-million-fold increase, which vastly exceeds the rate of transistor miniaturization for integrated circuit production predicted by Moore's Law.

This trend of an exponential increase in disk drive storage capacity is sometimes referred to as Kryder's Law.

As Kryder has observed, capacious hard drives are replacing low-capacity flash memory cards, which use electrically charged transistors rather than moving parts to record information. Soon, hard drives will migrate into phones, still cameras, PDAs, cars and everyday appliances. "In a few years, the average U.S. consumer will own 10 to 20 disk drives in devices that he uses regularly," Kryder predicts. These advances are forcing manufacturers to become much more nimble as their markets expand.

But now current hard-drive technologies are hitting a new wall. Hard disks typically store bits of information using a tiny head that flies across the surface of the disk and magnetizes billions of discrete areas in horizontal space that represent zero or one, depending on whether they are facing clockwise or counterclockwise. The magnetized areas are becoming so small that it is difficult for them to remain stable.

Kryder and his team are reviving a method called perpendicular recording to fix the problem. It flips the charges north to south, permitting the use of stronger magnetic fields in media that can store smaller bits. This approach has already been prototyped, which should pack in at least 200 gigabits per square inch within the next two years. Ultimately, Kryder thinks perpendicular drives will record 400 or 500 gigabits within four years. A research team headed by Dr. Kryder is currently investigating novel disk drive technologies with the potential to yield a terabit of stored information per square inch, a goal Kryder predicts will be achieved by 2012.

4.4.3 Kurzweil's Law of Accelerating Returns

In 2001, renowned futurist Ray Kurzweil proposed an extension of Moore's Law that he refers to as the Law of Accelerating Returns. Kurzweil's Law speculates that (based upon historical evidence) whenever a technology approaches some kind of a developmental barrier, a new technology will be invented to allow mankind to cross that barrier. Kurzweil justified his speculation by referring to technologies dating from far before the integrated circuit to future (and as-of-yet uninvented) forms of computation.

"Moore's Law of Integrated Circuits was not the first, but the fifth paradigm to provide accelerating price-performance. Computing devices have been consistently multiplying in power (per unit of time) from the mechanical calculating devices used in the 1890 U.S. Census, to Turing's relay-based "Robinson" machine that cracked the German Enigma code, to the CBS vacuum tube computer that predicted the election of Eisenhower, to the transistor-based machines used in the first space launches, to the integrated-circuit-based personal computers…An analysis of the history of technology shows that technological change is exponential, contrary to the common sense ''intuitive linear' view. So we won't experience 100 years of progress in the twenty first century – it will be more like 20,000 years of progress (at today's rate). The 'returns,' such as chip speed and cost-effectiveness, also increase exponentially. There's even exponential growth in the rate of exponential growth. Within a few decades, machine intelligence will surpass human intelligence, leading to…technological change so rapid and profound it represents a rupture in the fabric of human history." Figure 4.35 illustrates the Law of Accelerating Returns as applied to predicted supercomputer power, where the maximum anticipated computational power per processor grows at an exponential rate. Thus, Kurzweil conjectures that it is likely that some new type of technology will replace current integrated-circuit technology, and that Moore's Law will hold true long after 2020 (i.e., beyond the use of integrated circuits into more advanced future technologies).

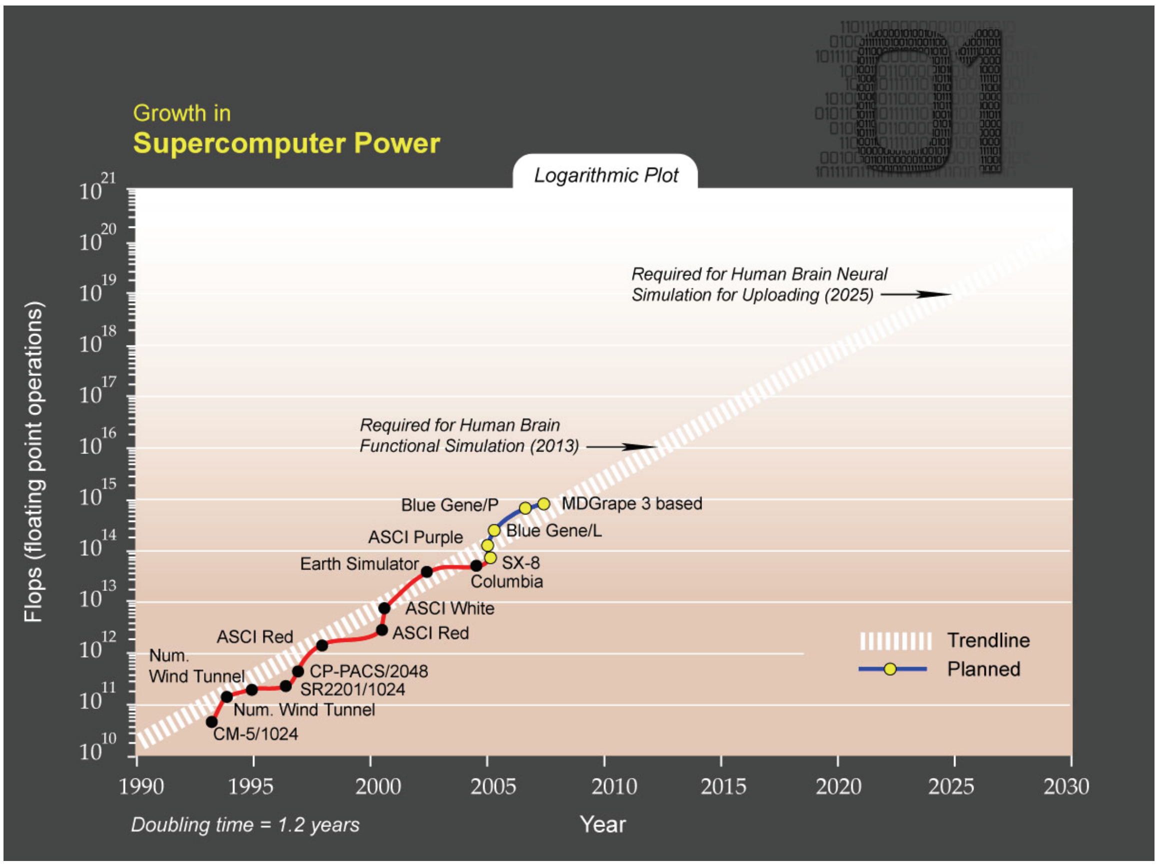


Figure 4.35. Kurzweil's illustration of exponential growth in supercomputer power (including his predicted point in time where simulation of human intelligence will be possible).

4.5 Emerging Technologies of Interest

In this section, data fusion and analysis technologies that are likely to emerge in the years 2020 – 2030 are discussed. In all cases, these emerging technologies are expected to evolve from current research into the technology areas previously described in sections 4.1 – 4.4.

4.5.1 Intelligent Sensor Webs

An Intelligent Sensor Web is a network of distributed multi-modal sensors that fuse data in a decentralized manner that will evolve from Pau's behavioral knowledge-based data fusion model (see section 4.2.1.5) or the distributed blackboard fusion architecture (see section 4.2.1.6). This sensor network is capable of sensing, recognizing, and then reporting acquired entities and objects. Since this is a spatially distributed technology, the implementation framework of the web will evolve from wireless sensor networks (see section 2.3.5.3) since they are not constrained by physical limitations.

Intelligent sensor web technology will be capable of servicing the Logistics Prediction and Preemption mission by allowing spatially distributed sensors mounted on networked platforms and infantry to dynamically collect, transmit, fuse, and analyze data on quantity and location of existing supplies and assets. By cooperatively tracking the status of supplies distributed across the operating environment as a function of time, intelligent sensor webs will provide military logisticians with real-time aggregated knowledge addressing re-supply requirements in various operational areas. In addition, intelligent sensor webs will also be capable of identifying and tracking hostile forces (such as terrorists or insurgents) that might intend to interfere with U.S./coalition force combat support missions.

4.5.2 Adaptive Sensor Webs

An Adaptive Sensor Web is a network of distributed multi-modal sensors that fuse data in a decentralized manner that will evolve from the Omnibus fusion model based on John Boyd's OODA loop (see section 4.2.1.7). This sensor network will be capable of adapting to dynamic levels of sensor data confidence to hone in on the best interpretation of a sensed operating environment situation. Adaptive sensor webs will prove to be very useful when mountable in a mobile and dynamic sensing environment, and thus will need to evolve from wireless sensor networks (see section 2.3.5.3) due to the latter's ability to be mounted into a multiplicity of different platform types as well as infantry.

In a fashion similar to that of intelligent sensor webs, adaptive sensor web technology will also be capable of servicing the Logistics Prediction and Preemption mission via spatially distributed networked sensors. However, there is an advantage that adaptive sensor webs have over intelligent sensor webs when servicing this mission. Although adaptive sensor webs will dynamically collect and transmit data in a manner similar to that used in intelligent sensor webs, the former sensor web technology will provide better data fusion and analysis support. This will be evidenced by an adaptive sensor web's capability to recursively modify the logistics common operational picture by prioritizing available asset quantity/location data as a function of data confidence (i.e., trustworthiness). This will allow the adaptive sensor web to selectively fuse the best data to generate the most reliable collective description of existing supplies and assets distributed across the operating environment as a function of time. In addition, adaptive sensor webs will also be capable of identifying and tracking hostile forces that might intend to interfere with U.S./coalition force combat support missions.

4.5.3 Formal Concept Analysis Based Data Mining

A database search engine that data mines to construct concept lattices that will evolve from a combination of current Formal Concept Analysis technology (see section 4.2.2) and data mining (a form of Predictive Analytics technology; see section 4.3.3). This will allow the search engine plus database to automatically generate an ontology by matching attributes of unknown or unrecognized entities and objects with attributes of known entities/objects. This will represent a form of automated data classification.

Formal Concept Analysis based data mining technology will be capable of servicing the Logistics Prediction and Preemption mission by allowing military logisticians to quickly search different dynamically-updated operating environment databases over the GIG to fuse and analyze mission-relevant data patterns. These data patterns might relate to operational situations such as

- U.S./coalition force asset distribution and status across the operating environment,
- Locations of progressing hostile activity across the operating environment, and
- Developing weather patterns that, when combined with certain types of terrain, might negatively interfere with re-supply convoys.

By associating and categorizing the status of different types of operating environment objects within a database as a function of common/shared object attributes, Formal Concept Analysis based data mining technology will provide the military logistician with a means to construct an integrated, coherent, and meaningful operational picture that best serves their specific mission needs.

4.5.4 Simulation-Based COA Analysis

A software package will evolve from a combination of the MMF-based JTIMS planning tool (for performing mission-to-task decomposition for combat support missions; see section 4.3.1.3) plus an agent-based model such as Cougaar or CoRBCAM (for simulation of the combat support plan to be analyzed for prediction and preemption purposes; see section 4.3.4). This emerging technology allows the military planner to explore possible courses of action (COAs) constructed with JTIMS by simulating friendly force performance (using a specific COA) with the agent-based model. Such an analysis process could require the modeling and simulation of a multiplicity of candidate combat support COAs, and would thus require a massively parallel computer architecture that would evolve from teraflop (i.e., one trillion floating point operations per second) technology (which may result from Kurzweil's Law of Accelerating Returns; see section 4.4.3). Finally, the time-series results of simulations are analyzed relative to one another via techniques evolved from state/phase space and world line analysis technology (see section 4.3.6) to explore a multiplicity of "what if" scenarios via tracking and comparison of COA-specific friendly force performance trajectories through a state space.

Simulation-based COA analysis technology will be capable of supporting the Logistics Prediction and Preemption mission by allowing military logisticians to

- create a set of alternate COAs that will potentially address a commander's mission objective,
- separately simulate U.S./coalition force deployment of each COA within a virtual operating environment, and
- analyze the mission effectiveness of each COA as a function of variable levels of uncertainty in the fused data used to configure the initial state of the simulated operating environment.

In the first stage of this COA analysis process, an MMF-based planning tool will be used to assign specific mission-oriented tasks to constituent elements of military units (including manned platforms, robotic platforms, infantry, and Logistics Operation Centers (LOCs). This task assignment process will basically associate the specific capabilities required to effectively execute a task with military elements that are equipped with those capabilities. For example, individual combat support unit platforms that support a sustainment mission might be assigned tasks as a function of mobility, sensor, firepower, and re-supply capacity (i.e., berth space) capabilities. Finally, this MMF-based planning process can be used to create additional alternate COA (where each COA involves assignment of tasks to specific platforms as a function of platform capabilities).

In the second stage of the simulation-based COA analysis process, military logisticians will test out the operational feasibility of each alternate COA by simulating (within a virtual operating environment) the dynamics of each U.S./coalition force entity that has been assigned specific time-phased tasks contributing to a particular COA. For the sustainment mission mentioned in the previous paragraph, the mission effectiveness of a particular course-of-action might be dynamically tracked by measuring quantities such as combat support entity health and task effectiveness (e.g., what percentage of initial re-supply stock is a platform still capable of transporting?) as a function of simulation time. Assuming that the fused data used to configure the initial state of a simulated operating environment might be rife with varying levels of uncertainty, a logistician will probably want to construct a variety of "what if" scenarios within which to test out each optional COA. For example, a set of "what if" scenarios might involve combinatorial variations in initial operating environment conditions such as enemy troop size, makeup, and location, weather conditions, and possible civil unrest conditions.

In the third and final stage of the simulation-based COA analysis process, military logisticians will use a post-processing software tool to study and analyze, for each simulated alternate COA, the variations in mission effectiveness resultant from executing the COA within different "what if" scenarios. Assuming that each optional COA has been simulated within the context of the full set of "what if" scenarios, a corresponding set of state space trajectories (dynamically tracking U.S./coalition force health and task effectiveness within each “what if” scenario as a function of simulation time) will be available for software analysis. If the state space trajectories are widely distributed across the battle state space (indicating extreme sensitivity to variations in “what if” scenario conditions), then the mission effectiveness of the associated COA will be as uncertain as the fused data used to configure the simulated operating environment. On the other hand, if the trajectories remain tightly clustered as they evolve through time in the battle state space, then the COA will be robust to variations in “what if” scenario conditions and the associated mission effectiveness will be highly predictable.

4.5.5 Social Network Analysis

When addressing asymmetric warfare threats to military supply chains in an operational context, the analysis of social networks can provide critical insight to preemptive planning. Figure 4.36 illustrates a diagrammatic example of a simple social network. Social network analysis views social relationships in terms of nodes and ties. Nodes are the individual actors within the networks, and ties are the relationships between the actors.

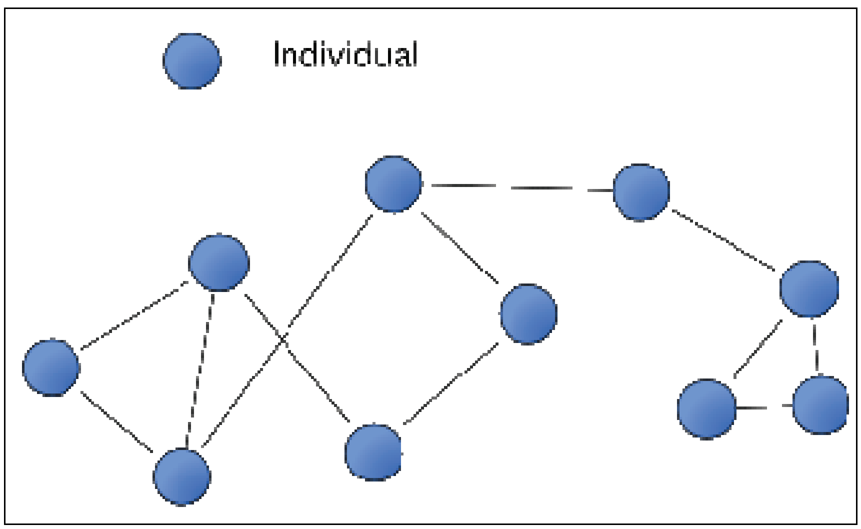


Figure 4.36. An example of a social network diagram.

The following techniques will emerge from current academic research within the field of social network analysis.

- Linkage analysis (a technology that will emerge from a combination of the distributed blackboard fusion architecture and the Omnibus fusion model (see sections 4.2.1.6 and 4.2.1.7, respectively)) consists of forming a graph that illustrates a person’s social network, storing this information in a database, and recording “association rules” and “transactions” for each relationship in order to permit the use of data mining algorithms. For example, current Internet site profiling uses a decision-tree-based technique called classification that can be used to distinguish people who are high credit risks from those who are low credit risks.

- The technique of trend discovery (a type of Predictive Analytics technology; see section 4.3.3) is used to exploit a database of sequences by recording sequential patterns and Web client queries. For example, trend discovery could be used to analyze the frequency of visits made to extremist/terrorist recruitment Web sites by Internet users to determine the potential size and danger of terrorist cells operating within a specific mission theater. Response analyzer algorithms can be used to identify trends in news group postings on a particular topic over time. However, it is often difficult to distinguish between responses for and against a particular topic, given that positive and negative postings tend to use almost identical vocabulary.
- Modeling social networks as Bayesian networks (another technique from Predictive Analytics technology that creates causal graphs associated with underlying probability distributions to represent likely associations that are meaningful to a human being) allows an intelligence analyst to represent suspected but uncertain relationships between potential terrorists or extremist insurgents within a theater of operations.

Finally, current research by Lefebvre and associates that will evolve into the integration of Reflexive Theory (see section 4.3.5) with the above technologies of distributed blackboard fusion architecture, the Omnibus fusion model, and Predictive Analytics should result in a future software technology allowing logistics analysts to anticipate and preempt terrorist interdiction with friendly force combat support operations.

4.5.6 Simulation-Based Reflexive Analysis

A software package that will evolve from the MMF-based JTIMS planning tool (see section 4.3.1.3), an agent-based model (see section 4.3.4), and Lefebvre's Reflexive Theory (see section 4.3.5). This allows the military planner to explore possible COAs by simulating an operating environment populated by hostile military, paramilitary, or civilian terrorist agents that themselves model and anticipate friendly force actions in an attempt to control and/or disrupt them. Such an analysis process would require the modeling and simulation of multiple recursive levels of decision-making within agents, and would thus require a massively parallel computer architecture that would evolve from teraflop (i.e., one trillion floating point operations per second) technology (which may result from Kurzweil's Law of Accelerating Returns; see section 4.4.3). Again, the time-series results of simulations are analyzed relative to one another via techniques evolved from state/phase space and world line analysis technology (see section 4.3.6) to explore a multiplicity of "what if" scenarios involving enemy forces with highly adaptive decision-making abilities.

Social network analysis technology will be capable of servicing the Logistics Prediction and Preemption mission by allowing military logisticians to search different intelligence databases over the GIG to fuse data reports on various suspected terrorist/insurgent individuals and groups operating either strategically or within a theater. The results of this data fusion process will uncover patterns of possible collaborative/coordinated activity involving social networks of likeminded individuals and groups dedicated to opposing U.S./coalition force mission objectives. By revealing the organizational structure and probable intentions of these loosely-coordinated hostile entities, social network analysis technology will provide the military logistician with a means to anticipate, predict, and thus preempt likely attacks upon U.S./coalition force combat support operations.

Simulation-based reflexive analysis technology will be capable of supporting the Logistics Prediction and Preemption mission by allowing military logisticians to

- create a set of alternate COAs for *both* U.S./coalition and enemy forces that will potentially address a specific commander's mission objective,
- separately simulate deployment of each *N* U.S./coalition force COA in combination with each *M* enemy force COA (i.e., a total of *N*M* combinations) within a virtual operating environment, and
- analyze the mission effectiveness of each *N* U.S./coalition force COA as a function of i) variable levels of uncertainty in the fused data used to configure the initial state of the simulated operating environment *and* ii) U.S./coalition force performance given enemy force deployment of each of their own *M* alternate COAs.

In the first stage of this reflexive analysis process, an MMF-based planning tool will be used in to assign specific mission-oriented tasks to constituent elements of U.S./coalition force units (including manned platforms, robotic platforms, infantry, and LOCs). This task assignment process will associate the specific capabilities required to effectively execute a task with military elements that are equipped with those capabilities. For example, individual platforms within a combat support unit that supports a sustainment mission might be assigned tasks as a function of mobility, sensor, firepower, and re-supply capacity (i.e., berth space) capabilities. Finally, this MMF-based planning process will be used to create a total of *N* alternate COAs (where each COA involves assignment of tasks to specific platforms as a function of platform capabilities).

In the second stage of the simulation-based reflexive analysis process, a reflexive tool will be used by U.S./coalition logistics planners to model the actions planned by hostiles (i.e., paramilitary units, terrorists, and/or insurgents) to disrupt friendly force combat support operations. This reflexive COA assignment process will i) model a hostile commander's cognitive interpretation of the tasks that his/her opponent (i.e., the U.S./coalition force commander) will assign to friendly military elements, and then ii) assign tasks to hostile paramilitary/terrorist/insurgent elements that will serve to interfere with U.S./coalition force tasks. For example, individual civilian hostiles within a terrorist cell that intends to disrupt a U.S./coalition force sustainment mission might be assigned coordinated suicide bombing actions that attempt to impede and detain the friendly force elements. Finally, this reflexive-based planning process will be used to create a total of *M* alternate COAs for members of the terrorist cell to execute.

In the third stage of the simulation-based reflexive analysis process, military logisticians will test out the operational feasibility of each of the *N* alternate U.S./coalition force COAs by simulating (within a virtual operating environment) the dynamics of each U.S./coalition force entity that has been assigned specific time-phased tasks contributing to a particular COA. For the sustainment mission mentioned in the previous paragraph, the mission effectiveness of a particular COA might be dynamically tracked by measuring quantities such as combat support entity health and task effectiveness (e.g., what percentage of initial re-supply stock is a platform still capable of transporting?) as a function of simulation time. Each U.S./coalition force COA will be simulated against each of the *M* hostile force courses-of-action, making for a total of $N*M$ simulated pairings of a U.S./coalition force course-of-action against an enemy force's opposing COA. Assuming that the fused data used to configure the initial state of a simulated operating environment might be rife with varying levels of uncertainty, a logistician will probably want to construct a variety of "what if" scenarios within which to test out each of the $N*M$ simulated friendly/enemy COA pairings. For example, a set of "what if" scenarios might involve combinatorial variations in initial operating environment conditions such as enemy troop size, makeup, and location, weather conditions, and possible civil unrest conditions. Finally, given *Q* different "what if" scenario variations on each of the $N*M$ COA pairings, the logistician would use an agent-based model embedded within the simulation-based reflexive analysis technology to run $N*M*Q$ different simulation instances.

In the fourth and final stage of the simulation-based reflexive analysis process, military logisticians will use a post-processing software tool to study and analyze, for each of the $N*M$ simulated friendly/enemy COA pairings, the variations in U.S./coalition force mission effectiveness resultant from executing a specific U.S./coalition force COA within different "what if" scenarios. Assuming that all of the $N*M*Q$ different simulation runs described in the previous paragraph have been computed, a corresponding set of $N*M*Q$ state space trajectories (dynamically tracking U.S./coalition force health and task effectiveness within each friendly/enemy course-of-action pairing and "what if" scenario as a function of simulation time) will be available for software analysis. If the state space trajectories associated with a particular U.S./coalition force course-of-action (i.e., the i^{th} friendly force COA, where $i = 1, 2, \ldots, N$) are widely distributed across the battle state space (indicating extreme sensitivity to variations in "what if" scenario conditions), then the mission effectiveness of the associated friendly force COA will be as uncertain as the fused data used to configure the simulated operating environment. On the other hand, if the trajectories remain tightly clustered as they evolve through time in the battle state space, then the i^{th} friendly force COA i) will be consistently effective (or consistently *in*effective) against each of the *M* hostile force COA and ii) will be robust to variations in "what if" scenario conditions. Thus, the mission effectiveness of the i^{th} friendly force COA will be highly predictable.

4.5.7 Cyc-Based Virtual Logisticians

The Cyc knowledge base (KB) is a formalized representation of a vast quantity of fundamental human knowledge: facts, rules of thumb, and heuristics for reasoning about the objects and events of everyday life. The means that knowledge is represented in Cyc is through a formal logical language called Cycle, which is a large and extraordinarily flexible knowledge representation language. CycL is essentially an augmentation of first-order predicate calculus (FOPC), with formal extensions that are capable of handling mathematical logic relationships such as equality, default reasoning, skolemization, and some second-order features. The Cyc KB consists of terms – which constitute the vocabulary of CycL – and logical assertions that relate those terms. These assertions include both simple ground assertions and rules. In other words, Cyc (based on its current developmental status) should continue to evolve into the future as a type of hybrid ontology (see section 4.1.3).

The Cyc KB is divided into many (currently thousands of) "micro-theories", each of which is essentially a bundle of assertions that share a common set of assumptions; some micro-theories are focused on a particular domain of knowledge, a particular level of detail, a particular interval in time, etc. This micro-theory mechanism allows Cyc to independently maintain and select between assertions that are prima facie contradictory. The Cyc inference engine performs automated operations in mathematical logical deduction (including modus ponens, modus tollens, and universal and existential quantification). Cyc can also perform adaptive searches over a solution space using a set of proprietary heuristics to efficiently arrive at optimal problem solutions (relative to all possible solutions available within the space). As its development continues into the future, the Cyc KB could potentially use a combination of many (perhaps all) different types of data fusion architectures to create and reason about a data-integrated common operational picture (COP) within a military application context. This future Cyc KB will thus evolve from a combination of the JDL process fusion model (see section 4.2.1.1), the Thomopoulos architecture (see section 4.2.1.2), the multi-sensor integration fusion model (see section 4.2.1.3), the behavioral knowledge-based data fusion model (see section 4.2.1.5), the distributed blackboard fusion architecture (see section 4.2.1.6), and the Omnibus fusion model (see section 4.2.1.7).

As illustrated in Figure 4.37, information stored in a database or on the web is made available to the Cyc inference engine as virtual assertions. These sets of virtual assertions are managed by heuristic level (HL) modules. For example, the inference engine "broadcasts" a query on the bus. An HL module recognizes that the request asks for an assertion that maps into its virtual knowledge space. The HL module intercepts the request, communicates with the database, web site or other knowledge source, and returns bindings to the inference engine. Inference then continues, combining information from multiple sources. Thus, when combined with simulation agent software technology (see section 4.3.4) and future computational technology (which may result from Kurzweil's Law of Accelerating Returns; see section 4.4.3), a future version of Cyc could instantiate a set of cooperating virtual human logistics analysts (i.e., agents that can effectively emulate a human logistician's decision-making process) that interact with the Global Information Grid (GIG) to perform net-centric analysis and planning.

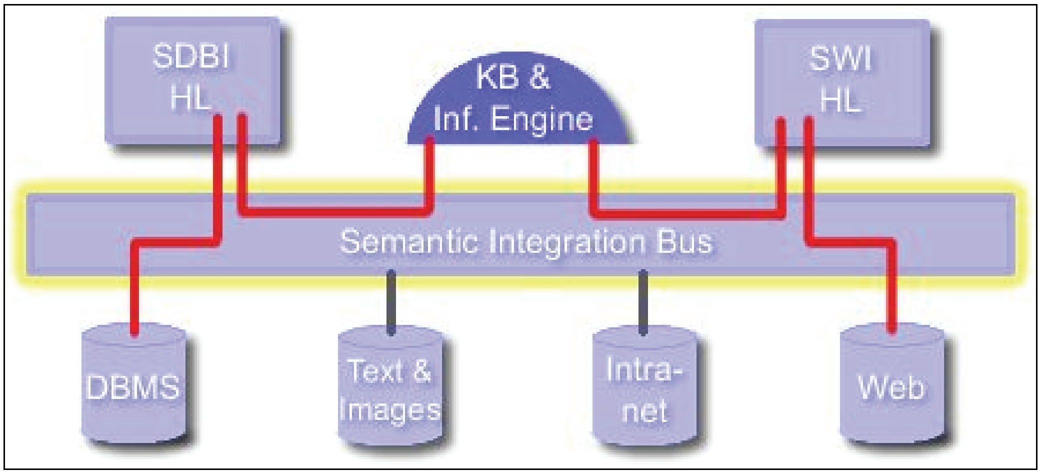


Figure 4.37. The semantic integration bus within the CyC KB.

Cyc-based virtual logistician technology will be capable of servicing the Logistics Prediction and Preemption mission by providing military logisticians with a low-cost and low-maintenance "staff" of software agents with essentially human intelligence and reasoning capabilities (as provided by the future evolved version of Cyc). Such a staff of virtual logisticians will themselves be able to use an entire spectrum of software-based Prediction and Preemption capabilities (ranging from current existing software and database technologies up to any and all of the emerging technologies of interest previously described in sections 4.5.1 – 4.5.6). Finally, the addition of a virtual logistician staff to supplement the human staff within a LOC will in turn increase the operational effectiveness of a typical 2030-era LOC by at least an order of magnitude.

4.6 Emerging Data Fusion and Analysis Technologies: Rankings and Quad Chart

4.6.1 Technology Rankings

4.6.1.1 Intelligent Sensor Webs

ISW			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			26		3.00
	1	Behavioral Knowledge-Based Fusion Model	7	3	0.81
	2	Distributed Blackboard Fusion Architecture	10	3	1.15
	3	Wireless Sensor Networks	9	3	1.04
Cost			46		1.37
	1	Raw Materials	3	1	0.07

	2 Hardware Processing Cost	6	1	0.13
	3 Software Development Cost	10	2	0.43
	4 Mfr Scalability	7	1	0.15
	5 Devices	8	1	0.17
	6 Engr-NRE	7	2	0.30
	7 Engr-Integration	5	1	0.11
Benefit to LPPC		81		2.49
	1 Losing the engagement (Mission) to the Enemy	2	2	0.05
	2 Soldiers dying or being wounded	6	3	0.22
	3 Running out of Ammunition	5	2	0.12
	4 Running out of Fuel	5	2	0.12
	5 Running out of Medical Supplies	5	2	0.12
	6 Running out of Water	5	2	0.12
	7 Running out of Batteries/Fuel Cells	5	2	0.12
	8 Breakdown of Equipment Not Due to Enemy	1	1	0.01
	9 Encountering Bad Weather	3	2	0.07
	10 Encountering Threat Forces	8	3	0.30
	11 Loss of Strategic Lift Assets and Their Cargo	1	3	0.04
	12 Loss of Theater Lift Assets and Their Cargo	5	3	0.19
	13 Closure of APODs and SPODs	1	1	0.01
	14 Closure of Sea Lanes	3	3	0.11
	15 Loss of LOCs	5	3	0.19
	16 Encountering Inaccessible Terrain with Convoys	7	3	0.26
	17 Untimely Delivery of Mission Critical Parts	2	1	0.02
	18 Loss of Comms w/log, intel and ops	3	2	0.07
	19 Loss of Common Operating Picture (COP)	9	3	0.33

Behavioral Knowledge-Based Fusion Model – There are many rapidly growing current technology areas where *a priori* knowledge of the behavior of objects or clients can be shared among networked decision-making entities to create a larger-scale situational picture (e.g., robotic swarms, networked ATMs, etc.). This will provide a stable foundation from which Intelligent Sensor Webs can evolve.

Distributed Blackboard Fusion Architecture – There is considerable ongoing research committed to the development of distributed blackboard fusion architectures to support opportunistic service-oriented computer networks. The distributed blackboard fusion architecture has already been applied to the development of distributed grid services for computationally intensive scientific processing such as studying climate change, investigating protein-related diseases, crypto-analysis, and intrusion detection systems. This will allow distributed blackboard fusion architectures to contribute to a stable foundation from which Intelligent Sensor Webs can evolve.

Wireless Sensor Networks – There are many companies that have integrated wireless communication capabilities with some form of sensor monitoring functions (e.g., Crossbow, Moteiv). Thus, wireless sensor networks are already emerging as a stable sub-technology.

Raw Materials – The raw materials that go into the construction of Intelligent Sensor Webs are the fundamental components making up the individual sensor "motes." These components include the sensor device, a micro-controller, and a transceiver on a small board configuration. Such raw materials can be mass-produced at very cost-effective rates.

Hardware Processing Cost – The raw materials making up the sensor "motes" within Intelligent Sensor Webs are all currently mass-produced in a very cost-effective manner. This should tend to minimize the associated hardware processing costs.

Software Development Cost – The ongoing but costly commitment to research and development of both behavioral knowledge-based data fusion and distributed blackboard data fusion in academia, business, and government strongly implies moderate software development costs for the future Intelligent Sensor Web technology that will evolve from these two sub-technologies.

Scalability – Blackboard fusion architectures were originally designed to solve problems that benefit from the parallel implementation of knowledge sources (such as databases). By implementing a distributed parallel blackboard architecture, the processing speed of the collective framework can be greatly increased. Thus, Intelligent Sensor Webs, which will evolve in part from current distributed blackboard fusion architectures, are readily scalable to improve processing speed and (in turn) lower net data processing costs.

Devices – The sensor "motes" making up the constituent elements of Intelligent Sensor Webs are designed with the capability of long-term operations with very small batteries such as coin and AA cells. This makes these devices very low-maintenance and cost-effective to operate.

Engineering: Non-Recurring Engineering – Behavioral knowledge-based fusion technology, distributed blackboard fusion technology, and wireless sensor network technology should all have an extensive but costly research and development history by 2020. This strongly implies that any future technology that will evolve from these sub-technologies (i.e., Intelligent Sensor Webs) will require moderate non-recurring software engineering costs from application-specific users of the future technology.

Engineering: Integration – One of the important design factors that companies currently investing in wireless sensor networks address is the low energy requirements of the entire system. By working to minimize power requirements of existing wireless sensor network technology, the future technology of Intelligent Sensor Webs that will evolve from these networks will be easily integrated into Prediction and Preemption hardware architectures.

Undesirable Outcomes to Preempt:

Soldiers dying or being wounded – When properly deployed, Intelligent Sensor Webs will be capable of sensing, recognizing, and then reporting identity and location of acquired enemy entities across a spatially distributed area. This will sometimes allow friendly combat support units to avoid exposing friendly soldiers to enemy engagements.

Encountering threat forces – When properly deployed, Intelligent Sensor Webs will be capable of sensing, recognizing, and then reporting identity and location of acquired enemy entities across a spatially distributed area. This will allow friendly combat support units to avoid exposing friendly assets to destruction by enemy forces.

Encountering inaccessible terrain with convoys – When properly deployed, Intelligent Sensor Webs mounted on spatially distributed surveillance and reconnaissance platforms will be capable of sensing, recognizing, and then reporting the location of forward inaccessible terrain back to convoy C2 platforms. This will often allow friendly combat support convoys to proactively anticipate inaccessible terrain and then plan for alternate routes (given the latter option can be realized).

Loss of Log COP – When properly deployed, Intelligent Sensor Webs will be capable of sharing logistics situational information across the GIG. This will serve to facilitate a continuous Log COP by allowing healthy autonomous sensors and sensor-equipped platforms to fill in for other damaged and/or destroyed sensors and sensor platforms.

4.6.1.2 Adaptive Sensor Webs

ASW			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			19		2.47
	1	Omnibus Fusion Model	10	2	1.05
	2	Wireless Sensor Networks	9	3	1.42
Cost			46		1.37
	1	Raw Materials	3	1	0.07
	2	Hardware Processing Cost	6	1	0.13
	3	Software Development Cost	10	2	0.43
	4	Mfr Scalability	7	1	0.15
	5	Devices	8	1	0.17
	6	Engr-NRE	7	2	0.30
	7	Engr-Integration	5	1	0.11
Benefit to LPPC			87		2.78
	1	Losing the engagement (Mission) to the Enemy	2	2	0.05
	2	Soldiers dying or being wounded	8	3	0.28
	3	Running out of Ammunition	5	3	0.17
	4	Running out of Fuel	5	3	0.17
	5	Running out of Medical Supplies	5	3	0.17

6	Running out of Water	5	3	0.17
7	Running out of Batteries/Fuel Cells	5	3	0.17
8	Breakdown of Equipment Not Due to Enemy	1	1	0.01
9	Encountering Bad Weather	6	2	0.14
10	Encountering Threat Forces	8	3	0.28
11	Loss of Strategic Lift Assets and Their Cargo	1	3	0.03
12	Loss of Theater Lift Assets and Their Cargo	5	3	0.17
13	Closure of APODs and SPODs	1	1	0.01
14	Closure of Sea Lanes	3	3	0.10
15	Loss of LOCs	5	3	0.17
16	Encountering Inaccessible Terrain with Convoys	8	3	0.28
17	Untimely Delivery of Mission Critical Parts	2	1	0.02
18	Loss of Comms w/log, intel and ops	3	2	0.07
19	Loss of Common Operating Picture (COP)	9	3	0.31

Omnibus Fusion Model – Although this technology was first presented in 2000 within the context of Aerospace Engineering, the Omnibus model of data fusion has recently been applied to research areas as diverse as multi-target tracking by sensor networks, intelligent fault detection, and human genome analysis. However, developing this goal-oriented/task-oriented data fusion method to a future level where it can effectively support Adaptive Sensor Webs by 2020 is questionable. Nevertheless, it is more likely the Omnibus fusion model will be able to support the evolution of Adaptive Sensor Webs by 2030.

Wireless Sensor Networks – There are many companies that have integrated wireless communication capabilities with some form of sensor monitoring functions (e.g., Crossbow, Moteiv). Thus, wireless sensor networks are already emerging as a stable sub-technology.

Raw Materials – The raw materials that go into the construction of Adaptive Sensor Webs are the fundamental components making up the individual sensor "motes." These components include the sensor device, a micro-controller, and a transceiver on a small board configuration. Such raw materials can be mass-produced at very cost-effective rates.

Hardware Processing Cost – The raw materials making up the sensor "motes" within Adaptive Sensor Webs are all currently mass-produced in a very cost-effective manner. This should tend to minimize the associated hardware processing costs.

Software Development Cost – The ongoing but costly commitment to research and development of the Omnibus data fusion model in academia, business, and government strongly implies moderate software development costs for the future Adaptive Sensor Web technology that will evolve from this sub-technology.

Scalability – Parallel implementation of an Omnibus fusion model over a network of computer databases will greatly increase the processing speed of the collective framework. Thus, Adaptive Sensor Webs, which will evolve in part from implementation of an Omnibus fusion model, are readily scalable to improve processing speed and (in turn) lower net data processing costs.

Devices – The sensor "motes" making up the constituent elements of Adaptive Sensor Webs are designed with the capability of long-term operations with very small batteries such as coin and AA cells. This makes these devices very low-maintenance and cost-effective to operate.

Engineering: Non-Recurring Engineering – Wireless sensor network technology and Omnibus fusion technology should have an extensive and costly research and development history by 2020 and 2030, respectively. This strongly implies that any future technology that will evolve from these sub-technologies (i.e., Adaptive Sensor Webs) will only require moderate non-recurring software engineering costs from application-specific users of the future technology.

Engineering: Integration – One of the important design factors that companies currently investing in wireless sensor networks address is the low energy requirements of the entire system. By working to minimize power requirements of existing wireless sensor network technology, the future technology of Adaptive Sensor Webs that will evolve from these networks will be easily integrated into Prediction and Preemption hardware architectures.

Undesirable Outcomes to Preempt:

Soldiers Dying or Being Wounded – When properly deployed, Adaptive Sensor Webs will be capable of sensing, recognizing, and then adaptively tracking locations of acquired enemy entities as the latter move across a spatially distributed area of operations. This will very often allow friendly combat support units to avoid exposing friendly soldiers to enemy engagements.

Running Out of Ammunition, Fuel, Medical Supplies, Water, and Batteries/Fuel Cells – When properly deployed on spatially distributed platforms and infantry units, Adaptive Sensor Webs will be capable of fusing and analyzing data reports addressing amount and location of existing ammunition, fuel, medical supply, water, and battery/fuel cell assets within the operating environment. Given these data reports will be continuously updated and distributed over the GIG, Adaptive Sensor Webs will allow military logisticians in LOCs to adaptively focus their attention on high-demand operational areas for combat support mission planning purposes.

Encountering Inaccessible Terrain with Convoys – When properly deployed, Adaptive Sensor Webs mounted on spatially distributed surveillance and reconnaissance platforms will be capable of sensing, recognizing, and reporting the location of forward inaccessible terrain. These Adaptive Sensor Webs will also be capable of adaptively exploring nearby terrain areas for accessibility to provide for alternate transportation routes.

Encountering Bad Weather – When deployed in a spatially distributed fashion, Adaptive Sensor Webs will be capable of sharing situational information on local weather conditions across the

GIG. This will then allow the Adaptive Sensor Web to fuse reports on weather conditions in different geographic areas and thus identify and anticipate potential hazardous weather as it starts to form. This will serve to preempt exposure of combat support units to bad weather only in situations where hazardous conditions can be anticipated sufficiently in advance of unit deployment.

4.6.1.3 Formal Concept Analysis Based Data Mining

FCA			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			18		3.00
	1	Data Mining search engines	8	3	1.33
	2	Formal Concept Analysis Methodology	10	3	1.67
Cost			30		1.53
	1	Software Development Cost	10	2	0.67
	2	Mfr Scalability	9	1	0.30
	3	Engr-NRE	6	2	0.40
	4	Engr-Integration	5	1	0.17
Benefit to LPPC			94		2.59
	1	Losing the engagement (Mission) to the Enemy	2	2	0.04
	2	Soldiers dying or being wounded	8	3	0.26
	3	Running out of Ammunition	5	2	0.11
	4	Running out of Fuel	5	2	0.11
	5	Running out of Medical Supplies	5	2	0.11
	6	Running out of Water	5	2	0.11
	7	Running out of Batteries/Fuel Cells	5	2	0.11
	8	Breakdown of Equipment Not Due to Enemy	1	1	0.01
	9	Encountering Bad Weather	7	2	0.15
	10	Encountering Threat Forces	9	3	0.29
	11	Loss of Strategic Lift Assets and Their Cargo	5	3	0.16
	12	Loss of Theater Lift Assets and Their Cargo	5	3	0.16
	13	Closure of APODs and SPODs	5	3	0.16
	14	Closure of Sea Lanes	5	3	0.16
	15	Loss of LOCs	5	3	0.16
	16	Encountering Inaccessible Terrain with Convoys	6	3	0.19
	17	Untimely Delivery of Mission Critical Parts	2	2	0.04
	18	Loss of Comms w/log, intel and ops	1	2	0.02
	19	Loss of Common Operating Picture (COP)	8	3	0.26

Data Mining Search Engines (Predictive Analytics) – As used within the Predictive Analytics business technology area, data mining search engines use customer data to build predictive models specialized for specific business goals. Thus, within the business intelligence domain, data mining search engines are a rapidly maturing technology due to continuing research and development in both academia and business.

Formal Concept Analysis Methodology – The dedicated commitment to academic research in the sub-technology of Formal Concept Analysis (FCA) methodology is evidenced by recent international conferences in France (5th International Conference on Formal Concept Analysis, 2007), Tunisia (4th International Conference on Concept Lattices and their Application, 2006), the Czech Republic (3rd International Conference on Concept Lattices and their Application, 2005), Australia (2nd International Conference on Formal Concept Analysis, 2004), and the USA (9th International Conference on Conceptual Structures co-located with the 1st Semantic Web Workshop and the International Workshop on Description Logics, Stanford, CA, 2001). In addition, there are many FCA software packages available for free download over the Internet (e.g., Tockit, ToscanaJ, Tupleware, ConExp). There are also commercial software applications based on FCA methodology (e.g., MailSleuth is an FCA-based plug-in for managing email in Microsoft Outlook).

Software Development Cost – The ongoing (and continuously increasing) interest in fairly costly Predictive Analytics research and development in both academia and business strongly implies moderate software development costs for data mining search engine technology. In addition, the dedicated commitment to academic research in FCA methodology further implies moderate software development costs for that sub-technology. Since Formal Concept Analysis Based Data Mining will evolve from a combination of these two sub-technologies, the net software development cost of the emerging technology should be manageable.

Scalability – Parallel implementation of data mining search engines using FCA methodology over a network of computer databases (which will be the basic function of the emerging Formal Concept Analysis Based Data Mining technology) will greatly increase the processing speed of the collective framework. Thus, the future Formal Concept Analysis Based Data Mining technology should be readily scalable to improve processing speed and (in turn) lower net data processing costs.

Engineering: Non-Recurring Engineering – Both moderately costly Predictive Analytics technology and (by comparison) fairly inexpensive Formal Concept Analysis methodology should have an extensive research and development history by 2020. This strongly implies that any future technology that will evolve from these sub-technologies (i.e., Formal Concept Analysis Based Data Mining) will only require moderate non-recurring software engineering costs from application-specific users of the future technology.

Engineering: Integration – Given the increasing ubiquity of Predictive Analytics technology plus the increasing academic research in Formal Concept Analysis methodology, the Formal Concept Analysis Based Data Mining technology that will evolve from these sub-technologies should be well founded on smart software design strategies. This strongly suggests that integration of Formal Concept Analysis Based Data Mining software into future Prediction and Preemption systems will be very cost effective.

Undesirable Outcomes to Preempt:

Soldiers Dying or Being Wounded – When properly deployed, Formal Concept Analysis Based Data Mining software technology will be capable of identifying acquired operating environment entities as either friendly, enemy, or neutral. This identification process will include unrecognized entities that can be identified via comparison to other entity types in a database using Formal Concept Analysis. This will often allow friendly combat support units to avoid exposing friendly soldiers to terrorist/insurgent activities.

Encountering Bad Weather – Formal Concept Analysis Based Data Mining software technology will be capable of comparing unfamiliar weather conditions to similar conditional descriptions within a database. This could then allow the Formal Concept Analysis Based Data Mining software to identify and anticipate potential hazardous weather as it starts to form. This will serve to preempt exposure of combat support units to bad weather only in situations where hazardous conditions can be anticipated sufficiently in advance of unit deployment.

Encountering Threat Forces – Formal Concept Analysis Based Data Mining software technology will be capable of comparing acquired entities of unknown origin or socio-political association to terrorist/insurgent profiles within a database. This will allow friendly combat support units to avoid exposing friendly assets to destruction by hostile entities (that might be difficult to visually identify as such upon initial contact).

Loss of Log COP – Formal Concept Analysis Based Data Mining software technology will be capable of categorizing operating environment entities and objects that might be difficult to identity upon initial contact (if, for example, the objects have suffered battle damage). This will serve to facilitate a continuous Log COP by progressively identifying friendly assets (by comparison with similar entities and objects within a database) regardless of the current visual signatures of those assets.

4.6.1.4 Simulation-Based COA Analysis

sCOA			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			26		2.65
	1	JTIMS Software	7	3	0.81
	2	Agent-Based Sim Software	10	3	1.15
	3	State Space / World Line Analysis Software	9	2	0.69

Cost			35		1.66
	1	Software Development Cost	5	2	0.29
	2	GOTS Software Cost	10	2	0.57
	3	Mfr Scalability	7	1	0.20
	4	Engr-NRE	8	2	0.46
	5	Engr-Integration	5	1	0.14
Benefit to LPPC			124		2.58
	1	Losing the engagement (Mission) to the Enemy	9	2	0.15
	2	Soldiers dying or being wounded	9	2	0.15
	3	Running out of Ammunition	7	3	0.17
	4	Running out of Fuel	7	3	0.17
	5	Running out of Medical Supplies	7	3	0.17
	6	Running out of Water	7	3	0.17
	7	Running out of Batteries/Fuel Cells	7	3	0.17
	8	Breakdown of Equipment Not Due to Enemy	3	2	0.05
	9	Encountering Bad Weather	2	2	0.03
	10	Encountering Threat Forces	9	2	0.15
	11	Loss of Strategic Lift Assets and Their Cargo	7	3	0.17
	12	Loss of Theater Lift Assets and Their Cargo	7	3	0.17
	13	Closure of APODs and SPODs	7	3	0.17
	14	Closure of Sea Lanes	7	3	0.17
	15	Loss of LOCs	5	2	0.08
	16	Encountering Inaccessible Terrain with Convoys	5	2	0.08
	17	Untimely Delivery of Mission Critical Parts	9	3	0.22
	18	Loss of Comms w/log, intel and ops	5	2	0.08
	19	Loss of Common Operating Picture (COP)	5	2	0.08

JTIMS Software – The Joint Training Information Management System (JTIMS) is a government off-the-shelf (GOTS) software tool that has been developed (by Dynamics Research Corporation) and used to support the Joint Training System. JTIMS is now capable of performing mission-to-task decomposition functions (using both the Army Universal Task List and the Universal Joint Task List) for COA planning in a manner consistent with the Missions and Means Framework (MMF). Thus, JTIMS is already a fully capable foundational element from which Simulation-Based COA Analysis technology will be able to evolve.

Agent-Based Simulation Software – Research and development in the sub-technology area of agent-based modeling and simulation has been steadily growing from its initial inception in the late 1980's to its current acceptance in academia, government, and business around the world. A multiplicity of recent conferences devoted to agent-based simulation research and development include:

- SwarmFest 2006 (University of Notre Dame, South Bend, IN);
- 2006 Conference on Social Agents: Results and Prospects (Argonne National Laboratory, Argonne, IL);
- 2006 IEEE/WIC/ACM International Conference on Intelligent Agent Technology (Hong Kong, China);
- 2005 Conference on Agent-Based Models for Economic Policy Design' (Bielefeld, Germany).
- Specific application domains where agent-based simulation software has been developed include
- Economics,
- Political Science,
- Culture/Anthropology/Archeology,
- Ecology,
- Biology and Medicine,
- Physics,
- Business/Industry, and
- Military Operations.

This argues in favor of agent-based simulation software being a well-developed sub-technology to support the evolution of future Simulation-Based COA Analysis technology.

State Space/World Line Analysis Software – The sub-technology of state space/world line analysis has been extensively developed and applied in the areas of control systems engineering and physics. However, there has been little work to date in applying this sub-technology to the areas of business process analysis or military operations analysis. One notable exception is the Course of Action Scheduling Tool (COAST), a software package developed by the Australian Defense Science and Technology Organization (DSTO) during 2002 and 2003. COAST applies state space/world line analysis techniques to the study of the possible ways in which an operational plan can be executed, subject to resource, timing, and synchronization constraints. There is thus some evidence that state space/world line analysis software can serve as part of the foundation from which Simulation-Based COA Analysis software can evolve, but there is also some risk due to the proprietary nature of the existing sub-technology as applied to the military operations analysis domain.

Software Development Cost – The ongoing (and continuously increasing) but costly interest in agent-based modeling and simulation research and development in academia, business, and government strongly implies moderate software development costs for this sub-technology area. In addition, translating the extensive library of existing software development of state space/world line analysis applications in the control engineering domain to the military operations domain should be straightforward but somewhat costly. Finally, the JTIMS software sub-technology is already in a very mature developmental state. Taken together, this implies moderate software development costs for all sub-technologies that will contribute to the evolution of the future Simulation-Based COA Analysis technology.

GOTS Software Cost – The JTIMS software sub-technology is a GOTS product that was developed (and is currently maintained) by one specific military contractor. Although it might be possible to redevelop a similar software package (that executes COA planning using the Missions and Means Framework) using government software engineers, the current widespread use of JTIMS for military planning purposes makes this redevelopment option impractical. Thus, there is some uncertainty as to the cost required to support integration of the JTIMS software into the emerging Simulation-Based COA Analysis technology.

Scalability – Many of the existing agent-based simulation software sub-technologies are explicitly designed for parallel implementation over a network of client and server computers. This will greatly increase the processing speed of the collective framework. Thus, the emerging Simulation-Based COA Analysis software technology (of which agent-based simulation software will form a significant part of) should be readily scalable to improve processing speed and (in turn) lower net data processing costs.

Engineering: Non-Recurring Engineering – Agent-based simulation software sub-technology will have an extensive research and development history by 2020. This strongly implies that any future technology that will evolve from this sub-technology will only require minimal non-recurring software engineering costs from application-specific users. However, the uncertainty in application-specific implementation and adjustment costs for both the JTIMS and state space/world line analysis software sub-technologies within the Simulation-Based COA Analysis technology implies a fair degree of non-recurring engineering cost uncertainty.

Engineering: Integration – Both the JTIMS and agent-based simulation software sub-technologies are strongly founded on smart software design strategies. In addition, the state space / world line analysis software currently used in the control engineering technology area is also designed according to similar design strategies. This strongly suggests that integration of Simulation-Based COA Analysis software into future Prediction and Preemption systems will be very cost effective.

Undesirable Outcomes to Preempt:

Losing the Engagement (Mission) to the Enemy – Simulation-Based COA Analysis software technology will allow mission planners to test out a multiplicity of alternate COAs within a simulated operating environment context, and then comparatively cross-analyze the outcomes of those COAs. This capability will allow the mission planner to realistically wargame and then identify a COA (or set of COAs) that is most likely to allow friendly forces to support their mission objective by defeating an enemy. Note that the success of this approach will be conditional on well-defined enemy tactics within the simulation.

Running Out of Medical Supplies – Simulation-Based COA Analysis software technology will allow mission planners to wargame and analyze the outcomes of potential encounters with one or more enemy forces. The friendly COAs within such operating environment simulations could incorporate medical unit operations to tend to wounded friendly soldiers. By tracking the use of medical supplies by the medical unit during the simulation, a mission planner will be able to predict and anticipate the rate and cumulative quantity of supplies that will likely be used up given such a mission.

Loss of Theater Lift Assets and Their Cargo – Simulation-Based COA Analysis software technology will be capable of simulating possible scenarios wherein enemy entities (such as terrorists or insurgents) work to destroy friendly lift assets and their cargo within theater operational environments. Such a capability will also allow mission planners to test out possible COAs to prevent enemy interference with friendly theater lift assets and their cargo.

Untimely Delivery of Mission Critical/Essential Parts and Spare Parts – Simulation-Based COA Analysis software technology will allow mission planners to explore alternate COAs for re-supply operations within an operating environment context. When combined with simulated combat operations, the Simulation-Based COA Analysis software will support the mission planner in identifying the best COA to proactively ensure timely delivery of mission critical/essential parts and spare parts to friendly entities in need of those assets.

4.6.1.5 Social Network Analysis

SNA			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			31		2.74
	1	Distributed Blackboard Fusion Architecture	8	3	0.77
	2	Omnibus Fusion Model	8	2	0.52
	3	Predictive Analytics	5	3	0.48
	4	Reflexive Analysis Methodology	10	3	0.97
Cost			30		1.57
	1	Software Development Cost	10	2	0.67
	2	Mfr Scalability	8	1	0.27

	3	Engr-NRE	7	2	0.47
	4	Engr-Integration	5	1	0.17
Benefit to LPPC			71		2.61
	1	Losing the engagement (Mission) to the Enemy	5	3	0.21
	2	Soldiers dying or being wounded	5	3	0.21
	3	Running out of Ammunition	1	1	0.01
	4	Running out of Fuel	1	1	0.01
	5	Running out of Medical Supplies	1	1	0.01
	6	Running out of Water	1	1	0.01
	7	Running out of Batteries/Fuel Cells	1	1	0.01
	8	Breakdown of Equipment Not Due to Enemy	1	1	0.01
	9	Encountering Bad Weather	1	1	0.01
	10	Encountering Threat Forces	5	3	0.21
	11	Loss of Strategic Lift Assets and Their Cargo	7	3	0.30
	12	Loss of Theater Lift Assets and Their Cargo	7	3	0.30
	13	Closure of APODs and SPODs	7	3	0.30
	14	Closure of Sea Lanes	7	3	0.30
	15	Loss of LOCs	7	3	0.30
	16	Encountering Inaccessible Terrain with Convoys	1	1	0.01
	17	Untimely Delivery of Mission Critical Parts	7	3	0.30
	18	Loss of Comms w/log, intel and ops	3	1	0.04
	19	Loss of Common Operating Picture (COP)	3	1	0.04

Distributed Blackboard Fusion Architecture – There is considerable ongoing research committed to the development of distributed blackboard fusion architectures to support opportunistic service-oriented computer networks. The distributed blackboard fusion architecture has already been applied to the development of distributed grid services for computationally intensive scientific processing such as studying climate change, investigating protein-related diseases, crypto-analysis, and intrusion detection systems. This will allow distributed blackboard fusion architectures to contribute to a stable foundation from which Social Network Analysis technology can evolve.

Omnibus Fusion Model – Although this technology was first presented in 2000 within the context of Aerospace Engineering, the Omnibus model of data fusion has recently been applied to research areas as diverse as multi-target tracking by sensor networks, intelligent fault detection, and human genome analysis. However, developing this goal-oriented/task-oriented data fusion method to a future level where it can effectively support Social Network Analysis (e.g., analyze the common goals that could link terrorists/insurgents listed within multiple databases) by 2020 is questionable. Nevertheless, it is more likely the Omnibus fusion model will be able to support the evolution of Social Network Analysis by 2030.

Predictive Analytics – There are currently numerous software tools available in the marketplace that can apply the sub-technology of Predictive Analytics to either the commercial business process or military operations prediction domain (and in some cases to both domains). These tools range from those that require need very little user sophistication (e.g., KnowledgeSEEKER or KXEN) to those that are designed for the expert practitioner (e.g., SPSS, SAS modules such as STAT, ETS, OR etc.). Thus, the Predictive Analytics sub-technology is already in a very mature developmental state, and will thus provide a stable contribution to the foundation from which future Social Network Analysis technology can evolve.

Reflexive Analysis Methodology – Since its inception in the Soviet Union over forty years ago, the sub-technology of Dr. Vladimir Lefebvre's Reflexive Analysis methodology has been applied to areas as diverse as psychological analysis, military decision-making, and (more recently) predictive analysis of hypothetical terrorist activities. Thus, it is reasonable to categorize Reflexive Analysis methodology as a mature sub-technology that will ably contribute to the technological foundation from which Social Network Analysis will evolve.

Software Development Cost – The ongoing but costly interest in Predictive Analytics research and development in both academia and business strongly implies moderate software development costs for data mining search engine technology. In addition, the continuing but somewhat costly research and development of distributed blackboard fusion architecture, Omnibus fusion, and Reflexive Analysis sub-technologies further implies moderate software development costs for these areas. Since future Social Network Analysis technology will evolve from a combination of these four sub-technologies, software development cost of the emerging technology should be moderately manageable.

Scalability – Blackboard fusion architectures were originally designed to solve problems that benefit from the parallel implementation of knowledge sources (such as databases). By implementing a distributed parallel blackboard architecture, the processing speed of the collective framework can be greatly increased. Thus, Social Network Analysis technology, which will evolve in part from current distributed blackboard fusion architectures, are readily scalable to improve processing speed and (in turn) lower net data processing costs.

Engineering: Non-Recurring Engineering – Distributed blackboard fusion architecture, Predictive Analytics, and Reflexive Analysis sub-technologies will all have an extensive (and very mature) research and development history by 2020. This strongly implies that any future technology that will evolve from these sub-technologies will only require minimal non-recurring software engineering costs from application-specific users. However, the uncertainty in application-specific implementation and adjustment costs for the Omnibus data fusion software sub-technologies within the Social Network Analysis technology implies a fair degree of non-recurring engineering cost uncertainty.

Engineering: Integration – Existing software applications in the sub-technology areas of distributed blackboard fusion, Omnibus fusion, Predictive Analytics, and Reflexive Analysis software are all based upon smart software design strategies. This strongly suggests that integration of Social Network Analysis software into future Prediction and Preemption systems will be very cost effective.

Undesirable Outcomes to Preempt:

Soldiers Dying or Being Wounded – Social Network Analysis software technology will be capable of identifying operating environment entities as friendly, enemy, or neutral based upon the socio-political groups to which they might belong or associate with. This identification process will thus be able to discern potential terrorists/insurgents among members of an indigenous population within theater areas. This will sometimes allow friendly combat support units to avoid exposing friendly soldiers to terrorist/insurgent activities. However, this predictive capability will only be as valid as the available intelligence on hostile indigenous entities.

Encountering Threat Forces – Social Network Analysis software technology will be capable of linking disparate entities into specific socio-political associations and groups which could be of a terrorist/insurgent nature. This will allow friendly combat support units to anticipate and avoid exposure to possibly hostile indigenous entities operating within an area. However, this predictive capability will only be as valid as the available intelligence on hostile indigenous entities.

Loss of Strategic Lift Assets and Their Cargo – Social Network Analysis software technology will be capable of predicting whether key officials operating in the vicinity of various strategic locations along a transport route will act to either cooperate or impede friendly logistics operations. Such a capability will allow mission planners to associate these key foreign officials with specific socio-political groups and organizations that might seek to disrupt U.S. and Coalition force operations by interfering with friendly strategic lift assets and their cargo.

Untimely Delivery of Mission Critical/Essential Parts and Spare Parts – Social Network Analysis software technology will allow mission planners to identify and link indigenous entities within theater to specific socio-political associations and groups which could be of a terrorist/insurgent nature. Thus, by correctly identifying and avoiding such disruptive indigenous entities, the mission planner will be able to proactively ensure timely delivery of mission critical/essential parts and spare parts to friendly entities in need of those assets.

4.6.1.6 Simulation-Based Reflexive Analysis

RA			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			35		2.74
	1	JTIMS	7	3	0.60
	2	Agent Based Simulation	9	3	0.77

	3	Reflexive Analysis	10	3	0.86
	4	State Space/World Line	9	2	0.51
Cost			35		1.66
	1	Software Dev Cost	5	2	0.29
	2	GOTS Software Cost	10	2	0.57
	3	Mfr Scalability	7	1	0.20
	4	Engr-NRE	8	2	0.46
	5	Engr-Integration	5	1	0.14
Benefit to LPPC			112		2.82
	1	Losing the engagement (Mission) to the Enemy	9	3	0.24
	2	Soldiers dying or being wounded	9	3	0.24
	3	Running out of Ammunition	4	3	0.11
	4	Running out of Fuel	4	3	0.11
	5	Running out of Medical Supplies	4	3	0.11
	6	Running out of Water	4	3	0.11
	7	Running out of Batteries/Fuel Cells	4	3	0.11
	8	Breakdown of Equipment Not Due to Enemy	3	2	0.05
	9	Encountering Bad Weather	2	2	0.04
	10	Encountering Threat Forces	10	3	0.27
	11	Loss of Strategic Lift Assets and Their Cargo	7	3	0.19
	12	Loss of Theater Lift Assets and Their Cargo	7	3	0.19
	13	Closure of APODs and SPODs	8	3	0.21
	14	Closure of Sea Lanes	7	3	0.19
	15	Loss of LOCs	7	3	0.19
	16	Encountering Inaccessible Terrain with Convoys	5	2	0.09
	17	Untimely Delivery of Mission Critical Parts	8	3	0.21
	18	Loss of Comms w/log, intel and ops	5	2	0.09
	19	Loss of Common Operating Picture (COP)	5	2	0.09

JTIMS Software – The Joint Training Information Management System (JTIMS) is a GOTS software tool that has been developed (by Dynamics Research Corporation) and used to support the Joint Training System. JTIMS is now capable of performing mission-to-task decomposition functions (using both the Army Universal Task List and the Universal Joint Task List) for COA planning in a manner consistent with the Missions and Means Framework (MMF). Thus, JTIMS is already a fully capable foundational element from which Simulation-Based COA Analysis technology will be able to evolve.

Agent-Based Simulation Software – Research and development in the sub-technology area of agent-based modeling and simulation has been steadily growing from its initial inception in the late 1980's to its current acceptance in academia, government, and business around the world. A multiplicity of recent conferences devoted to agent-based simulation research and development include

- SwarmFest 2006 (University of Notre Dame, South Bend, IN);
- 2006 Conference on Social Agents: Results and Prospects (Argonne National Laboratory, Argonne, IL);
- 2006 IEEE/WIC/ACM International Conference on Intelligent Agent Technology (Hong Kong, China);
- 2005 Conference on Agent-Based Models for Economic Policy Design' (Bielefeld, Germany).
- Specific application domains where agent-based simulation software has been developed include
- Economics,
- Political Science,
- Culture/Anthropology/Archeology,
- Ecology,
- Biology and Medicine,
- Physics,
- Business/Industry, and
- Military Operations.

This argues in favor of agent-based simulation software being a well-developed sub-technology to support the evolution of future Simulation-Based Reflexive Analysis technology.

Reflexive Analysis Methodology – Since its inception in the Soviet Union over forty years ago, the sub-technology of Dr. Vladimir Lefebvre's Reflexive Analysis methodology has been applied to areas as diverse as psychological analysis, military decision-making, and (more recently) predictive analysis of hypothetical terrorist activities. Thus, it is reasonable to categorize Reflexive Analysis methodology as a mature sub-technology that will ably contribute to the technological foundation from which Simulation-Based Reflexive Analysis will evolve.

State Space/World Line Analysis Software – The sub-technology of state space/world line analysis has been extensively developed and applied in the areas of control systems engineering and physics. However, there has been little work to date in applying this sub-technology to the areas of business process analysis or military operations analysis. One notable exception is the Course of Action Scheduling Tool (COAST), a software package developed by the Australian Defense Science and Technology Organization (DSTO) during 2002 and 2003. COAST applies state space/world line analysis techniques to the study of the possible ways in which an operational plan can be executed, subject to resource, timing, and synchronization constraints. There is thus some evidence that state space/world line analysis software can serve as part of the foundation from which Simulation-Based Reflexive Analysis software can evolve, but there is also some risk due to the proprietary nature of the existing sub-technology as applied to the military operations analysis domain.

Software Development Cost – The ongoing (and continuously increasing) research and development in both agent-based modeling and simulation and Reflexive Analysis sub-technologies in academia, business, and government strongly implies moderate software development costs for these areas. In addition, translating the extensive library of existing software development of state space/world line analysis applications in the control engineering domain to the military operations domain should be straightforward but somewhat costly. Finally, the JTIMS software sub-technology is already in a very mature developmental state. Taken together, this implies moderate software development costs for all sub-technologies that will contribute to the evolution of the future Simulation-Based Reflexive Analysis technology.

GOTS Software Cost – The JTIMS software sub-technology is a government off-the-shelf (GOTS) product that was developed (and is currently maintained) by one specific military contractor. Although it might be possible to redevelop a similar software package (that executes military planning using the Missions and Means Framework) using government software engineers, the current widespread use of JTIMS for military planning purposes makes this redevelopment option impractical. Thus, there is some uncertainty as to the cost required to support integration of the JTIMS software into the emerging Simulation-Based Reflexive Analysis technology.

Scalability – Many of the existing agent-based simulation software sub-technologies are explicitly designed for parallel implementation over a network of client and server computers. This will greatly increase the processing speed of the collective framework. Thus, the emerging Simulation-Based COA Analysis software technology (of which agent-based simulation software will form a significant part of) should be readily scalable to improve processing speed and (in turn) lower net data processing costs.

Engineering: Non-Recurring Engineering – Both agent-based simulation software and Reflexive Analysis sub-technologies will have an extensive research and development history by 2020. This strongly implies that any future technology that will evolve from these sub-technologies will only require minimal non-recurring software engineering costs from application-specific users. However, the uncertainty in application-specific implementation and adjustment costs for both the JTIMS and state space/world line analysis software sub-technologies within the Simulation-Based Reflexive Analysis technology implies a fair degree of non-recurring engineering cost uncertainty.

Engineering: Integration – The JTIMS, agent-based simulation, and Reflexive Analysis software sub-technologies are founded on smart software design strategies. In addition, the state space/world line analysis software currently used in the control engineering technology area is also designed according to similar design strategies. This strongly suggests that integration of Simulation-Based COA Analysis software into future Prediction and Preemption systems will be very cost effective.

Undesirable Outcomes to Preempt:

Soldiers Dying or Being Wounded – Simulation-Based Reflexive Analysis software technology will allow mission planners to simulate the decision-making processes of hostile entities within an operating environment context. Through such predictive simulations, friendly combat support units will be guided by mission planners on the best way to avoid exposing friendly soldiers to terrorist/insurgent activities.

Running Out of Medical Supplies – Simulation-Based Reflexive Analysis software technology will allow mission planners to wargame and analyze the outcomes of potential encounters with one or more enemy forces. The friendly mission within such operating environment simulations will be able to incorporate medical unit operations to tend to wounded friendly soldiers. By tracking the use of medical supplies by the medical unit during the simulation, a mission planner will be able to predict and anticipate the rate and cumulative quantity of supplies that will likely be used up to treat Soldier injuries resulting from specific hostile force combat decisions and actions.

Closure of APODs and SPODs – In military deployments, the aerial or seaport of debarkation (APOD/SPOD) is often the most constraining part of a military transportation operation. Simulation-Based Reflexive Analysis software technology will be able to simulate friendly transport logistics within an APOD or SPOD as well as predict terrorist/insurgent activities that might seek to disrupt the APOD/SPOD infrastructure.

Untimely Delivery of Mission Critical/Essential Parts and Spare Parts – Simulation-Based Reflexive Analysis software technology will allow mission planners to model and simulate potentially disruptive interactions of hostile entities (i.e., terrorists and insurgents) with friendly force re-supply operations within an operating environment context. When combined with simulated combat operations, the Simulation-Based Reflexive Analysis software will support the mission planner by predicting the degree to which hostile entity actions interfere with the timely delivery of mission critical/essential parts and spare parts to friendly entities in need of those assets.

4.6.1.7 Cyc-Based Virtual Logisticians

Cyc-Based Virtual Logistician			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Maturation			50		2.48
	1	Hybrid Ontology Software	10	3	0.60
	2	JDL Process Fusion Model	5	3	0.30
	3	Multi-Sensor Integration Fusion Model	5	2	0.20
	4	Behavioral Knowledge-Based Fusion Model	5	3	0.30
	5	Distributed Blackboard Fusion Architecture	5	3	0.30
	6	Omnibus Fusion Model	5	2	0.20
	7	Agent-Based Simulation Software	7	3	0.42
	8	Future Computational Technology	8	1	0.16
Cost			48		1.83
	1	Raw Materials	3	2	0.13
	2	Hardware Processing Cost	6	1	0.13
	3	Software Development Cost	9	2	0.38
	4	Mfr Scalability	7	1	0.15
	5	Devices	8	2	0.33
	6	Engr-NRE	10	3	0.63
	7	Engr-Integration	5	1	0.10
Benefit to LPPC			133		2.77
	1	Losing the engagement (Mission) to the Enemy	5	2	0.08
	2	Soldiers dying or being wounded	7	2	0.11
	3	Running out of Ammunition	9	3	0.20
	4	Running out of Fuel	9	3	0.20
	5	Running out of Medical Supplies	9	3	0.20
	6	Running out of Water	9	3	0.20
	7	Running out of Batteries/Fuel Cells	9	3	0.20
	8	Breakdown of Equipment Not Due to Enemy	7	3	0.16
	9	Encountering Bad Weather	7	2	0.11
	10	Encountering Threat Forces	8	2	0.12
	11	Loss of Strategic Lift Assets and Their Cargo	7	3	0.16
	12	Loss of Theater Lift Assets and Their Cargo	7	3	0.16
	13	Closure of APODs and SPODs	7	3	0.16
	14	Closure of Sea Lanes	5	3	0.11
	15	Loss of LOCs	7	3	0.16

16	Encountering Inaccessible Terrain with Convoys	8	3	0.18
17	Untimely Delivery of Mission Critical Parts	9	3	0.20
18	Loss of Comms w/log, intel and ops	2	2	0.03
19	Loss of Common Operating Picture (COP)	2	2	0.03

Hybrid Ontology Software – The Cyc knowledge base (KB) is a type of hybrid ontology software sub-technology that allows military and business analysts to create an information management system that can incrementally add new databases to its cumulative knowledge base and support more complex database queries than any one of the individual databases can support alone. The Cyc KB is being developed by Cycorp, Inc., (in Austin, TX), with the eventual goal of allowing computers to effectively perform human-like reasoning. Given the continuing development of the Cyc KB software and the fiscal stability of Cycorp, Inc., it is very likely that this instance of hybrid ontology sub-technology will strongly contribute to the foundation from which Cyc-Based Virtual Logisticians will evolve in the future.

JDL Process Fusion Model – The JDL Process fusion model is widely accepted for military applications. There is an ongoing research and development program in the area of concealed weapons detection sponsored by the Air Force Research Laboratory (AFRL) and National Institute of Justice (NIJ); it is within this context that the JDL Process fusion model sub-technology first emerged. This strongly suggests that this sub-technology will provide a stable contribution to the technological foundation from which Cyc-Based Virtual Logisticians will evolve.

Multi-Sensor Integration Fusion Model – The sub-technology of multi-sensor integration fusion works to recursively combine data from different sensors to better define the properties of sensed objects (just as a human combines information gathered from individual senses to better identify objects perceived within a local environment). While the multi-sensor integration fusion model will readily be capable of identifying obvious objects in the near future (e.g., a chair or a fire), it is unclear whether this data fusion sub-technology will be able to identify more complex and subtle entities (e.g., an indigenous person within an operational environment who might be a terrorist or insurgent).

Behavioral Knowledge-Based Fusion Model – There are many rapidly growing current technology areas where *a priori* knowledge of the behavior of objects or clients can be shared among networked decision-making entities to create a larger-scale situational picture (e.g., robotic swarms, networked ATMs, etc.). This will provide a stable foundation from which Cyc-Based Virtual Logisticians can evolve.

Distributed Blackboard Fusion Architecture – There is considerable ongoing research committed to the development of distributed blackboard fusion architectures to support opportunistic service-oriented computer networks. The distributed blackboard fusion architecture has already been applied to the development of distributed grid services for computationally intensive scientific processing such as studying climate change, investigating protein-related diseases, crypto-analysis, and intrusion detection systems. This will allow distributed blackboard fusion architectures to contribute to a stable foundation from which Cyc-Based Virtual Logisticians can evolve.

Omnibus Fusion Model – Although this technology was first presented in 2000 within the context of Aerospace Engineering, the Omnibus model of data fusion has recently been applied to research areas as diverse as multi-target tracking by sensor networks, intelligent fault detection, and human genome analysis. However, developing this goal-oriented/task-oriented data fusion method to a future level where it can effectively support the goal-directed analysis executed by Cyc-Based Virtual Logisticians by 2020 is questionable. Nevertheless, it is more likely the Omnibus fusion model will be able to support the evolution of Cyc-Based Virtual Logisticians by 2030.

Agent-Based Simulation Software – Research and development in the sub-technology area of agent-based modeling and simulation has been steadily growing from its initial inception in the late 1980’s to its current acceptance in academia, government, and business around the world. A multiplicity of recent conferences devoted to agent-based simulation research and development include

- SwarmFest 2006 (University of Notre Dame, South Bend, IN);
- 2006 Conference on Social Agents: Results and Prospects (Argonne National Laboratory, Argonne, IL);
- 2006 IEEE/WIC/ACM International Conference on Intelligent Agent Technology (Hong Kong, China);
- 2005 Conference on Agent-Based Models for Economic Policy Design’ (Bielefeld, Germany).
- Specific application domains where agent-based simulation software has been developed include:
    - Economics
    - Political Science
    - Culture/Anthropology/Archeology
    - Ecology
    - Biology and Medicine
    - Physics
    - Business/Industry
    - Military Operations

This argues in favor of agent-based simulation software being a well-developed sub-technology to support the evolution of future Cyc-Based Virtual Logistician technology.

Future Computational Technology (as predicted by Kurzweil) – The future emergence of an as-of-yet unknown computational technology is essentially impossible to predict with any confidence. Kurzweil's prediction of such a sub-technology is predicated upon humanity's past tendency to increasingly exploit existing technology in the search for novel improvements to that technology. Assuming that a human-level reasoning capability will require vastly superior information processing capability than is currently available (e.g., affordable quantum microprocessors), there is little evidence to strongly support such a future computational technology being commercially available by 2030 to support Cyc-Based Virtual Logistician technology.

Raw Materials – Given that the raw materials that go into the making of still-to-be-designed computational hardware devices are themselves unknown at this time, it is unclear what their cost will be. However, if this future computational hardware does emerge (as Kurzweil predicts it will), then it is likely that the cost of raw materials will be manageable.

Hardware Processing Cost – As with raw materials, the processing cost of still-to-be-designed computational hardware devices is unknown at this time. However, it is very likely that existing hardware processing techniques will contribute to making processing of future computational devices very cost-effective.

Software Development Cost – The deciding factor that will dominate the software development cost for the emerging Cyc-Based Virtual Logistician technology is licensing of the Cyc KB. Although the original Cyc software is proprietary, a smaller version of the knowledge base software was released as *OpenCyc* under an open source license allowing free download over the Internet. More recently, a special version of the Cyc KB software has been made available to artificial intelligence (AI) researchers (under a research-purposes license) as *ResearchCyc*. It is unclear whether OpenCyc will be able to fully support the evolution of future Cyc-Based Virtual Logistician technology, raising the possibility of costly licensing fees if the proprietary version of the Cyc KB software is required.

Scalability – Blackboard fusion architectures were originally designed to solve problems that benefit from the parallel implementation of knowledge sources (such as databases). By implementing a distributed parallel blackboard architecture, the processing speed of the collective framework can be greatly increased. Thus, Cyc-Based Virtual Logistician technology, which will evolve in part from current distributed blackboard fusion architectures, is readily scalable to improve processing speed and (in turn) lower net data processing costs.

Devices – As with raw materials, the still-to-be-designed computational hardware devices required to support the emerging Cyc-Based Virtual Logistician technology are themselves unknown at this time, and thus per-device cost is unclear. However, if this future computational hardware does emerge, then it is likely that the cost of devices will be manageable.

Engineering: Non-Recurring Engineering – All of the software-based sub-technologies that will contribute to the evolution of Cyc-Based Virtual Logistician technology (including all of the data fusion models, the Cyc KB software, and agent-based simulation software) will have an extensive research and development history by 2030 (at the latest). This strongly implies that any future technology that will evolve from these sub-technologies will only require minimal non-recurring software engineering costs from application-specific users. However, the inherent unpredictability (or at least severe uncertainty) in the specific nature of any future as-of-yet un-invented computational hardware sub-technology implies a dangerous degree of non-recurring engineering cost uncertainty. Even in the case of an expected future computational sub-technology (such as quantum computers), the exact design nature of the finalized product that will emerge (probably something very different from current laboratory prototypes in the case of quantum computation) makes estimation of non-recurring engineering costs very difficult.

Engineering: Integration – As related in the above paragraph, all software-based sub-technologies that will contribute to the evolution of Cyc-Based Virtual Logistician technology should achieve full developmental maturity by 2030. This strongly implies that each of these sub-technologies will be at a point where integration into future Prediction and Preemption systems will be very cost effective. In addition, although the exact nature of the future computational hardware sub-technology that will host the software sub-technology is highly uncertain, continuing developmental trends in hardware miniaturization (i.e., nanotechnology) imply that the future processor sub-technology will also support cost-effective system integration.

Undesirable Outcomes to Preempt:

Encountering Threat Forces – Cyc-Based Virtual Logistician software technology will be capable of simulating a group of virtual logistics analysts that cooperatively and collectively gather and fuse all available data addressing potential threat forces that might exist within an operating environment. Guidance from these virtual logisticians will allow friendly combat support units to anticipate and avoid exposure to possibly hostile entities operating within an area. However, this predictive capability will only be as valid as the available intelligence on hostile indigenous entities.

Running Out of Ammunition – Cyc-Based Virtual Logistician software technology will allow a group of virtual logistics analysts to wargame and analyze the outcomes of potential friendly force encounters with one or more enemy forces. These encounters (between friendly and enemy agents within an embedded combat simulation) will likely involve engagements that force simulated agents to expend ammunition. By tracking the use of ammunition during the combat simulation, virtual logisticians will be able to predict and anticipate the rate of use and total quantity of ammunition required by friendly forces during the anticipated combat operation.

Encountering Bad Weather – Cyc-Based Virtual Logistician software technology will allow a group of virtual logistics analysts to run simulations of weather models and then analyze the results. These virtual analysts will also be capable of fusing and analyzing weather system data collected over the GIG in order to identify and anticipate potential hazardous weather before or as it starts to form. Note that this type of predictive analysis will serve to preempt exposure of combat support units to bad weather only in situations where hazardous conditions can be anticipated sufficiently in advance of unit deployment.

Untimely Delivery of Mission Critical/Essential Parts and Spare Parts – Cyc-Based Virtual Logistician software technology will allow a group of virtual logistics analysts to explore alternate COAs for re-supply operations within an operating environment context. When combined with simulated combat operations, the group of virtual logisticians can actively support the (human) mission planner in identifying the best COA to proactively ensure timely delivery of mission critical/essential parts and spare parts to friendly entities in need of those assets.

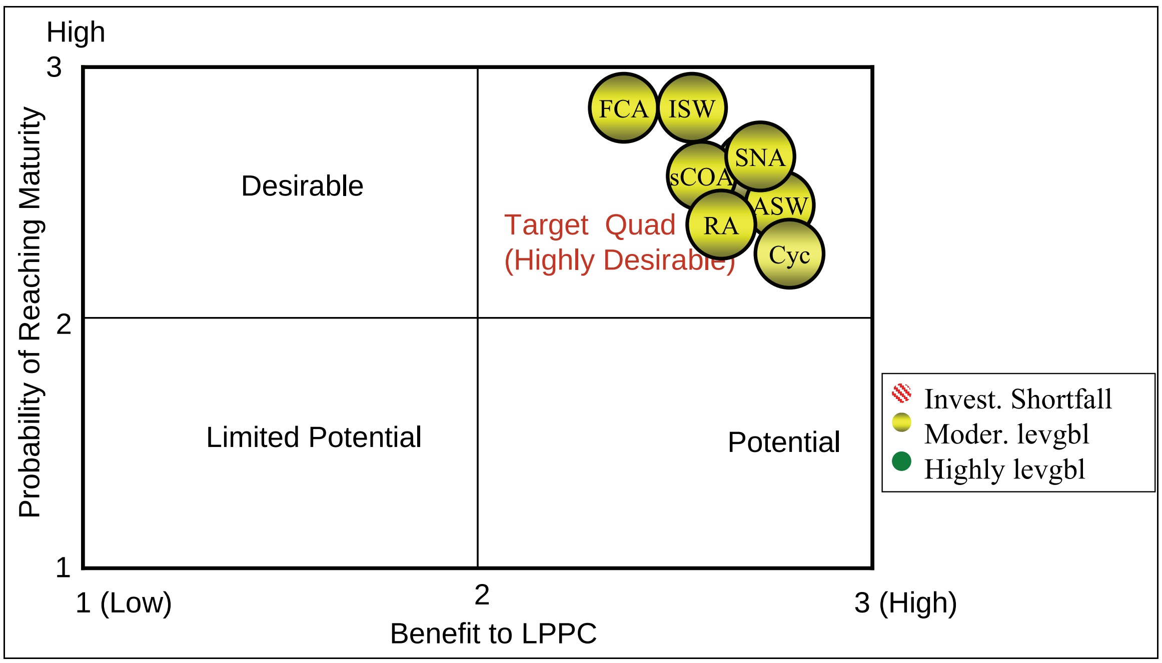


Figure 4.38. Data Fusion Quadrant Chart

Symbol	Technology	Section
ISW	Intelligent Sensor Webs	4.5.1
ASW	Adaptive Sensor Webs	4.5.2
FCA	Formal Concept Analysis	4.5.3
sCOA	Simulations Based Course of Action	4.5.4
SNA	Social Network Analysis	4.5.5
RA	Reflexive Analysis	4.3.5
Cyc	Cyc-Based Virtual Logistician	4.5.7

4.7 Data Fusion and Analysis Conclusions

Data fusion and analysis is best considered as a two-part process. In the first part, raw facts gathered from multiple sources are fused into a common operational picture (COP) of the shared operating environment. Since the operating environment is typically an environment in which complete information is difficult or impossible to obtain, data fusion must strive to alloy available information in a manner that minimizes uncertainty in a military decision. Although there is a multiplicity of different approaches to data fusion, the consistent thread among the best approaches is the use of a common set of algorithms and rules that facilitate the conversion of raw facts into useful information that would lead to actionable knowledge. The Distributed Blackboard Fusion Architecture approach to fusion applies such a rule set to all sources providing data to be fused. Given that the Distributed Blackboard Fusion Architecture sub-technology contributes to the emerging Intelligent Sensor Webs, Social Network Analysis, and Cyc-Based Virtual Logistician technologies, the former can be viewed as a key contributor to essential data fusion and analysis technologies anticipated in the 2020–2030 timeframe.

In the second part of the data fusion and analysis process, the COP generated via data fusion must be analyzed using qualitative and quantitative measures to first yield actionable knowledge, which is then used to develop potential courses of action (COAs).

The key to making analyses relevant to prediction and preemption is the use of operating environment simulations that account for logistical and therefore mission repercussions if recommended COAs are not accepted. The critical sub-technologies that will contribute to operating environment simulation are the JTIMS software tool (which applies the MMF methodology), agent-based simulation software tools (e.g., Cougaar and CoRBCAM), and state space/world line analysis software. These sub-technologies will then contribute to the emergence of Simulation-Based COA Analysis, Simulation-Base Reflexive Analysis, and Cyc-Based Virtual Logistician technologies. Finally, when all of the above essential technologies emerge in the 2020 - 2030 timeframe, a powerful suite of software tools will be available to the logistician for mission-critical prediction and preemption.

---

[75] Adapted from Jack H. Sheehan, Paul H. Deitz, Britt E. Bray, Bruce A. Harris, and Alex B.H. Wong. "The Military Missions and Means Framework," Proceedings of the Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC), 2003

[76] John Boyd. *Patterns of Conflict*, December 1986. Available online at http://www.d-n-i.net/boyd/patterns.ppt.

[77] James Llinas. *Data Fusion Overview*, Center for Multisource Information Fusion, University of Buffalo, Buffalo, New York, October 2002. Available online at http://www.infofusion.buffalo.edu/tm/Dr.Llinas'stuff/DataFusionOverview.ppt.

[78] Thomas A. Ferryman. "Essential Elements of Prediction," Annex C in *Logistics Prediction and Preemption Experiment Phase I – Overview*, 18 December 2006.

[79] James Llinas. *An Introduction to Data and Information Fusion*, Center for Multisource Information Fusion, University of Buffalo, Buffalo, New York, June 2001. Available online at http://www.infofusion.buffalo.edu/tm/Dr.Llinas'stuff/An_introduction_to_data_and_information_fusion.ppt.

[80] Adapted from Anne-Claire Boury-Brisset, *Ontology-based Approach for Information Fusion*.

[81]James Llinas and E. Little. *An Ontology Action Plan for the Information Fusion Community*, Center for Multisource Information Fusion, University of Buffalo, Buffalo, New York, June 2001. Available online at http://www.infofusion.buffalo.edu/tm/Dr.Llinas'stuff/An_ontology_action_plan_for_the_information_fusion_community.ppt.

[82]D. Jones, T. Bench-Capon, and P. Visser. "Methodologies for Ontology Development," in *Proceedings of IT&KNOWS (Information Technology and Knowledge Systems) of the 15th IFIP World Computer Congress*, Budapest, Hungary, 1998.

[83]James Llinas and E. Little. *An Ontology Action Plan for the Information Fusion Community*, Center for Multisource Information Fusion, University of Buffalo, Buffalo, New York, June 2001. Available online at http://www.infofusion.buffalo.edu/tm/Dr.Llinas'stuff/An_ontology_action_plan_for_the_information_fusion_community.ppt.

[84]Alexander H. Levis. "Homeland Defense: Data Integration/Fusion," *Proceedings of the Workshop on the Mathematical Sciences' Role in Homeland Security*, the National Academies Press, Washington, D.C., 2004.

[85]Adapted from Jaime Esteban, Andrew Starr, Robert Willetts, Paul Hannah, and Peter Bryanston-Cross. "A Review of data fusion models and architectures: towards engineering guidelines," in *Neural Computation & Applications* (2005) 14: 273–281.

[86]J Llinas and DL Hall. "An introduction to multi-sensor data fusion," in *Proceedings of the IEEE International Symposium on Circuits and Systems*, 6:537–540, 1998.

[87]S Paradis, J Roy, and W Treurniet. (1998) "Integration of all data fusion levels using a blackboard architecture," in *Proceedings of the 3rd Eurofusion Conference*, October 1998, pp.195–202.

[88]SC Thomopoulos. "Sensor integration and data fusion," in *Proceedings of SPIE 1198: Sensor Fusion II: Human and Machine Strategies*, 1989, pp.178–191

[89]R Luo and M Kay. "Multi-sensor integration and fusion: issues and approaches," in Proceedings of SPIE 931: Sensor Fusion, 1988, pp. 42–49

[90]CJ Harris, A Bailey, and TJ Dodd. "Multi-sensor data fusion in defense and aerospace," in *The Aeronautical Journal* 102(1015), 1998, pp. 229–244.

[91]LF Pau. "Sensor data fusion," in *Journal of Intelligent and Robotic Systems*, Volume 1, 1988, pp.103–116.

[92]J Schoess and G Castore. "A distributed sensor architecture for advanced aerospace systems," in *Proceedings of SPIE 932: Sensor Fusion*, 1988, pp. 74–86.

[93]M Bedworth and J O'Brien. "The omnibus model: a new model of data fusion?" in Proceedings of the 2nd International Conference on Information Fusion, Sunnyvale, CA, 1999.

[94]Rudolf Wille. "Restructuring Lattice Theory: An Approach Based On Hierarchies of Concepts," published in *Ordered Sets*, I. Rival, Editor, Dordrecht-Boston, Reidel Press, 1982, pp. 445-470.

[95]Yaneer Bar-Yam. *Dynamics of Complex Systems*. Reading, MA: Perseus Books, 1997, pp 258-294.

[96]Adapted from Britt Bray. "Tutorial: Putting the MMF to Work to Drive Analysis," presented at The 22nd Annual National Test and Evaluation Forum, Jacksonville, FL, 06 March 2006.

[97]P. H. Deitz and A. Ozolins. Computer Simulations of the Abrams Live-Fire Field Testing, U.S. Army Ballistic Research Laboratory Memorandum Report BRL-MR-3755, 1989.

[98]J. Klopcic, M. W. Starks, and J. N. Walbert. A Taxonomy for the Vulnerability/Lethality Analysis Process, U.S. Army Ballistic Research Laboratory Memorandum Report BRL-MR-3972, 1992.

[99]A *course of action* is a possible military solution to achieve the mission objective(s) of a military force that must comply with the force commander's guidance and intent.

[100]Adapted from Maria L. Minchew. "The Connection Between Functions and Capabilities," in Proceedings of the 74th Military Operations Research Society Symposium (MORSS), U.S. Air Force Academy, Colorado Springs, CO, June 2006.

[101]Adapted from Britt Bray, loc.cit.

[102]Wikipedia entry for "predictive analytics" available online at http://en.wikipedia.org/wiki/Predictive_analytics

[103]W.W. Eckerson, "Predictive Analytics- Extending the Value of Your Data Warehousing Investment," TDWI Best Practices Report 2007

[104]Behavior Representation in Modeling and Simulation (BRIMS) Conference, Baltimore, MD, 16-18 May 2006.

[105]Vladimir A. Lefebvre, *Algebra of Conscience*, Dordrecht, Holland: Kluwer Academic Publishers, 2001.

Chapter 5. Exploitation and Assessment

P. J. Grazaitis

"Throughout the struggle, it was in his logistic inability to maintain his armies in the field that the enemy's fatal weakness lay. Courage his forces had in full measure, but courage was not enough. Reinforcements failed to arrive, weapons, ammunition and food alike ran short, and the dearth of fuel caused their powers of tactical mobility to dwindle to the vanishing point. In the last stages of the campaign they could do little more than wait for the Allied advance to sweep over them."

- Dwight D. Eisenhower, as quoted in the British Army Doctrine Publication, Volume 3, Logistics (June 1996)

5.1 Introduction

This section of the paper will focus on the technologies associated with exploitation and assessment pursuant to prediction and preemption capabilities and their relevance to military mission success. The prior chapters cover the fundamental building blocks for a logistical prediction and preemption capability (LPPC). An LPPC will enable Army decision makers to assess the impact of future conditions on the mission, thereby allowing commanders to take preemptive actions based upon informed operational decisions. These will culminate in executions of courses of actions that will change the future state to yield conditions that enhance the probability of mission success.

The exploitation phase of LPPC is the implementation of the COAs to ensure successful completion of the assigned mission by preempting the occurrence of one or more of the 19 undesirable situations. When one or more of the 19 undesirable situations occurs during the mission, we need to document it as part of the assessment phase of LPPC and attempt to learn what pieces of information, data, or knowledge could have foretold of this undesirable event (or events). This will enable us to gain greater insight into relevant "data" associated with causes in the logistics enterprise that create undesirable effects in the operating environment. This iterative LPPC methodology will serve to ensure the most robust logistics COAs to enable successful outcomes to future combat missions.

Based upon decades of military experience and expertise in understanding the cause and effect relationships between warfare processes and undesirable events/situations occurring within the operating environment, the researchers and authors have applied their military judgment to identify those elements of data/information/knowledge ("data") pertinent to predicting and preempting 19 undesirable events listed in table 1.1. Preventing these 19 situations from occurring is essential to the exploitation & assessment phase of the LPPC. Appendix B lists the specific pertinent "data" and the sources for that "data" by organization.

A prediction and preemption capability is a critical decision-support capability. In looking at the logistics enterprise, it is clear that advanced prediction and preemption capabilities are not only possible but, essential to the military decision making process to ensure the Army's continued dominance on the battlefield through successfully executed missions. Technologies are and will be available such that an enterprise-wide, comprehensive predictive capability serving the entire logistics community can be realizable by the 2020-2030 timeframe.

1. Methodologies and technologies required to develop an advanced, enterprise-class logistics prediction and preemption capability (LPPC). Prediction, for the express purpose of knowledge exploitation in support of logistical decision making, has the following characteristics:

   a. A methodology for identifying and developing prediction requirements.

   b. Ability to assess and re-address prediction requirements based on prediction failures, changes in technology or changes in doctrine.[106]

   c. Ability to exploit and assess predictive knowledge impacts on logistical operations in response to dynamically changing conditions in the operating environment with the express purpose of ensuring mission success.

   d. A focus on Soldier ability to use these capabilities effectively, as well as consideration of the requisite acquisition, training, and maintenance requirements.

2. Key technologies that must be considered for integrating the advanced technologies of data collection, communication, and fusion are described in chapters two through four. These must be combined into a seamless enterprise information technology (IT) system supporting exploitation and assessment of predictive knowledge.

3. Examples of some advanced technologies both real and conceptual that will be integrated into an advanced predictive enterprise information system in the 2020-2030 era.

Army Supply System Example:

Using the Army's logistic system as an example, it can be viewed as a complex set of vertical logistical business processes that are loosely linked together along the logistical classes of supply (see figure 5.2). An enterprise approach is deemed appropriate because prediction capabilities and the ability to preempt are applicable across the enterprise. This means that the predictive capabilities and preemptive exploitation will cut across the full spectrum of operational and logistical warfighting and business sectors. The critical events that would have a detrimental impact on mission success are the events the Army should try to prevent or mitigate, because it is well known that these events can lead to mission failure in the operating environment. Table 1.1 (repeated here for convenience as table 5.1) contains a list of what is considered by subject matter experts as critical events. This list of events is where an enterprise-wide suite of predictive capabilities in the form of models, simulations, and analytic tools must be directed as a first step.

The Army must do the following early on: develop a quantitative understanding of its business process and how problems, inefficiencies or failures in a given business sector can impact mission success; develop robust, fundamental methodologies for identifying key business processes that directly impact the critical events listed in table 5.1; develop and implement a framework process to identify additional predictive capabilities needed in key Army logistical business sectors.

Table 5.1. Examples of Military Critical Events that May Jeopardize Mission Success.

Military Critical Events Jeopardizing Mission Success
1. Losing the engagement (mission) to the enemy
2. Soldiers dying or being wounded
3. Running out of Ammunition
4. Running out of Fuel
5. Running out of Medical Supplies
6. Running out of Water
7. Running out of Batteries/Fuel Cells
8. Breakdown of Equipment Not Due to Enemy Action
9. Encountering Bad Weather
10. Encountering Threat Forces
11. Loss of Strategic Lift Assets and Their Cargo
12. Loss of Theater Lift Assets and Their Cargo
13. Closure of APODs and SPODs
14. Closure of Sea Lanes
15. Loss of Lines of Communication (LOCs)
16. Encountering Inaccessible Terrain with Convoys
17. Untimely Delivery of Mission Critical/Essential Parts and Spare Parts
18. Loss of Communications w/ logistics, intelligence and operations
19. Loss of Common Operating Picture

The Army must understand the cause and effect relationships of business processes pertaining to the critical events. Prediction will provide more accurate and actionable knowledge that can be exploited through the Army's decision making process to mitigate or prevent the occurrences listed above. To bring this about, a deliberate process is required starting with an established methodology.

5.1.1 Methodology

The data requirements to support the LPPC predictive analytics will require drawing information and knowledge about sustainment commodities (see table 5.2) such as inventory and asset visibility – critical events 3, 4, 5, 6, 7, 11, 12, 17, and 19 from table 5.1. In addition, other information and knowledge of the operating environment will be required to effect prediction – critical events 2, 8, 9, 10, 13, 14, 15, 16, and 18 from table 5.1. Knowledge from combat operations (G3), intelligence (G2), and Joint/Coalition Forces will all be necessary to minimize uncertainty while maximizing the impact of that knowledge for mission success.

Table 5.2. Classes of Supply.

Classes of Supply	
Class	**Supplies**
I	Subsistence, gratuitous health and comfort items.
II	Clothing, individual equipment, tentage, organizational tool sets and kits, hand tools, unclassified maps, administrative and housekeeping supplies and equipment.
III	Petroleum, fuels, lubricants, hydraulic and insulating oils, preservatives, liquids and gases, bulk chemical products, coolants, deicer and antifreeze compounds, components, and additives of petroleum and chemical products, and coal.
IV	Construction materials, including installed equipment, and all fortification and barrier materials.
V	Ammunition of all types, bombs, explosives, mines, fuzes, detonators, pyrotechnics, missiles, rockets, propellants, and associated items.
VI	Personal demand items (such as health and hygiene products, soaps and toothpaste, writing material, snack food, beverages, cigarettes, batteries, and cameras—nonmilitary sales items).
VII	Major end items such as launchers, tanks, mobile machine shops, and vehicles.
VIII	Medical materiel including repair parts peculiar to medical equipment.
IX	Repair parts and components to include kits, assemblies, and subassemblies (repairable or non-repairable) required for maintenance support of all equipment.
X	Material to support nonmilitary programs such as agriculture and economic development (not included in Classes I through IX).
Miscellaneous	Water, salvage, and captured material.

A top-down model for developing LPPC Exploitation and Assessment technologies is shown in figure 5.1. This methodology represents the basic layers for developing a comprehensive assessment and exploitation suite of tools that will support Army logistical decision making across all warfighting and business sectors. The top layer, frameworks, represents a critical first step required to identify what prediction capabilities are required. A framework approach forces the basic question of ‘what is it that the Army needs to predict’ to be answered in a comprehensive and structured manner. This step in the methodology has been answered in table 5.1. From this point, everything flows top down until you have the specific analytics (algorithm classes) required. From these analytic requirements, specific technologies (i.e., software implementations) can be identified as relevant to embodying the necessary analytics. Each of these broad areas in the methodology (figure 5.1) will be discussed in further detail in this chapter.

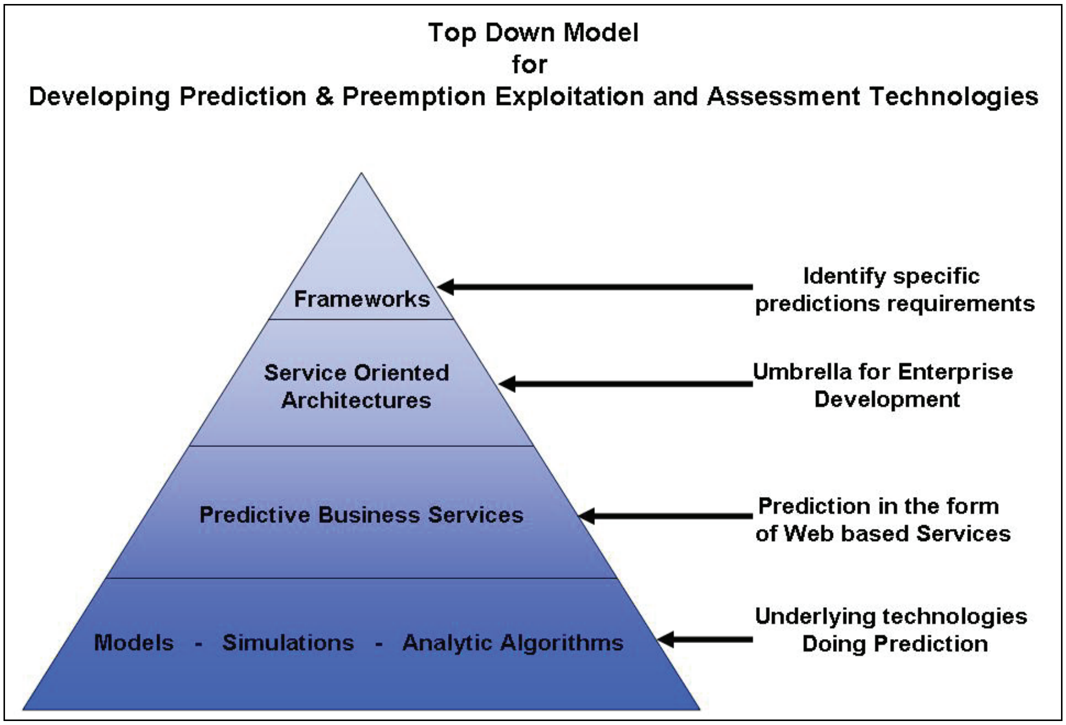


Figure 5.1. Top-Down Model for Developing LPPC Exploitation & Assessment Technologies.

Given the inherent dynamic nature of warfare, one or more of the critical events listed in table 5.1 is likely to occur. For that reason, understanding cause and effect relationships is the key to identifying required prediction capabilities.

For example, planning and establishing a sustainment site is a process that must occur during a military operation and must be successful if mission success is to be achieved. Failure to properly plan and establish an ammunition resupply point, for example, could result in degradation of operations due to weather impacts or enemy attack. Similarly, terrain features could prevent the ability to store required inventory and limit resupply capability. Predictive analytics to support decision making in the planning and layout of sustainment sites will help mitigate the impact of these challenges.

Another example can be found in preventive maintenance. Maintenance is an Army process that must occur during military operations and is essential for mission completion. Failure to properly perform diagnostics on a system during a scheduled maintenance could lead to system failure resulting in mission failure. Advanced prognostics, something the Army is currently investigating, is a type of prediction that would provide advanced indication of system component failures. This ties in further to the rest of the supply chain. Lead time for parts and repairs must be included when considering time-between-overhaul (TBO). The length of the prognostic window will directly impact the maintainer's input to obtain resupply. The key point is that many logistical processes must be synchronized across the enterprise. These logistical warfighting and business processes must be considered in a holistic sense in order to achieve success.

Figure 5.2 depicts a typical military supply chain from the manufacturer to the retail. It is basically a set of transportation links and logistical operation nodes through which sustainment flows. The Army has many business process areas that occur all along the supply chain which are also depicted in the figure. Each business sector has its own unique set of business processes and operations that need to occur successfully for the supply chain to operate in a lean and efficient manner while meeting sustainment objectives. Business processes vary from node to node, link to link, and from commodity to commodity. It is within these business processes where predictive capabilities are needed to predict the changing requirements over time. These are the access or entry points for new predictive capabilities to ensure that logisticians have the actionable knowledge needed to exploit and preempt dynamic conditions that can potentially lead to events listed in table 5.1.

With sustained operations for the combatant commander as a primary goal, the key question is "Which logistical business process sectors and which of their associated business operations are the most critical to mission success?" A framework approach, with a focus on logistical business processes, will be critical to answering this question completely and in a systematic manner.

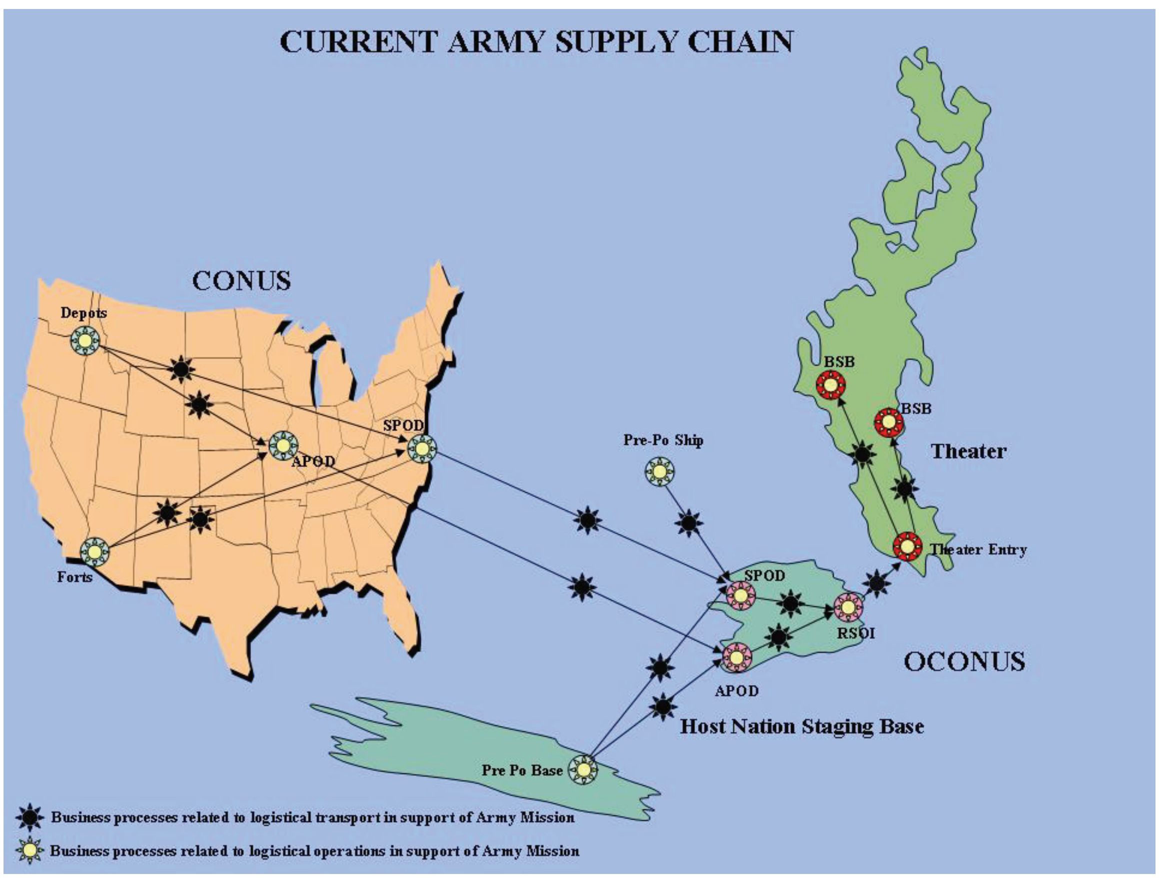


Figure 5.2. Army supply chain.

5.1.2 A Framework Approach

If one looks across the Army's supply chain, factors in all the classes of supply and all the business processes involved to move those sustainment commodities through the supply chain, it is easy to visualize the potential requirement for an infinite number of prediction capabilities. To add to the complexity of determining prediction requirements, technology and doctrinal policy change over time, which necessitates new and adaptable predictive capabilities. This leads to the realization that the problem of prediction and preemption is large and complex. As pointed out earlier, a framework methodology is needed to adequately address a problem of this magnitude.

The goal of this framework is to provide a systematic breakdown of the prediction challenge (breaking it down into sizable bites). In looking across the Army's supply chain and associated business processes, it becomes clear that prediction capabilities that will be required in the 2020-2030 era will be a suite of tools targeted to support the deployed/employed BCTs through the exploitation of predictive knowledge and the execution of preemptive actions. This suite of tools will need to employ a diversity of modeling, simulation, and analytic algorithms which will be designed to meet the specific prediction requirements supporting specific business processes for a given logistical business sector.

To accomplish this, the framework process needs to employ a set of steps that look across the Army's supply chain using a top-down method. It must identify the general business sectors within the supply chain and their linkage to mission success. The critical events, listed in table 5.1, are linked to each other using cause-and-effect relationships in order to determine their criticality.

Once the prediction capabilities have been identified through this top-down method, the next question to be answered is 'what types of analytics are needed to generate the prediction?' The framework identifies the specific technological means through a bottom-up method to answer this question. Again, this requires a systematic bottom-up process to identify the specific analytic technologies (e.g., algorithms, models, simulations) either existing, or in need of development, that can generate the prediction, identify the required data and knowledge elements to satisfy the analytics, identify the technologies to produce the data and knowledge elements required, and identify the communication infrastructure needed to support a push/pull migration of that knowledge. This bottom-up approach provides a mechanism for identification and development of prediction capabilities that can be grouped into a suite of tools supporting specific logistical business sectors that have been determined to be critical to the deployed/employed BCT's mission success. Many such tool suites will be required across many business sectors across the Army's supply chain. As will be discussed later, these tool suites can be brought together to collaboratively share data and knowledge under the umbrella of the Army's Integrated Logistics Architecture. This architecture provides an operational framework and standards for end-to-end integration, alignment, and interoperability amongst architectures.

This is important for developing a predictive enterprise information technology system that will be integrated into the overall logistics enterprise.

Table 5.3 below is a summary of this framework concept for developing Army Supply Chain prediction requirements and the supporting technologies required to implement those prediction capabilities.

Table 5.3. Framework for Determining Prediction and Assessment Capability.

1	Segment the Army's supply chain process into a set of logistical business areas from manufacturer to retail for all sustainment commodities.
2	Segment the general business areas into a set of business processes that support the specific business area operations.
3	Identify those business processes that are critical to preventing or mitigating the occurrences of events listed in Table 5.1.
4	Segment a given business process into a set of business process metrics and functions.
5	Determine the prediction capabilities that are critical to supporting decision making for a given business process.
6	Identify the analytic tools (e.g. model, simulation, analytic algorithm, etc.) required to generate the prediction needed to support the decision making process.
7	Based on the identified analytic tools, determine the data, knowledge elements, fidelity required to generate a reliable and reasonably accurate prediction.
8	Data and knowledge elements will dictate the advanced technologies needed and where the technologies need to be located to generate accurate data and knowledge elements.
9	Data generation will dictate the network communication, information, and software technology infrastructure needed to support push/pull data migration.
10	Changes in technology, doctrine, and/or policy require reassessment of prediction requirements.

Item 10 in table 5.3 suggests a framework process for determining prediction capabilities that are cyclical. This continuous reassessment of prediction requirements is driven by assessment failures of the predictive tool itself, policies change over time, or technology changes. It can be expected that, due to these continuous changes, prediction requirements may change, but those events we want to preempt from occurring will remain. It must be recognized that what actually occurs in the operating environment may sometimes be just the exact opposite of what was predicted. A cyclical methodology must be employed in such cases and a self-examination as to why a particular prediction capability has failed or its accuracy has decreased. This may occur due to the need for more fidelity in the data, new algorithms, or the need for additional data classes to be incorporated into the analytics. For whatever the reason, critical failures of a predictive analytic will require immediate assessment of impact and rigorous examination to determine possible remedies. This provides the mechanism to ensure that an LPPC does not become obsolescent with time. Hence, the framework provides a methodology to continuously reassess prediction requirements. This framework concept is pictured in figure 5.3.

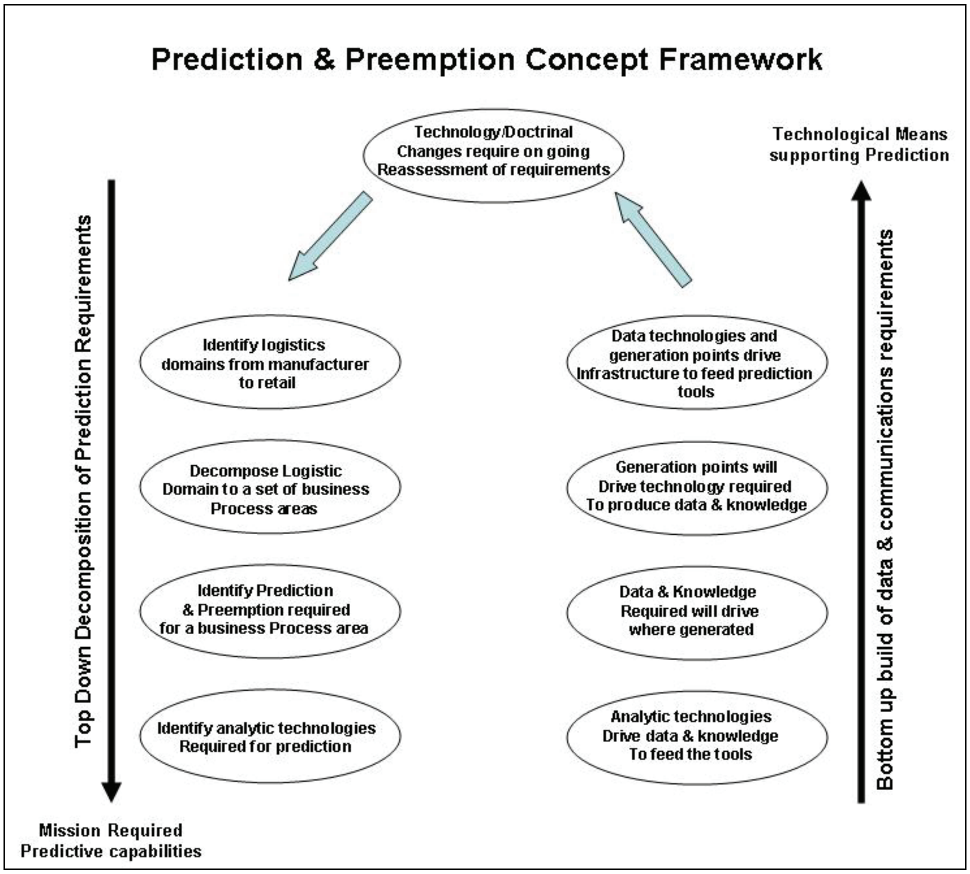


Figure 5.3. Prediction & preemption concept framework.

Note that the framework in figure 5.3 combines the process of a top-down decomposition of logistic business operations into required prediction capabilities along with a bottom-up build process for identifying the technologies and technological capabilities required to generate the prediction.

The complexity of decomposition comes from the fact that the Army's logistical supply chain and its associated business sectors are more complex and dynamic in nature than a commercial supply chain. The Army must transition from a peacetime footing to a wartime footing when global events dictate such a change. The transition from peacetime to wartime has major consequences for preventing or mitigating the events listed in table 5.1. This means the business processes for any given business sector within the Army's supply chain will be *dynamic*[17] in nature. The business sectors that make up the Army logistical supply system will necessarily have to transition over time. This will mean that within various business sectors, some business processes will have to transition, others will no longer apply, and new business processes will have to be implemented to meet the planning for and execution of missions. This adds levels of complexity to prediction and preemption that is not typical of commercial logistical operations.

[17] In this case, we mean dynamic in the mathematical sense (chaotic).

That complexity must be factored into identifying and developing critical predictive requirements for Army logistical operations.

In factoring in this additional complexity, there would naturally be some business processes that are specific for peacetime, wartime, and transitioning to and from these operational states in each and every business sector. To deal with this complexity, a simple broad-based framework is needed which is applicable to all Army operational scenarios across the full spectrum of warfare. The framework can be viewed as a series of transitions from one operational state to the next operational state that the Army cycles through as it prepares for and executes any military operation.

If business processes for a given event have been identified as critical to mission success (through the previously described decomposition process), then predictive capabilities to support the deployed/employed BCTs will be critical as well. Additional consideration to identify the business processes associated with the transition through those operational conditions is described in table 5.4. Failure to consider the operational conditions could allow key prediction and preemption capabilities to be overlooked.

Table 5.4. Concept model of Army operational conditions.

Operational Condition	Description
Steady State (peacetime operations)	The day-to-day CONUS/OCONUS business processes covering training, exercises, and other daily operations
Mission Planning	Business processes geared to mobilization for deployment and the pre-deployment planning associated with it
Deployment	Business processes associated with deployment to theater in preparation for mission execution
Mission Execution	Business processes associated with actual execution of the mission, which continue to include elements of mission re-planning and re-deployment
Retrograde	Business processes associated with leaving an area of operations for redeployment to another region or to CONUS/OCONUS bases
Nation Building/Humanitarian	May or may not be part of a post military operation. If it is, those business processes associated with planning and executing re-construction, policing, training, governmental functioning.

This will result in a set of business processes and a set of prediction capabilities that are associated with the various conditions and transitions between those conditions. Figure 5.4, is a graphical representation of this Army transition model.

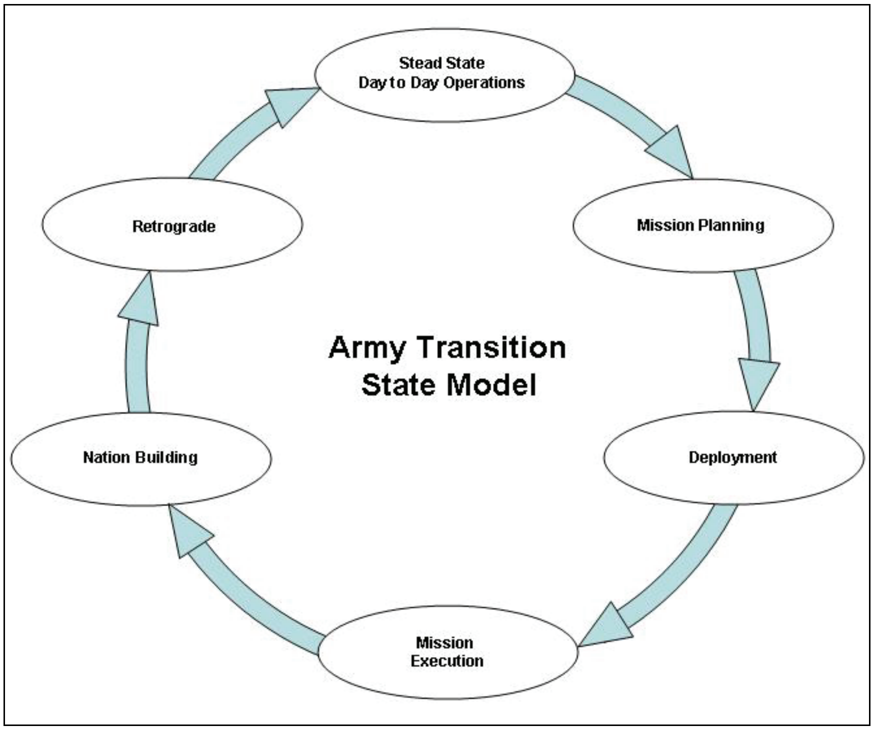


Figure 5.4. Army transition state model.

The second half of the framework recognizes that you need some methodology in a bottom-up approach to take the predictions that are considered essential for mission success and develop the analytics required, identify data and knowledge elements to feed the analytics, identify technologies to generate that data and knowledge, and develop the communications infrastructure required to push/pull all that data and knowledge across the logistics enterprise.

The prediction capabilities required will dictate the analytics required to generate the most reliable and accurate prediction. The analytics will dictate the data requirements. The data will dictate the technologies needed to produce them. The data to be generated will dictate, to a certain degree, the communications infrastructure needed to meet data fidelity, currency, and warehousing requirements.

All of the technologies required, from communications, data, to analytics will be driven, to some degree, by the specific prediction capability desired.

5.1.3 Service Oriented Architecture: Casting Predictive Tools as a Services Oriented Information Enterprise System

This section will focus on the next tier in the model, architectures, and more specifically Service Oriented Architecture (SOA). A SOA integrates various data sources for prediction, from across all Army logistical warfighting and business areas, into a network-centric enterprise-wide capability. SOA would serve to integrate all the technologies, data, fusion, and communications.

Its primary focus would be to provide services to the end user in the information enterprise (logistics enterprise).

The primary reason for focusing on SOA is that it has a number of benefits from the end user's perspective in implementing enterprise class information systems. A SOA approach to enterprise information systems focuses on applications, functions, and tools as services. Users of the enterprise information system want the systems to provide information and knowledge through data retrieval, exchange, and analytics without getting into the technical weeds. This is critical to overall system usability and will be a critical issue in the success or failure of any enterprise-wide system for an LPPC.

5.1.4 Predictive Business Services: Incorporating Business Process Integration (BPI) into Web Services Under a SOA Umbrella for Improved Usability and Understanding

Prediction capabilities under a SOA umbrella are the services that are to be provided to the logistician in an Army-wide predictive enterprise information system. Under this architecture the prediction suite of tools and applications are viewed as services to be performed that provide actionable knowledge in support of course of action analysis for logistical business operations. SOAs are an approach to enterprise business systems and business applications that consider these resources as services available and discoverable on a network. Such services provide functionality to the business while hiding the underlying implementation details.

There are a number of approaches that can be taken to implement the predictive business services. One methodology that appears to a gaining favor in the commercial sector is to implement the new services in the form of a web-based service for better business process integration. "In short, Web Services allow applications to be assembled from collections of software components using data from different documents or sources, thereby simplifying and streamlining business process coordination between disparate systems, business units, and business entities."[107] So it would seem reasonable that a web service approach to implementing predictive business services would be a choice methodology for integrating predictive business services into an Army enterprise IT system.

Consider the relentless expansion of IT systems throughout all aspects of the military today. FCS, for example, will bring several orders of magnitude increase in information technology present on the battlefield. A key issue will be maintaining sufficient personnel with the key technology skills to deploy, operate, and maintain this ever growing information enterprise. Lessons learned in Operation Iraqi Freedom reflect this concern: The battalion was issued two Movement Tracking Systems (MTS) before crossing the Iraqi boarder, but neither was complete, no training provided on them, most of the system installation was left up to the unit.

There is no question that as the Army evolves and we enter the 2020-2030 era, technology will grow exponentially in the form of sensors and micro electronics that will provide unimaginable amounts of data. Prediction and preemption capabilities will only add to the mass of data that will be generated to become part of the Army's logistical information enterprise. An analogous situation is occurring in the corporate business domain. Companies are experiencing an explosion of available information. According to a 2003 study by the University of California, Berkeley's computer-science school, the volume of data on the web tripled between 2000 and 2003, from less than 50 terabytes to 167 terabytes. In 2002, print, film, magnetic, and optical storage media yielded about 5 quintillion (that's 5 times 10 to the 18th power) bytes of new data, 37,000 times the amount of information in the Library of Congress. The trend - 30% annual growth in the volume of information produced - shows no sign of slowing. It is for this reason that careful consideration must be given to the architecture of the enterprise IT system that will need to pull prediction-related information together.

To fit an SOA model, predictive tools should be viewed as services requested by Soldiers and delivered by the Army's logistical enterprise IT systems. In the SOA model, developing the predictive analytics through the use of web services isolates the Soldier from the technologies under the hood of an enterprise IT vehicle. Web services and the concept of service portfolios bring a number of advantages to the table. First and foremost, the portfolio concept ties in nicely with the framework breakdown of Army sustainment operations. Each business sector would have a portfolio of prediction services designed specifically to support its decision making requirements.

For the Army, as technology and doctrine change, the need for new or updated prediction capabilities will be identified. As these new prediction capabilities are developed into actual predictive services, they can plug into the portfolios associated with the appropriate logistical business sectors. The web services based SOA model provides a high degree of flexibility and scalability. From the Soldier's perspective, he or she is isolated from the technologies. The Soldier is exposed to a web-based user interface that consumes data and information from other systems (services) across other domains behind the scenes in much the same manner as when querying commercial internet service providers such as Travelocity, Amazon, Google, AOL, or Army Knowledge Online (AKO).

The web services SOA model concept is pretty simple conceptually, but the implementation technologies are quite complex. For example, Knowledge Based Systems Inc. proposed maintenance information enterprise architecture to PM UH-60 that incorporated information from experimental Health and Usage Monitoring Systems (HUMS) as part of the overall maintenance enterprise. Figure 5.5[108] is the concept architecture proposed to PM UH-60.

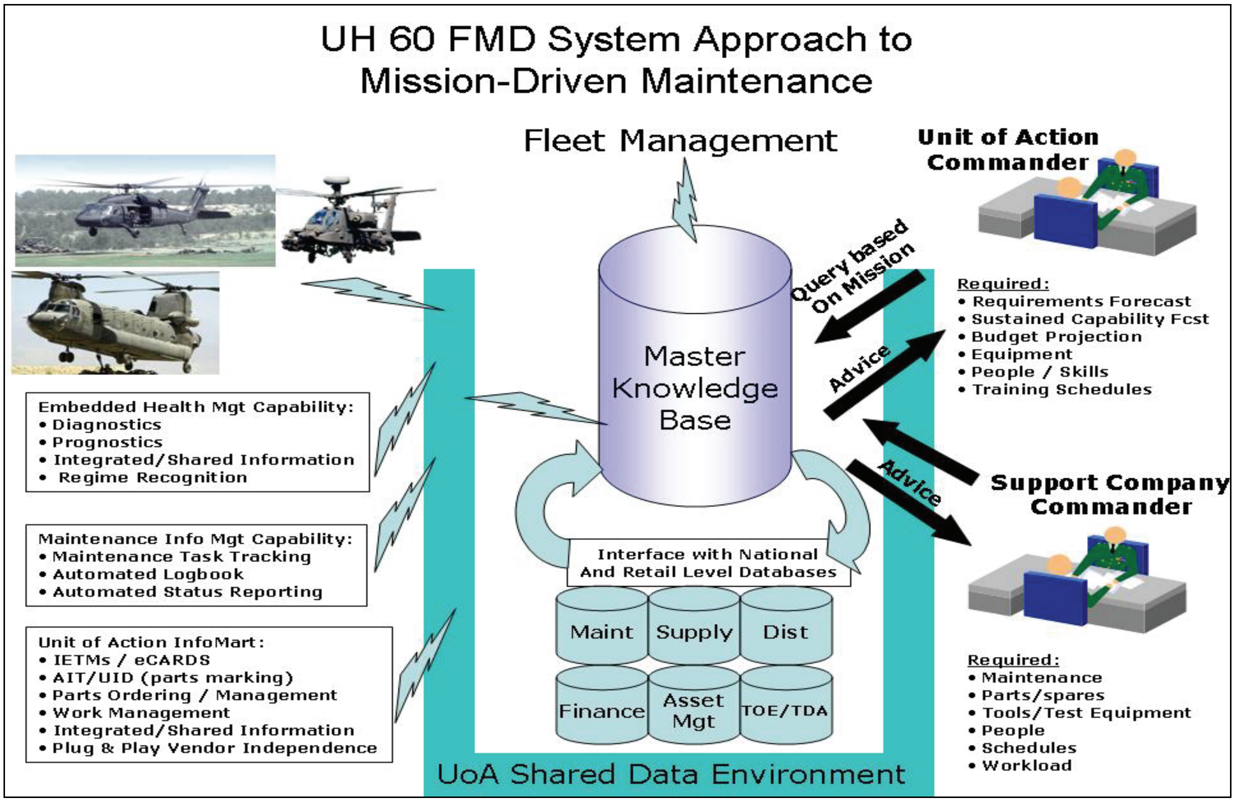


Figure 5.5. UH-60 FMD system approach to mission-driven maintenance.

Figure 5.6 is a web services SOA approach using the concept of web portfolios. This approach is not tied to any particular information system technology platform. The architecture can be implemented on any distributed network backbone, existing or built from the ground up. Services required in any given business sector can be “plugged in” and used as needed. Additional business processes can be defined and added to the enterprise as needed. This portfolio “plug & play” concept also supports the cyclic assessment process of predictive analytics. As discussed earlier, predictions may produce bad forecasts from time to time. The framework cycle process provides a mechanism for reassessment of existing predictive analytics, removing, modifying, or creating new predictive analytics based on this reassessment. The service portfolio concept with its “plug & play” capabilities allows predictive analytical tools to be quickly pulled from, or placed into, a portfolio as needed.

Note that in this example, the implementation is heavily dependent on intelligent agents to perform much of the technical work behind the scenes, thus isolating the user requesting a service from the underlying technology. To accomplish this, software agent technology would be the technology employed to make it imperceptible to the user. For effectiveness, the agents would have to know something about sources of data that are relevant to performing the service. Software agent technology is one of those broad technology areas that will be useful in implementing a web services SOA enterprise information system. Software agent technology is discussed in some detail later in this report.

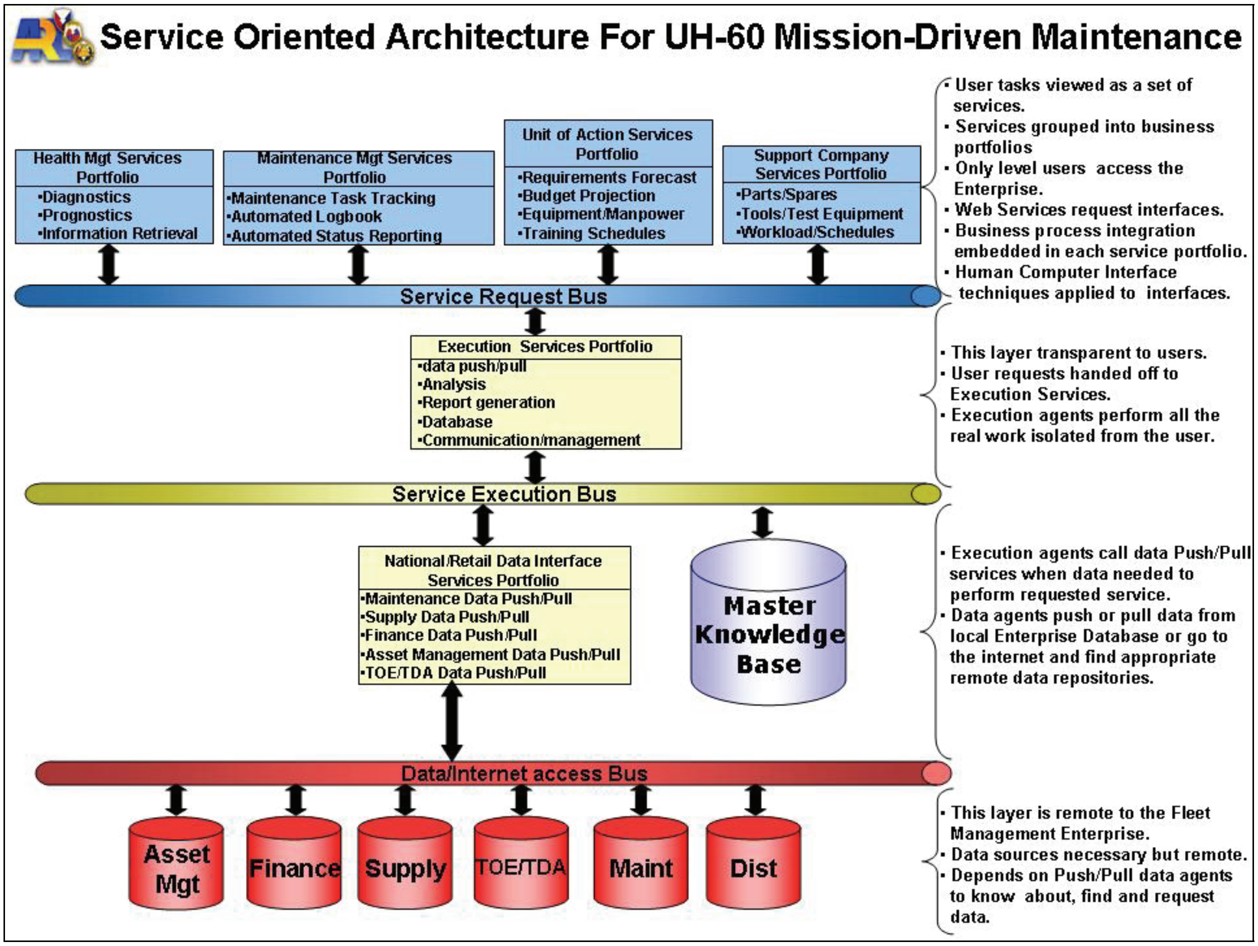


Figure 5.6. Service oriented architecture.

Figure 5.6 as architected provides the predictive and visibility services. These are shown in the blue portfolio boxes at the top of figure 5.6. They provide the actionable knowledge needed to prevent or mitigate the following critical events listed in table 5.1: untimely delivery of mission critical/essential parts & spares; loss of common operating picture; and losing the engagement. This example does show how a SOA can be constructed and how predictive and visibility services can potentially affect one or more of the critical events listed in table 5.1. It also demonstrates how complex it is to architect and implement such a network-centric enterprise IT system targeted at prediction and preemption of events critical to the successful completion of combat missions.

Figure 5.6 is just one possible approach to implementing a Web services SOA model and is shown here to emphasize how such a model can be used to simplify Soldier interfaces and improve usability. To implement such a SOA will require the Army to develop a better understanding of its logistical business processes as they change over time and the impact of new technologies on logistics operations. The general consensus among experts in this field is to build from the bottom up slowly. “You can’t buy SOA. You can buy tools that may help you get closer to a SOA, but there is no easy purchase that can make SOA a reality without a lot of work over time, says Ron Schmelzer, a senior analyst with ZapThink."[5]

Given that we know what the end state is regarding events that need to be preempted, what "data" elements need to collected, and where those "data" elements reside within the Army and Joint/Coalition Force, the next step is to establish business process metrics. This is a critical step recognized by corporations when developing any business performance management technique, process, or tool.[18] Prediction services are business management tools for the Army. Business process metrics enable business process integration to take place.

Business process integration is required when developing any type of information technology capability. The Web service should present information to the Soldier in a manner that is familiar and aligned with the Soldier's business processes. If not, the Soldier will not feel comfortable using the tool and will be prone to entering incorrect data resulting in inaccurate predictions. To integrate the Soldier's appropriate business processes into predictive Web services, it is critical to match key business metrics to the particular prediction capability. The same is true with the resulting output from a prediction service. It must intuitively convey meaningful and actionable knowledge to the Soldier.

BPI will accomplish several key objectives in the resulting predictive web services. It will improve usability in executing the service request. The prediction results will convey actionable knowledge to the Soldier that is intuitive and meaningful. Training requirements will be reduced because of the improved usability of the resulting web service tools. To illustrate this point, consider this analogy with video games. People who rent video games rarely start out by reading the instructions about how to play the game. Most jump in immediately and, within an hour or two of just playing around with the gaming software, they have figured out most of the rules and objectives of the game (i.e., the game's business process). The gamers are off and running. The reason this occurs is because the game's business process rules are integrated into the software requiring little training or reading by those who play video games. If the gamers had to spend several hours reading 'how to play' for every video game they rent, the video gaming industry would not be the success story that it is today. Developing predictive Web services under a SOA model must be as easy and intuitive to use by the Soldier as video games are for the general public. BPI is one method to accomplish this objective. But this will require a major upfront effort in the development process to define and develop those metrics and to ensure that business process integration is accomplished early on.

Although the Web services SOA model brings many benefits, further consideration beyond simple Web interfaces will be essential for success. A Web wrapper and appropriate middleware will need to be developed and placed around the analytical tools to make the prediction analytics function as a Web service. The interface to this wrapper is critical to overall usability and

[18]The biggest challenge in performance management often comes right at the beginning: metrics definition and development.

successful execution of the predictive service being requested. From a usability point of view, the interface must go beyond the effort to develop a Web-based front end where simple radio buttons, cascading menus, etc. are selected and the request is submitted and some analytical Excel display, chart or table is produced. It must integrate the Soldier's business practices and business metrics into the Web service itself in a way that it understands the meaning and intent of the user requesting the service. In addition, emerging technology from the field of semantic interpretation by computer machinery must also be leveraged.

Emerging research into the field of semantic interpretation holds promise for developing advanced Web-based interfaces that improve a machine's understanding of a human's request for information. Critical to achieving this in a SOA enterprise system using web services is research into the development of an emerging technology called the 'Semantic Web'. This is an effort to build intelligence into the Web interfaces by providing semantic interpretation into the human requests for information. "With the Semantic Web, Web services applications will be smarter and more comprehensive."[7] For example, everyone can relate to a standard Web query through a search engine like Google. No matter how one qualifies the search parameters, the search usually returns dozens if not hundreds of URLs. Some are clearly unrelated to the information desired and often times there are duplicate URLs throughout the return list. It often takes significant time to parse through everything to get down to the relevant links. "Paul Shabajee, research fellow working at the ILRT and HP labs, explained that while search engines perform simple linguistic analyses based on free-text search terms effectively, they produce lists of results that require the human user to make the smart inferences about which of the data are relevant. … In short, Web pages aren't precise enough for software to process and "understand" the content of the page. Accordingly, semantic Web technologies will allow machines to make those inferences. Presently, search engines simply return all Web pages featuring the search text a user has entered. The solution is "robots" - pieces of semantic Web code - and machine readable languages, or knowledge representation syntax, which allow a user's computer to filter information in such a way that returned results are more precisely fitted to the search."[109]

Table 5.5. Prediction & preemption technology categories.

Technology Categories	Description
Web	Those software technologies that are used to develop the Web interface front ends that interact with software agents performing the dirty work under the hood of the prediction and preemption enterprise information systems.
Intelligent Software Agents	Intelligent software agents will perform the bulk of the nuts and bolts operations of finding and gathering data to feed to the analytics, as well as gathering up the prediction and preparing it for presentation to the service requestor
Data	The required elements to feed to a specific analytical engine to do a prediction. Some data elements will come directly from sensors. Others will come from repositories. The location, currency, and structure of the data will dictate software used for repositories.

Networking	Bandwidth, data sources, data currency requirements, and networking design will impact where data repositories are setup, how data are pushed and pulled, and what the data structure looks like. These networking characteristics will drive application software tool choices as well as design implementation of repositories and software agents.
Analytics	These are the "nuts and bolts" technologies and techniques that use current and historical data to generate a prediction. These include a wide range of diverse technologies including but not limited to statistical analytics, models, and simulations.

Table 5.6. Web technologies.

HTML	HTML stands for **H**yper **T**ext **M**arkup **L**anguage. An HTML file is a text file containing small markup tags. The markup tags tell the Web browser how to display the page
XML	XML, Extensible Markup Language, was designed to describe data and to focus on what data are. HTML was designed to display data and focus on how data look.
SOAP	SOAP stands for Simple Object Access Protocol. SOAP is a simple XML-based protocol to let applications exchange information over HTTP.
RSS	RSS stands for **R**eally **S**imple **S**yndication. RSS is a method that uses XML to distribute web content on one web site, to many other web sites.
OWL	The OWL, Web Ontology Language, is designed for use by applications that need to process the content of information instead of just presenting information to humans.
WAP	WAP stands for Wireless Application Protocol. The WAP protocol was designed to show internet contents on wireless clients, like mobile phones.
HTML DOM	The HTML Document Object Model (HTML DOM) defines a standard way for accessing and manipulating HTML documents.
JavaScript	JavaScript was designed to add interactivity to HTML pages
VBScript	VBScript is a scripting language
Pearl	Pearl is a Scripting Language
AJAX	AJAX stands for Asynchronous JavaScript And XML. AJAX is not a new programming language, but a technique for creating better, faster, and more interactive web applications.
AppML	AppML is not a programming language. It is a declarative language, used to describe applications.
WML	WML stands for **W**ireless **M**arkup **L**anguage. It is a mark-up language inherited from HTML, but WML is based on XML, so it is much stricter than HTML.
WMLScript	WML is used to create pages that can be displayed in a WAP browser. Pages in WML are called DECKS. Decks are constructed as a set of CARDS.
Flash	Macromedia Flash is a multimedia graphics program especially for use on the Web. Flash enables you to create interactive "movies" on the Web.
SVG	SVG stands for **S**calable **V**ector **G**raphics. SVG is used to define vector-based graphics for the Web. SVG defines the graphics in XML format.
Microsoft .NET	.NET is Microsoft's new Internet and Web strategy, a new Internet and Web-based infrastructure, delivers software as Web Services, a framework for universal services, a server centric computing model

5.1.5 Analytics, Models, Simulation: Technological Nuts & Bolts for a Predictive Enterprise Information System

This section represents the fourth tier of the model in figure 5.1. The analytical engines that will actually perform the service of making a prediction are the technological nuts and bolts for a predictive enterprise information system. These are the actual execution applications that will use the data provided to actually perform the analytics to make a prediction or provide a forecast. There are a number of techniques used to make predictions. Most fall into the broad categories of statistical analytics, models, simulations, and data mining. More specific examples of analytic methods are, time series analysis, regression models, perturbation models, Wavelet based methodologies, Artificial Neural Network (ANN) non-linear, non-parametric models, ensemble prediction methods[110], and the list goes on.

The development of specific predictive services to do the prediction will need to focus on the appropriate methods or techniques to perform this task from an analytic standpoint. This will require extensive research, development, and validation testing to ensure that the prediction does indeed provide reliable and accurate actionable knowledge for the Soldiers at the level of accuracy required. The specific analytical methods will be driven to a large extent on the nature of the data and, data availability, as well as the nature of the specific prediction to be made. There is no magic bullet to accomplish this and time consuming research and development will be necessary to develop the analytics required.

To make the point, consider this comment on forecasting in an announcement for a conference on the 'Future of Forecasting' that was held at the University of Leipzig, Germany in December of 2005. "Until the early 1970's, there were great expectations about the promises of economic forecasting. Considerable resources were expended to improve existing methods and to develop new methodologies. As a result, much was accomplished. However, there were many forecast failures in the late 1970's and a number of theoretical "revolutions" offered explanations for these errors. These discussions were intellectually stimulating, but they have not led to a substantial improvement in forecast accuracy. An examination of the forecast accuracy that has been observed over the past 50 years indicates that the errors (as a percent of GDP) remain unchanged."[111]

There appears to be a strong belief in the forecasting community that revolutionary methods are unlikely and that novel and hybrid implementation of existing methods are more likely to provide forecasting solutions. For example, the national center for environmental decision-making research brings this issue up on their web site. "The main problem with forecasting methods is lack of use, not lack of tools. Methods also are available to enhance the use of forecasting and ensure the soundness of forecasting results."[112] The key will be the ability to characterize and develop a thorough understanding of the prediction requirement. This is important for deciding what technologies to employ to develop a reliable forecasting capability for a given problem. "The techniques appropriate to any given forecasting situation depend on numerous factors, such as the amount of data available, the nature of the phenomenon being forecasted, the time horizon of the forecast and many others. Characterization of the forecast problem in terms of these factors will allow the astute forecaster to dip into the toolbox and find the appropriate technique-or at the very least, the most appropriate technique, since there are no guarantees that a good technique necessarily exists for the phenomenon being forecast."[113] The point is to do the research up front to develop the understanding and nature of the prediction desired in order to develop the prediction analytics.

To implement those critical prediction capabilities will require meticulous and dedicated research and development into understanding the nature of the issue and the data to support developing reliable and accurate prediction capabilities. This is not to say that new and novel analytics should not be an on going endeavor to assess what is emerging from government, university, and corporate domains that could produce more accurate prediction capabilities over traditional methods. The point being made here is that improvements are not likely to come from some breakthrough in statistical methods but more likely to come from some from hybridization using a combination of a number of traditional technologies and methods. Consider Zaptron Systems, Inc., for example. Zaptron has invented technologies that combine fuzzy logic with Fourier analysis and time series forecasting to provide an advanced forecasting capability.[114]

A similar situation applies to modeling and simulation. There are a number of traditional methods used to produce model simulation predictions. For example, Monte Carlo simulations, discrete event simulation, rule-based simulation models, optimization models, system dynamics models, correlation models (data mining), and list goes on. As technology produces exponential growth in data and the requirement for evermore complex prediction capabilities grow, model simulation techniques will look to a combination of existing techniques to provide better and more accurate predictions. ARL is currently exploring unique hybrid and combinatorial forecasting techniques under a small business innovative research (SBIR) initiative to examine the potential to address complex time varying issues that are difficult to forecast in general, and whether such combinatorial forecasting techniques can provide more accurate predictions. This ARL SBIR effort developed an experimental framework concept where a variety of analytical techniques could reside. They are used as needed to develop a variety of simulation scenarios for an analysis using a combination of analytic techniques through a simulation engine to generate condition forecasts. Figure 5.7 is a graphic of this experimentation framework concept. This is one future concept for developing hybrid or combinatorial prediction techniques through model simulation. As a proof of concept experiment, ATLAS was used to examine CH-47 buy strategies to predict optimum strategies that maximize parts availability while minimizing parts costs. This ATLAS exercise was validated against the standard procedures in place for developing buy strategies, the Requirement Determination Execution System (RDES). It was validated that ATLAS was able to provide significantly better forecasts than traditional methods.

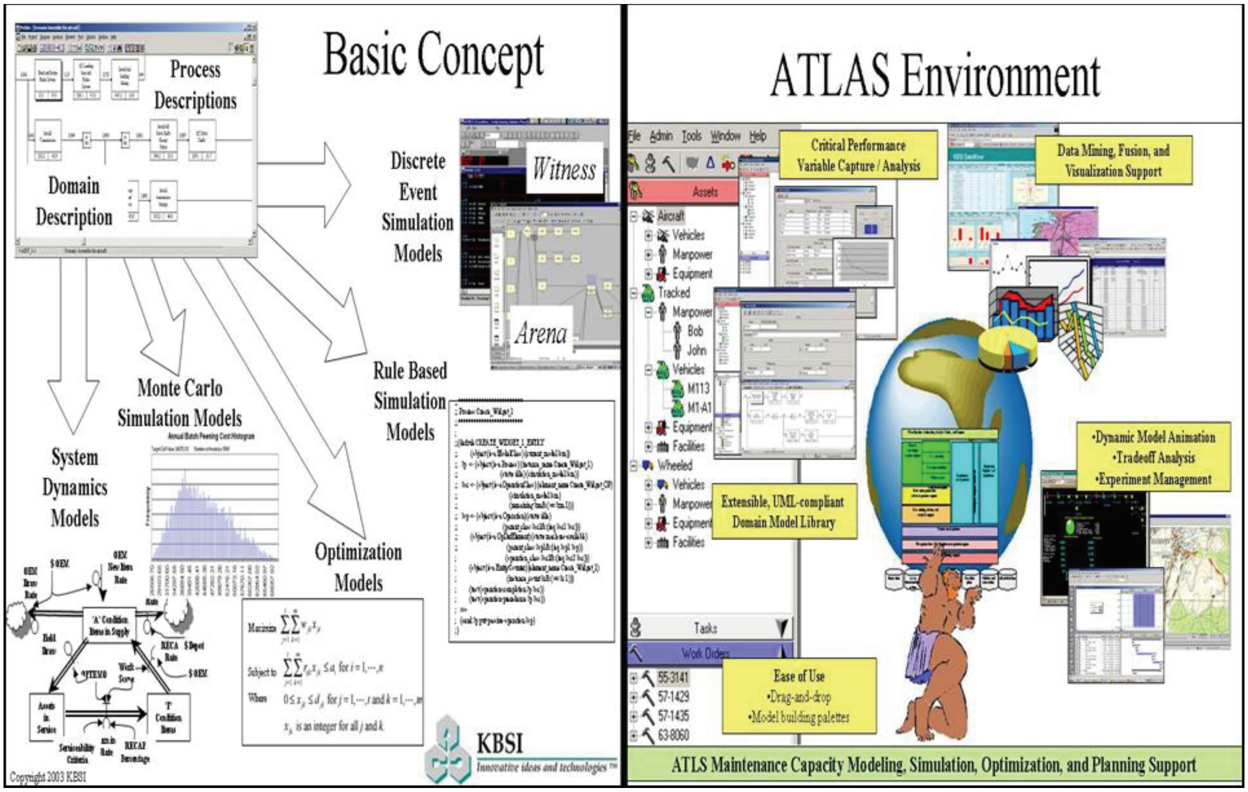


Figure 5.7. ATLAS experimentation framework.

Advanced prediction tools such as ATLAS do not necessarily need to take the approach of developing advanced theoretical or statistical methods to meet prediction requirements. As discussed earlier, novel approaches using a combination of traditional forecasting methods are often sufficient to provide more accurate predictions over traditional methods or provide predictive capabilities that are not possible with a single traditional method alone. Regardless, significant research is still required to identify and combine these prediction methods in a way that they provide reasonable and accurate predictions that meet Army requirements. Development of specific analytics to support a critical predictive capability will likely be a major undertaking in some cases to develop, verify, and validate that the new analytics provides reasonably accurate and actionable knowledge that will prevent or mitigate events listed in table 5.1.

5.1.6 The Enterprise Glue: Technologies Needed to Pull it all Together

For the purpose of exploitation and assessment of predictive knowledge, research was conducted across a number of diverse technologies to determine the best method to collect advancing technologies in the data generation, communications, and data fusion fields. This collecting process helps create an enterprise information system supporting prediction and preemption. An enterprise information system supporting course of action (COA) decision making across the entire military logistics domain with the objective of preventing or mitigating the occurrence of the events is listed in table 5.1. To achieve this objective, research indicated that a strong focus on broad technology families and methodology was critically important. A top-down methodology model was developed in figure 5.1 that identifies broad technology families required to implement a prediction and preemption capability as an enterprise class information system. What has not been discussed is how these broad technology families must come together in a way such that the required data can be seamlessly found and retrieved to make a prediction. This is what is referred to as "gluing" technology. In this case the glue is in the form of software agent technology.

It is the last piece of the technological puzzle that puts it all together and makes it work in a seamless transparent manner to the end user. This can be clearly understood by asking the question 'where does the data and knowledge come from to do the analytics?' In the discussion about a methodological framework, it was discussed that in order to provide a particular prediction capability, that analytics involved would dictate the data and/or knowledge that would be needed to feed the analytical engine to generate the prediction required. But it did not answer the question 'where do I need to go to get that data'? In an SOA approach where prediction capabilities are in the form of web service request to hide the nuts and bolts technologies from the user, the question becomes 'how can this be done in a manner that is transparent to the user'?

A key emerging technology that will allow this to occur will be software agent technology. The concept of software agents has been around but some of the technical risks involved, particularly security risks, has held back the use of this technology. But, software agent technology will be critical to implementing a service oriented enterprise system with Soldier usability being a key objective. Figure 5.6 depicts a web services SOA model that was developed by ARL for an enterprise information system supporting UH-60 Mission Driven Maintenance concept. An important objective of the web services SOA model is to frame the analytical tasks as services to be performed and to isolate the technologies from the users. The same concept would be used in a web services SOA model for a prediction and preemption enterprise information system supporting the military logistics domain. Software agent technology is a technology that arrived on the scene about the same time as the emergence of the World Wide Web. Software agents will be the critical gluing technology that isolates the user from the nuts and bolts technology behind a predictive web service request. Table 5.7[115] is a list of some of the benefits of using agent technology.

Table 5.7. Benefits of agent-based technology.

Agents can provide better support for mobile clients
Agents facilitate semantic information retrieval
Agents facilitate real-time interaction with servers
Agent based queries/transactions can be more robust
Agent based transactions & queries can be expressed more flexibly
Agents enable semantic routing

The concept of agents to perform the bulk of the search, retrieve and compute task to perform a service with little intervention by the user is a powerful concept. In a prediction and preemption web services SOA model as described in this report, software agents behind the web service interface will have the semantic intelligence built, in to analyze and filter the request on behalf of the Soldier to ensure that the appropriate prediction service is executed and appropriate data is returned to render it accurate and reliable in an IBM research paper. "One of the implicit hopes for intelligent agents is that they will enable (non-specialist) users to enter queries or transactions in natural language without knowing how or where the request can be satisfied. The agents will reformulate the concept of the query into more precise terms and will identify one or more servers likely to be able to satisfy the request. A mobile agent will then be dispatched with the query and will presumably at some future time return the results to the delighted user." [116]

Software agents can have many characteristics; they can be mobile, act autonomously, make decisions, etc. Table 5.8 is a list of some of the characteristics of software agents. But they also bring concerns—security being the biggest. When one considers letting loose software agents to migrate from machine to machine, execute on those machines, communicate with other software agents on those machines and pass information between agents, it becomes clear why security would be a major concern. This is a serious issue today in implementing software agents. With the push for a better usability and a friendly network, the semantic web concept and intelligent software agent technologies will encourage the software industry to address security and other concerns associated with implementing software agents. The software agent properties described in table 5.8[117] are essential characteristics needed in software agents to keep the technology nuts and bolts under the hood of the enterprise information system employed for prediction and preemption.

Table 5.8. Software agent classifications.

Properties	**Meaning**
Reactive	Responds in a timely fashion to changes in the environment
Autonomous	Exercises control over its own actions
Goal-Oriented	Does not simply act in response to the environment
Temporally Continuous	Is a continuously running process
Communicative	Communicates with other agents, perhaps including people
Learning	Changes its behavior based on its previous experience
Mobile	Able to transport itself from one machine to another
Flexible	Actions are not scripted
Character	Believable "personality" and emotional state

For the purposes of this section on assessment and exploitation, it is sufficient to mention that data will feed the analytic engines for prediction services. The analytics will need data and knowledge elements to be able to perform the task of making a reliable and reasonably accurate prediction to support a course of action decision. When developing an SOA, based predictive enterprise information system that uses web services to formulate the prediction, the key question is ‘where did these data come from’ and/or where are the data located’? For example, consider the following sources: raw sources like sensors, pre-analyzed (i.e., knowledge) data from sensor hardware or embedded computers, and repositories like data warehouses. This section will not get into the details of data or data repositories short of saying they will exist, can be deployed in a number of fashions (central warehouse, distributed, local data marts), and the methods and architectures used for data repositories within the enterprise information system will have a direct impact on the predictive technology used. For example, a particular predictive service may rely on near real time data in order to provide an accurate prediction. Data warehousing design may make it impossible to retrieve that data in a timely fashion to use a particular prediction analytic if the prediction is time sensitive. On the other hand, knowing this, alternative prediction methodologies or techniques may be employed to compensate for this shortfall. The point is that the prediction service desired, the nature of the data sources, and location of the data sources will dictate to some extent the prediction analytics required to do the prediction. Collaboration with the architects of the logistical data repositories, communication infrastructure employed, and data collaboration across information domains such as intelligence and operations, will be critical in a net-centric operating environment in order to fully take advantage of prediction for the purpose of exploitation of the knowledge for course of action decision making to prevent or mitigate the occurrence of critical events listed in table 5.1.

5.2 The Potential Prediction Capabilities for the Future

A focus on some experimental prediction tools under development by ARL for proof of concept will demonstrate the potential that advanced prediction capabilities can bring to the table. It also illustrates why developing these technologies as an enterprise information system is ideally suited to providing a collaborative prediction and assessment environment in a network-centric operating environment.

Prediction capabilities are critical to planning. For the Army in the 2020-2030 era, this will be of paramount importance since the Army will have already transformed into rapidly deployable and highly mobile combat brigades. Predictive Planning for sustainment will be continuous and mobile. Logistical support units will be just behind the combat brigades and just as mobile. The planning process of using paper maps and taking days to develop a logistics course of action to deploy or move a retail ammunition supply point are over. The process of planning will be part of the predictive enterprise information system. Planning will have its own set of prediction and forecasting requirements that will be essential to establishing and operating a lean and efficient sustainment node. Table 5.9 represents a list of some of the typical predictive capabilities that may be desired as part of the planning process in a highly mobile logistical support unit.

Table 5.9. Typical predictive capabilities desired at the unit level.

1.	Based on a weather forecast, predict trafficability of the terrain I have to operate in if I get ¼, ½, ¾, 1, 1+ inch of rain.
2.	Based on a weather forecast, predict potential ponding areas where I have to establish a sustainment camp.
3.	Based on intelligence reports, predict my visual vulnerability to the enemy.
4.	Based on intelligence reports, predict the risk potential of enemy attack.
5.	Based on time varying changes to operational tempo, predict if on hand stock is sufficient to support my customers.
6.	Based on terrain suitability analysis, predict the optimum layout for my ammunition supply point that meets quantity distance safety and minimizes physical foot print on the ground and visibility to the enemy.
7.	Based on terrain analysis, estimate the amount of engineering support required to prepare the proposed site.

As an example of what a future predictive planning capability might look like, consider ARL's logistic site planning tool developed under an SBIR program. This prototype tool currently has a working fuel and ammunition module. It currently looks at a variety of terrain and commodity constraints to allow the logistician to address many of the predictions listed in table 5.9. Below is a sample analysis performed by this prototype tool to assist petroleum planners in developing a forward area fuel distribution point while factoring in proximity to roads, proximity to customers, terrain slope, and traffic flow. Extensive constraint rules can be added, standard National Geospatial and Intelligence Agency digital terrain products are used, Petroleum business processes are incorporated to enhance usability, and the look-and-feel interface is the Common Joint Mapping toolkit. This particular analysis was performed on a mobile laptop computer. With advances in computer power, more time will be spent framing the prediction to be performed than the analysis itself. Today this type of analysis and layout can be performed in less than an hour.

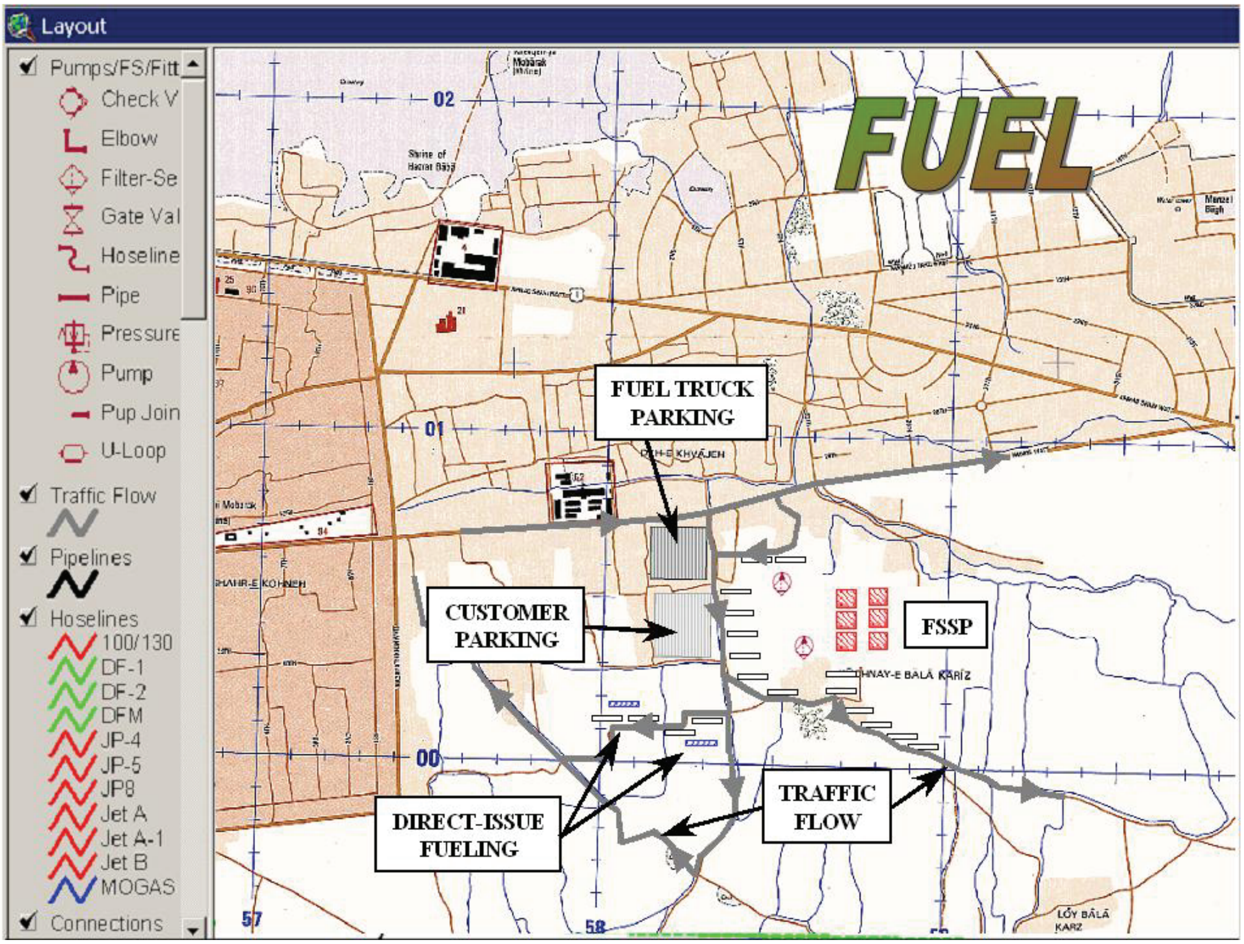


Figure 5.8. ARL's prototype logistics site planning tool.

Figure 5.9 shows what was performed to demonstrate the potential versatility of ARL's logistics site planning tool. Although only fuel and ammunition planning rules are in the tool, it was demonstrated that a predicted flood projection map for hurricane Katrina in New Orleans could be pulled in easily as a terrain overlay and used to begin planning humanitarian relief operations based on predicted flood and infrastructure damage (i.e., impassible roads, lost bridging) to predict optimal areas for establishing humanitarian relief points. A predictive logistical planning tool like ARL's prototype can address a number of constraints including METT-TC constraints which directly address a number of critical events listed in table 5.1. For example, weather effects such as ponding/flooding and soil trafficability; terrain analysis for slope, vegetation density, and soil trafficability; Terrain/Intel analysis for enemy line-of-sight analysis, enemy weapons system ranging, and probability of insurgency/IED attack.

A growing area of concern with ARL's Human Research and Engineering Directorate is the ability to forecast personnel requirements and specialized skills that will be required by the Army to deploy, operate, and maintain the growing number and complexity of information technology systems. As the Army migrates to and begins to depend on more and more information technology, the question of whether the Army will be able to attract, train, and retain high aptitude recruits and develop the specialized skills to deploy, operate, and maintain its complex information technology infrastructure is becoming a serious issue. If not, the Army will face a major skilled manpower issue that may not be easily addressed by contractor support on the battlefield.

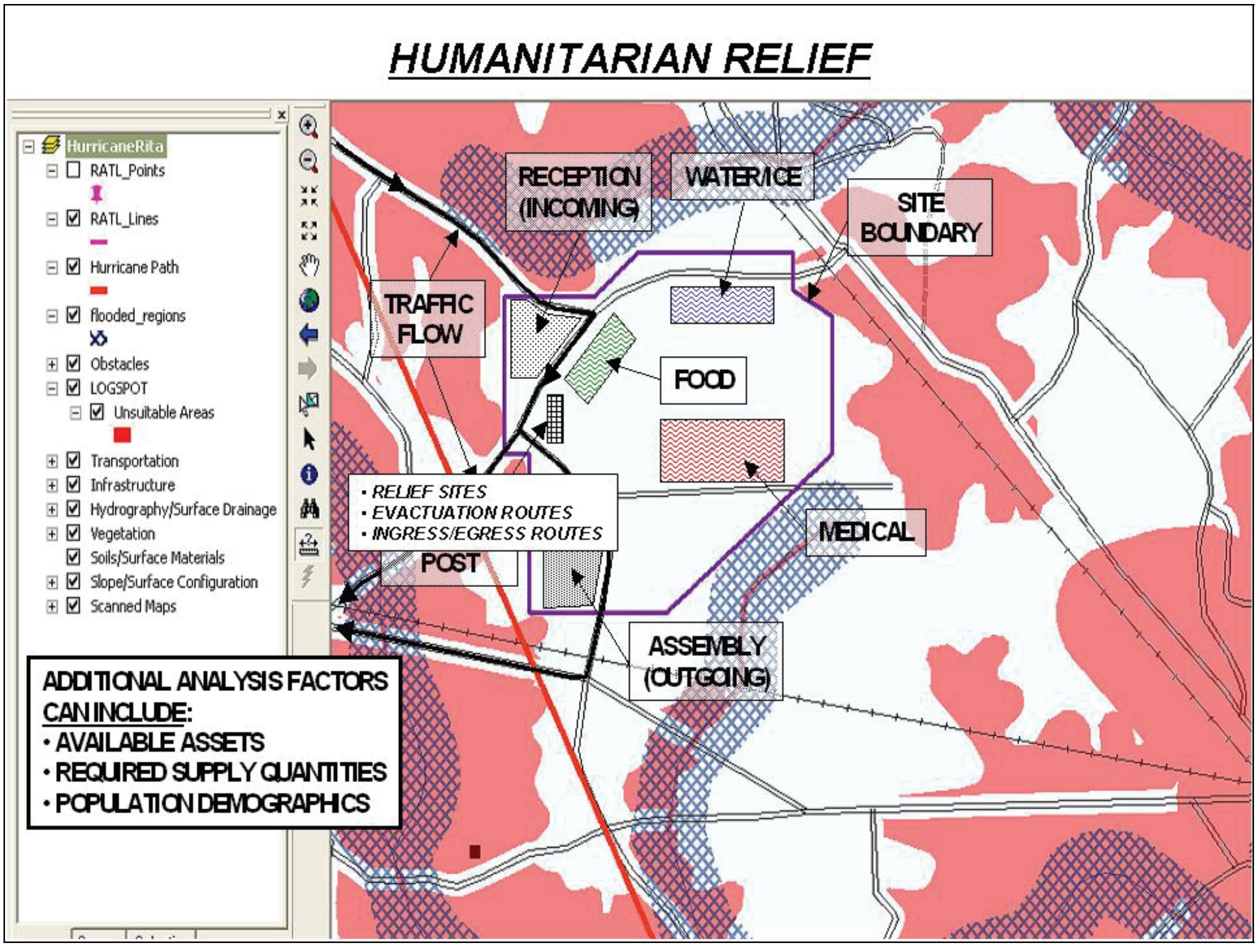


Figure 5.9. ARL logistics site planning tool showing fuel and ammo planning rules and import of New Orleans flood projection map.

ARL's Human Research and Engineering Directorate is conducting research to determine if predictive methodologies can be developed to forecast what the manpower requirements and specialized skill needs would be to support a particular software system being developed in a post fielding environment. From research conducted, figure 5.10 shows some of the identified factors that contribute to software maintenance burden and just how many factors can drive the software maintenance burden. ARL's research into post fielding software maintenance has considerable potential to be a valuable prediction technology to IT program managers.

ARL's research has the potential to lead to a prediction capability for the future that will more accurately predict the number of information technology specialists and the skill sets required to deploy, operate, and maintain the software information systems the Army will need to support its network-centric operating environment of the future. As the Army continues to depend on information and information technology to provide the combatant commander with decision superiority on the battlefield, growth in quantity and complexity of such systems will continue. This demand will continue to put a burden on the Army to recruit, train, and retain a staff of highly qualified IT specialists to deploy, operate, and maintain its information systems. The ability for the Army to forecast its personnel and skill needs for information technology systems has a direct bearing on preventing or mitigating the occurrence of the number one critical item in table 5.1, losing the engagement (mission) to the enemy. If an Army is heavily dependent on information and information technology for mission success, it is essential to properly forecast staffing needs and skill requirements.

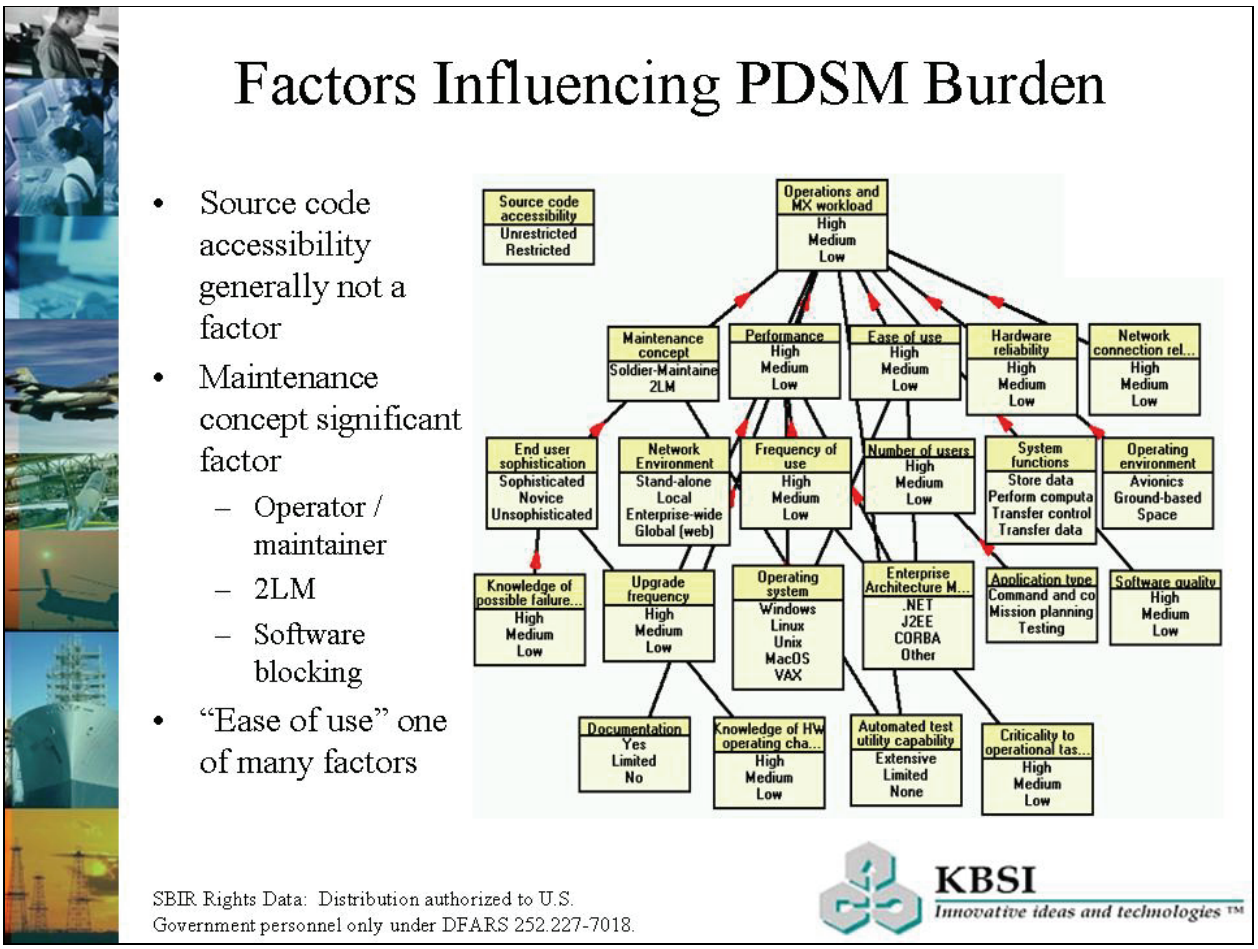


Figure 5.10. Factors contributing to software maintenance burden.

As a corollary to this issue of post deployment software maintenance, it is clear that in addition to software information systems, software systems are rapidly becoming an integral part of every weapon systems platform being developed or under consideration for development. By the 2020-2030 era, and certainly beyond, virtually every weapon system platform the in the Army inventory will be heavily dependent on software to perform. What this means is that a symbiotic hardware-software relationship will exist in which both the software and the hardware must be operational and perform satisfactorily in order for the weapon system to be effective. (While this has been a historical problem from an operational perspective, the increase in technical requirements for the LPPC will exacerbate the challenge for the log community as well.) If the hardware or the software fails, then the weapon system will not operate. This will mean that the whole concept of system reliability, availability, maintainability will drastically change. The techniques currently used to test and determine reliability for mechanical systems is very different than software systems. The Army's whole concept for reliability testing, and the concept of availability, and maintenance policies will need to change and in some cases significantly. The whole concept of prognostics/diagnostics and the physics of failure may be a moot point beyond 2030 because all the effort in these areas today is toward mechanical systems. With a heavy dependence on embedded software systems, the question to ask is 'how do we do prognostics/diagnostics on software?' or 'What is meant by the physics of failure for software'? Prediction of software failures for complex information systems will be an interesting challenge for the Army.

The exploitation and assessment of prediction knowledge has focused on the broad technology areas that must come together to realize a comprehensive robust enterprise IT system that supports prediction for the purpose of exploitation and assessment. Many of the key component technologies, data generation, communications, and data fusion, are discussed in great detail in other sections of this paper. But, many other technologies which are not talked about will contribute to advanced prediction capabilities for the 2020-2030 timeframe. For example, this section of the paper focused on web services and broad-based emerging technologies associated with the web such as the semantic web. Underlying the implementation of the web services are a host of software communication technologies that are critical to the implementation of web-based application including web services. Table 5.5 lists broad technology categories that will directly impact a future prediction and preemption capability and table 5.6 is a partial list of some key technologies that are critical to implementing web services applications. Some of these technologies are mature and some have only recently arrived on the scene. But in all cases, the technologies are changing. This list, and how the web performs in the 2020-2030 era, will be significantly different than today.

There are numerous software technologies like the web that will contribute to the development and functioning of an enterprise information system for prediction. These include operating system technologies like UNIX, Win XP, and LINIX, and programming languages such as JAVA, C, C++, and C#. The list can be exhaustive and although many of these technologies have direct impact on the implementation of the broader technologies discussed in this section, they have little or no impact on preventing or mitigating the events listed in table 5.1.

5.2.1 Advanced Technologies

If the methodologies and technologies discussed in this report are adapted and appropriate research and development is applied, an advanced enterprise-wide information system will be realized that delivers advanced predictive capabilities providing accurate exploitable knowledge supporting logistical decision making that enhances possible mission success. Many of the technologies discussed so far in this paper are in development, rapidly evolving, and being driven primarily by the commercial sector. They are just beginning to emerge in applications. Adaptation and application to provide predictive capabilities for the military can be fully realized in the 2020-2030 timeframe with limited capabilities being realized sooner. As advanced as these capabilities are, significant advances over these capabilities will be realizable just beyond 2030. The majority of these advances will be realized through a combination of advancing technologies that will focus on quicker more natural ways for Soldiers to visualize and understand their situation. They will present information in a way that optimizes comprehension by the human brain.

These advances will be made by bringing together advances in gaming theory, chaos theory, data visualization, and virtual reality. They will combine with advances in traditional methods of modeling, simulation, statistical analytics, data mining, web services, business intelligence, and software agents to provide advanced visualization, collaboration, and decision making. Soldiers will gain situational understanding and an awareness of the impact of predictive knowledge on mission success. Beyond 2030, the following advanced predictive capabilities are likely if technology advancement continues at its current pace, the Army invests in research and development to explore application of these technologies, and the Army explores how best to apply these technologies to the predictive enterprise information system.

5.2.1.1 Collaborative Virtual Tactical Operation Center (VRTOC)

Figure 5.11 illustrates the vision for a VR technology-based tactical operations cell (TOC) of the future. The logistical operation cell is computer generated with the logistician immersed for the purpose of conducting logistical planning and operations. The VR logistical TOC can be on the move within a moving vehicle near the engagement. Collaborative knowledge sharing can be achieved quickly amongst military commanders since military commanders can be immersed into the VR TOC from anywhere within the operating environment. This can easily include various logisticians across the command structure, intelligence officers, or the combatant commander as well. A VR TOC would allow rapid collaboration and exchange of information quickly when needed. The fact that data and analytics can cut across a number of Military domains, not just logistics, via virtual display wall, means that data fusion amongst combatant commanders will occur quickly with less room for misunderstanding of the situation. Figure 5.9 shows a VR logistical TOC where other logisticians have entered the discussion virtually from all around the operating environment for a status review. Past, present, and future forecasts have been presented in a way that allows logisticians to rapidly fuse information and discuss strategy.

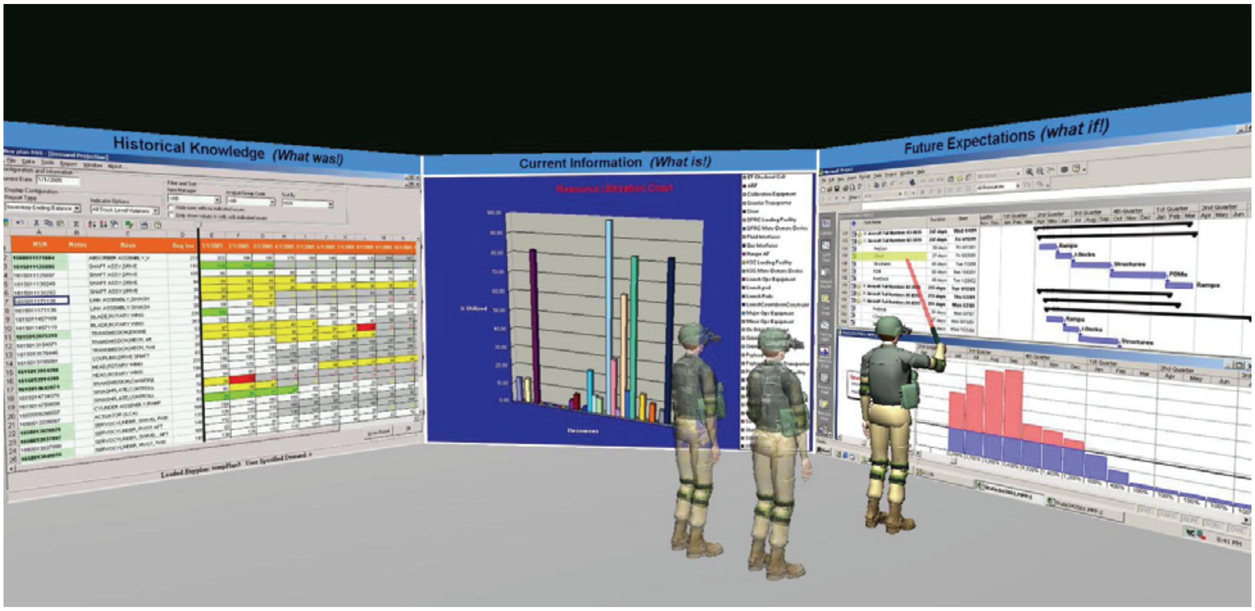


Figure 5.11. Collaborative virtual tactical operations center.

VR technology—as a means to implement a prediction enterprise information system for the 2020-2030 era and beyond—could prevent or mitigate the following critical events listed in table 5.1: running out of ammunition, fuel, water, food, medical supplies, and batteries. Collaborative situational awareness will reduce latencies and improve responsiveness within the supply chain through more timely command decisions. A VR TOC would still be susceptible to communications disruption as any communication system would in the operating environment, but the collaborative potential of this technology from anywhere at anytime across the operating environment should provide significant and timely situational awareness across all domains resulting in more responsive and agile operations. This is likely to provide a significant advantage to the combatant commander in executing the mission and improving the likelihood of mission success. A VR logistical TOC would provide displays of the logistical common operations picture and provide better collaboration, more responsive and agile support to changing conditions in the operating environment such that the military will be able to mitigate most of the critical events in table 5.1.

5.2.1.2 Immersive Data Visualization

Data mining techniques today use statistical methods to develop knowledge and to extract data for predictive analytics. Virtual reality and advances in database technologies will immerse Army logisticians into a three-dimensional virtual environment to visualize logistical data repositories in three dimensions. By immersing Soldiers into their data warehouses, they can do a virtual walk through or fly through of their data repositories of interest. Data visualization and VR "enable users to increase the amount of information that can be extracted from databases. The extracted information is presented in a manner that takes advantage of the human visual system which is unrivaled as a processor of spatial data and as a pattern recognizer".[118] Figure

5.12 depicts a three dimensional view of a data repository with collaboration partners doing a walk-through.

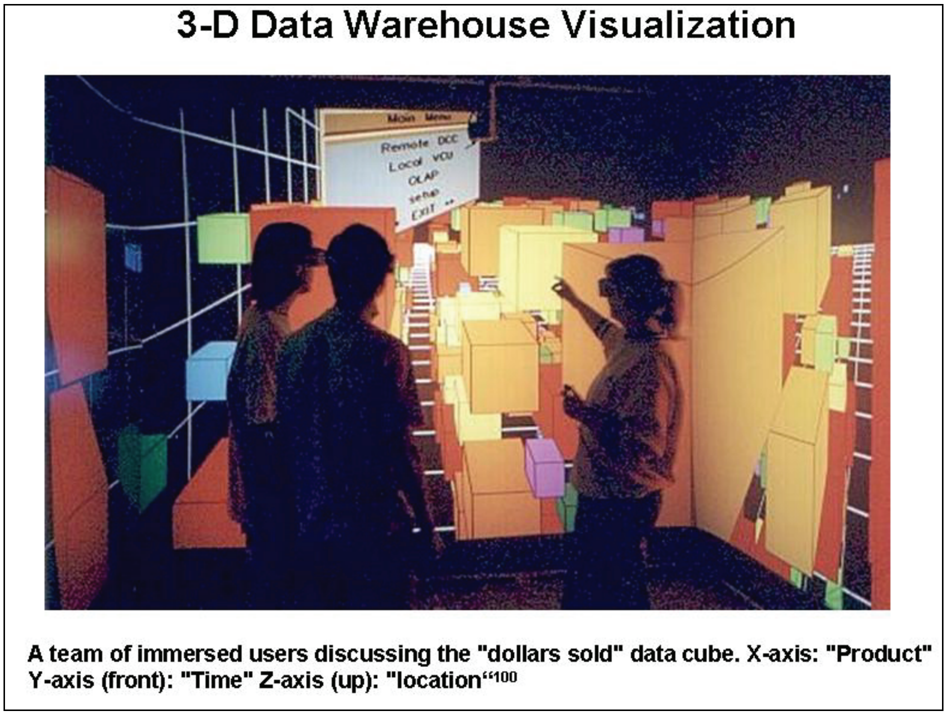


Figure 5.12. 3D data warehouse visualization.

5.2.1.3 Gaming & Simulation Games

Computer based video games have been around for sometime and with the advent of high powered PCs, dedicated video processors and the internet, the gaming industry has exploded into a multi-billion dollar industry. Combining simulation and virtual reality technology provides the potential to immerse game players into synthetic environments with realistic feedback to the immersed players. With each new technology evolution in computation hardware and software, the gaming industry takes one more step to towards a multi-player immersed gaming environment.

The military has been looking at these technologies and its application to learning and training as noted in a technical report by the office of the Secretary of Defense. “The military and business have noted the potential in such areas as problem solving, metacognition, and decision making. However, much of the research in this area lags behind the technological advances, focusing on user demographics, attention spans, and perceptual skills, instead of addressing the impact these games might have on player’s analysis, decision making, and reflection skills. In part, the current body of research represents the interests of the gaming industry, which is more focused on exploiting any new technology to satisfy the attitudes, preferences, and expectations of its users, rather than the interests of education and training. It also reflects the fact that this is an area that suffers from limited research and strategic planning.”[119]

In terms of exploitation and assessment of predictive knowledge, the combination of gaming, simulation, predictive and visualization technologies can be brought together to develop a capability to assess the impact of a prediction over time. Assessment of predictions can be made as to their impact on logistical operations, sustainment inventories, and logistical assets over time and impact on mission success. It could also be used to assess the likely impact of policy changes implemented as a result of a prediction. This advanced gaming technology has a diverse usage for strategic and tactical planning, training, as well as assessing multiple courses of action and their impact over time on sustainment posture.

As indicated in this report, the gaming industry is not focused on this technology from an education and training standpoint. The report also noted that research into applying this technology for military applications in the area of training and education is far behind the technology developments. The application of this combination of technologies will require many years of research to be able to exploit these capabilities. First applications will likely come in the area of learning and training simulators to include the military logistics domain. Additional resources will have to be applied to further push the technology to develop a prediction course of action assessment tool.

5.3 Essential Exploitation and Assessment Technologies: Ranking & Quad Chart

Scoring was performed based upon the methodology described in section 1.4.1. The broad technologies discussed in this chapter on Exploitation & Assessment are considered essential to developing not just a set of exploitation and assessment tools but an enterprise-wide capability. It is a capability that fosters sharing and exchange of vital logistical information and knowledge across all Army domains with a strong focus on the Soldier who exploits this predictive knowledge. The assessment of each technology area examines technical, cost, and logistical impact drivers. For technical drivers, specific technologies are examined as to respective importance in developing a predictive enterprise information system. Higher weight indicates increased relevance of pacing sub-technologies to a predictive enterprise IT system. The score rating for the technical drivers indicates the risk associated with developing and maturing that technology to a point of being available for use by the 2020-2030 timeframe. Results are summarized in figure 5.4.

The cost drivers are many of the key drivers that are prominent with all information technology development. It boils down to cost to develop, test, and verify as reliable and accurate any software system. Software is inherently costly. The weight is the likelihood that a given cost driver is going to have a major influence on technical development. A higher weight indicates that this cost driver will be an important factor in the development of the technologies. The score value is an assessment of the likelihood that cost will be considered a major risk factor in developing the technology. Higher score indicates higher costs to proliferate the technology.

Factors for Benefit to LPPC can be quite broad but it is essential that they address one or more of the critical events listed in table 5.1. These events are most critical to causing mission failure.

For each technology area, the impact on one or more of the 19 events is listed. For predictive analytic technologies, the relevance is to all 19 events since this is central to the prediction theme of generating actionable knowledge to exploit and prevent or minimize those events listed in table 5.1 from occurring in the first place. As pointed out in the methodology section, a framework is needed to identify those critical business processes that have an impact on preempting or mitigating those undesirable events. (Hence, intuitively, predictive analytic technologies' Benefit to LPPC should have an impact on all 19 events.)

1. Business Process Integration Technologies

BP			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Reaching Maturity			49		2.24
	1	Business Intelligence	8	2	0.326531
	2	Enterprise Resource Planning	10	3	0.612245
	3	Load-Extract-Transform technology	7	2	0.285714
	4	Java	8	3	0.489796
	5	Ruby	6	1	0.122449
	6	Unified Modeling Language	10	2	0.408163
Cost			24		3.00
	1	Software Engineering	8	3	1
	2	Software Testing	9	3	1.125
	3	Skilled Military IT specialist	7	3	0.875
Benefit to LPPC			171		2.47
	1	Losing the engagement (Mission) to the Enemy	9	3	0.16
	2	Soldiers dying or being wounded	9	2	0.11
	3	Running out of Ammunition	9	3	0.16
	4	Running out of Fuel	9	3	0.16
	5	Running out of Medical Supplies	9	3	0.16
	6	Running out of Water	9	3	0.16
	7	Running out of Batteries/Fuel Cells	9	3	0.16
	8	Breakdown of Equipment Not Due to Enemy	9	2	0.11
	9	Encountering Bad Weather	9	2	0.11
	10	Encountering Threat Forces	9	2	0.11
	11	Loss of Strategic Lift Assets and Their Cargo	9	1	0.05
	12	Loss of Theater Lift Assets and Their Cargo	9	2	0.11
	13	Closure of APODs and SPODs	9	2	0.11
	14	Closure of Sea Lanes	9	1	0.05
	15	Loss of LOCs	9	3	0.16

16	Encountering Inaccessible Terrain with Convoys	9	3	0.16
17	Untimely Delivery of Mission Critical Parts	9	3	0.16
18	Loss of Comms w/log, intel and ops	9	3	0.16
19	Loss of Common Operating Picture (COP)	9	3	0.16

Business Process Integration is an emerging technology that is gathering momentum in concert with several other related technologies to improve use of the enterprise, enterprise application tools, and to convey meaningful and intuitive information about the enterprise business operations to decision makers at all levels.

Technology drivers -

Business Intelligence

Weight (8) – Essential to gaining insight across the enterprise on how operations are running and why a high weight was assigned. Emerging recognition by corporate business sector that business process and business analytics are critical to understanding business operations. Critical to addressing Soldier usability and decision making across all predictive analytics.

Score (2) - Technologies are beginning to hit the marketplace but issues involving governance rules and standards have yet to mature. As a result, a moderate level of technical risk is to be expected with this emerging technology in the near term, but is expected to be a mature, stable technology by 2020 and beyond.

Enterprise Resource Planning (ERP)

Weight (10) - ERP technologies, typically built on top of commercial databases, provide common business predictive analytics in the commercial marketplace. ERP technologies can serve as the foundation to developing a comprehensive predictive enterprise information system, providing the analytics to meet fundamental forecasting requirements for the Army.

Score (3) ERP technologies have been around for over a decade. ERP technology is continually evolving with ever more complex predictive being incorporated. Risk is considered medium due to continual evolving of this technology.

Load-Extract-Transform (ELT) technologies

Weight (7) An ancillary support technology for ERP information systems in dealing with well established large stove piped data repositories. Such tools support push/pull operations to bring legacy data to or from an ERP system. The Army, as well as the DoD, has many stovepiped legacy data repositories still in use. Such legacy systems will be updated over time but, due to cost, it is expected that many legacy data repositories will still be around in 2020 and beyond.

ELT technologies are considered critical to implementing an enterprise-wide predictive capability while minimizing cost.

Score (2) The technical risk is considered medium because some systems were developed under contract and have custom developed data repositories. Developing ELT capabilities for these information repositories could prove to be technically challenging.

Java

Weight (8) An object programming language that has become a de facto standard for developing many of today's commercial enterprise information systems and associated enterprise tools. For that reason, this technology and it evolvement in the future will be critical to implementing an enterprise class predictive information system.

Score (3) Java is a mature language today. Continued evolution will occur beyond 2020. Evolutionary changes are managed through a Java development group which minimizes technical risk associated with evolutionary changes in software systems.

Ruby

Weight (6) A Java like object programming language that is getting increased attention in the software engineering world because of it simplicity to rapidly develop compact code with less development overhead. This is an emerging language that could play into development of enterprise information systems. The potential to reduce development cost on large enterprise class software system could have major implications for developing an Army wide prediction capability.

Score (1) Although Ruby has demonstrated some key advantages over Java on complex software development projects to date, it does not have sufficient interest or mass necessary for a mainstream programming language. Time will tell if Ruby is embraced by software engineers, but, even if it is, it will take at least 6-10 years to become a standard, thus the technical risk is high.

Unified Modeling Language (UML)

Weight (10) UML modeling tool that is suited to modeling processes and operations and has found strong acceptance within the business community to model and develop a better understanding of its own business processes and operations. UML is likely to play a key role in develop a similar understanding of the Army's logistical business processes as a first step in understanding how these processes can impact mission success. A number of commercial tools exist to translate UML models into Java code

Score (2) Although UML has been around for awhile, it has taken a long time to become a standard tool for business process modeling. Evolutionary changes do go through an established development group but seem to take a long time to evolve to a formal standard that is released.

The technical risk is due to implementation of change and the potential that another modeling tool may emerge as a defector standard sometime over the next decade.

Cost Drivers

Software Engineering/Development

Weight (8) Business process integration is just now coming into the market place. Because of the complexity and uniqueness of the Army's supply chain, it will require customized software to ensure business process integration is integrated into the predictive tools developed. Software engineering and development to achieve this will be a high cost driver.

Score (3) Even when leveraging commercial off the shelf products, software development will still be required to realize unique capabilities required to provide predictive exploitation. Any software development of this complexity is deemed high cost risk.

Software Testing

Weight (9) Software testing to ensure that business process integration is correct will be required. Verification and validation of any software, especially custom developed application is critical to ensure software reliability.

Score (3) Most software testing during development is typically code exercising looking for code bugs. Testing for logic bugs can be difficult, time consuming, and costly. In a predictive information system, it may be very difficult to near impossible to determine if the prediction is inaccurate due to data inaccuracies or logic problem in the code. Risk level is considered high.

Skilled Military information technology (IT) specialist

Weight (7) An important issue because the Army needs to know whether it can recruit, train, and maintain a staff with the technology expertise to deploy, operate and maintain a complex enterprise information system for prediction and forecasting. A high importance is assigned for this driver.

Score (3) This is a growing concern about how the Army is going to meet its objective of having Soldiers with the advanced skills and experience to use this technology. As advanced IT systems appear everywhere on the battlefield, contractors on the battlefield may not be sufficient to meeting skilled manpower needs. Risk is considered high.

2. Geospatial Analysis Technologies

GA			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Reaching Maturity			27		2.33
	1	Common Joint Mapping ToolKit	9	3	1

	2	Mobile GIS/GPS	8	2	0.592593
	3	Logistic site & transport planning	10	2	0.740741
Cost			25		2.36
	1	Software Engineering	8	2	0.64
	2	Software Testing	9	3	1.08
	3	Skilled Military IT specialist	8	2	0.64
Benefit to LPPC			171		2.72
	1	Losing the engagement (Mission) to the Enemy	10	3	0.18
	2	Soldiers dying or being wounded	8	2	0.09
	3	Running out of Ammunition	10	3	0.18
	4	Running out of Fuel	10	3	0.18
	5	Running out of Medical Supplies	10	3	0.18
	6	Running out of Water	10	3	0.18
	7	Running out of Batteries/Fuel Cells	10	3	0.18
	8	Breakdown of Equipment Not Due to Enemy	9	2	0.11
	9	Encountering Bad Weather	10	3	0.18
	10	Encountering Threat Forces	10	3	0.18
	11	Loss of Strategic Lift Assets and Their Cargo	6	1	0.04
	12	Loss of Theater Lift Assets and Their Cargo	7	2	0.08
	13	Closure of APODs and SPODs	10	2	0.12
	14	Closure of Sea Lanes	1	1	0.01
	15	Loss of LOCs	10	3	0.18
	16	Encountering Inaccessible Terrain with Convoys	10	3	0.18
	17	Untimely Delivery of Mission Critical Parts	10	3	0.18
	18	Loss of Comms w/log, intel and ops	10	3	0.18
	19	Loss of Common Operating Picture (COP)	10	3	0.18

Geospatial analysis technologies are considered essential for predictive deployment planning, planning on the move, and in support of ongoing logistical operations. METT-TC factors are known constraints to all military logistics operations across many business processes. Planning to prevent or mitigate those effects via prediction analytics is essential for the future.

Technical Drivers

Common Joint Mapping Toolkit (CJMTK)

Weight (9) CJMTK is the DoD approved geospatial information system (GIS). It is being developed under a long term, well planned out ten year cycle with periodic product improvements and support through a contracted commercial developer. Weight is high since

GIS is important to address many METT-TC constrains associated sustainment operations. Importance is considered moderately high

Score (3) The DoD is developing CJMTK under a rigorously controlled path. While other commercial products exist, CJMTK will likely remain the de facto standard for DoD use for the foreseeable future. Technical risk is considered low.

Mobile GIS/GPS Technology

Weight (8) The commercial marketplace is pushing this technology for updating outdated terrain data with more recent data. This is a product that although important today could be superseded by advanced data collection methodologies in the 2020-2030 era and beyond. Importance is considered moderate

Score (2) Technical risk is considered low. This technology is in widespread use today. Advances in collection and transmission of such mobile data gathering system for geospatial information have been ramping up to support business, local and state government land and demographic analysis.

Logistical Site Planning Tools

Weight (10) It is considered essential for deployment and on the move predictive planning of sustainment sites and lines of communication where METT-TC constraints are critical factors to mission success. CJMTK and other commercial tools exist, but require extensive configuration and significant customized algorithms provide the predictive planning envisioned beyond 2020.

Score (2) Technical risks are associated with customized analytics that would be needed, as well as insurances that CPU horsepower continues to evolve as in the past. A medium risk is associated with development of predictive sustainment planning tools as part of a comprehensive predictive enterprise information system.

Cost Drivers (Same as for Business Process Integration.)

3. Data Warehousing

DW			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Reaching Maturity			24		2.42
	1	Database Development	10	3	1.25
	2	On-Line Transaction Processing (OLAP)	7	2	0.583333
	3	DataMarts / Data Cubes	7	2	0.583333
Cost			33		2.52
	1	Software Engineering	8	2	0.484848
	2	Software Testing	9	3	0.818182
	3	Skilled Military IT specialist	8	3	0.727273

	4	Networking Topology/Infrastructure	8	2	0.484848
Benefit to LPPC			159		2.58
	1	Losing the engagement (Mission) to the Enemy	10	3	0.19
	2	Soldiers dying or being wounded	8	2	0.10
	3	Running out of Ammunition	10	3	0.19
	4	Running out of Fuel	10	3	0.19
	5	Running out of Medical Supplies	10	3	0.19
	6	Running out of Water	10	3	0.19
	7	Running out of Batteries/Fuel Cells	10	3	0.19
	8	Breakdown of Equipment Not Due to Enemy	10	2	0.13
	9	Encountering Bad Weather	10	2	0.13
	10	Encountering Threat Forces	10	2	0.13
	11	Loss of Strategic Lift Assets and Their Cargo	3	1	0.02
	12	Loss of Theater Lift Assets and Their Cargo	3	2	0.04
	13	Closure of APODs and SPODs	4	1	0.03
	14	Closure of Sea Lanes	1	1	0.01
	15	Loss of LOCs	10	3	0.19
	16	Encountering Inaccessible Terrain with Convoys	10	2	0.13
	17	Untimely Delivery of Mission Critical Parts	10	3	0.19
	18	Loss of Comms w/log, intel and ops	10	3	0.19
	19	Loss of Common Operating Picture (COP)	10	3	0.19

Although data warehousing is a reasonably mature technology, it continues to evolve and is the underpinning technology for enterprise class information systems of any kind and will be for a predictive enterprise information system as well. Several important sub-technologies make up this technology. When used to support a network distributed enterprise information system, configuration of the data repositories is just as important as the technology itself. Configuration of the repositories can impact data latencies which have ramification for predictive analytics that depend on near real time data for accurate predictions.

Technical Drivers

Database Technology

Weight (10) Although a relatively mature technology, the technology of the database continues to evolve incorporating new data format elements such as the concepts of a storing a table within a table data field or the concept of large binary objects being a data field. Additionally databases are not longer one single entity on a single computer. That can be distributed across network systems or be independent and networked together loosely or tightly depending on requirements. As an enterprise foundation technology, high weight is assigned to this standard technology.

Risk (3) Risk is considered high due more to implementation methodology rather than technology evolution. Database design to support data warehousing requires an intimate knowledge of business operations and processes to determine the data, data refresh, and data fidelity requirements for the database to support business analytics. This would be especially true with predictive analytics.

On-Line Transaction Processing (OLAP)

Weight (7) This technology allow slicing and dicing the store data across multiple business sectors to create multi-dimensional views of business operations and provide analytics on how business transactions are performing. It is not certain how critical this technical capability will be to prediction. OLAP technology could provide key fundamental knowledge that could be feeder data to prediction algorithms. This has yet to be determined, since configuration of complex multidimensional views of data across business operations is required and can only come from a thorough understand of business process, so a moderate Weight on importance is assigned.

Risk (2) OLAP tools have been around and continue to evolve. Their use in prediction technology will require sophisticated designs to generate multi-dimensional views of the Army's transactional business processes, so the risk is considered high.

Data Marts/Data Cubes

Weight (7) This really comes into play with large distributed data warehouse systems where mini databases or data marts and multi-dimension data cubes are created for specific applications. Application of this technology is likely, but is really dependent on the enterprise data architecture implemented.

Risk (2) technical risk is moderate. The technology is mature and most of the risk comes from proper architectural design and implementation to support the predictive capabilities desired. Poor design will lead to data latency issues that can affect any type of analytics including predictive analytics.

Cost Driver

All cost drivers in business process integration apply here.

Networking Topology/Infrastructure

Weight (8) The importance is critical as a cost driver and is applicable in most enterprise information systems, since data repositories tend to be distributed across the enterprise. Distribution methodologies across the network become important not only technically, but also from an operational cost stand point. High weight is attached to this cost driver.

Risk (2) Distributed data repositories across the network can be manpower intensive managing distributed repositories that may be physically scattered around the world. Keeping all the data repositories in sync and providing troubleshooting should something get out of sync could be manpower intensive. The Army is a perfect example of an environment where systems would be globally distributed. Technical risk is considered high.

4. Predictive Analytics

PA			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Reaching Maturity			50		1.60
	1	Modeling	10	2	0.4
	2	Simulation	10	1	0.2
	3	Statistical	10	2	0.4
	4	Data Mining	10	2	0.4
	5	Combinatorial	10	1	0.2
Cost			36		3.00
	1	Software Engineering	8	3	0.666667
	2	Software Testing	9	3	0.75
	3	Verification/Validation Analytics	10	3	0.833333
	4	Engr-Integration	9	3	0.75
Benefit to LPPC			190		3.00
	1	Losing the engagement (Mission) to the Enemy	10	3	0.16
	2	Soldiers dying or being wounded	10	3	0.16
	3	Running out of Ammunition	10	3	0.16
	4	Running out of Fuel	10	3	0.16
	5	Running out of Medical Supplies	10	3	0.16
	6	Running out of Water	10	3	0.16
	7	Running out of Batteries/Fuel Cells	10	3	0.16
	8	Breakdown of Equipment Not Due to Enemy	10	3	0.16
	9	Encountering Bad Weather	10	3	0.16
	10	Encountering Threat Forces	10	3	0.16
	11	Loss of Strategic Lift Assets and Their Cargo	10	3	0.16
	12	Loss of Theater Lift Assets and Their Cargo	10	3	0.16
	13	Closure of APODs and SPODs	10	3	0.16
	14	Closure of Sea Lanes	10	3	0.16
	15	Loss of LOCs	10	3	0.16
	16	Encountering Inaccessible Terrain with Convoys	10	3	0.16
	17	Untimely Delivery of Mission Critical Parts	10	3	0.16

18	Loss of Comms w/log, intel and ops	10	3	0.16
19	Loss of Common Operating Picture (COP)	10	3	0.16

Prediction analytics are the nuts and bolts tools that will make up a predictive enterprise information system. It is also considered the most technically challenging and potentially costly to develop.

Technical drivers

Modeling

Weight (10) A number of commercial modeling tools exist for the purpose of developing specific models for making a forecast. Some of these tools may be leveraged, but more complex predictive analytics are required to address ever more complex problems, and new innovative models will need to be developed. Technology requirements needed to develop new modeling capabilities are considered significant.

Risk (2) Technical risk is considered high. To develop innovative models to generate predictive knowledge for exploitation depends heavily on those models generating accurate and reliable knowledge. This requires an intimate knowledge of the problem. The complexity of the prediction process, will likely require innovative solutions to be developed, and that will also require a high level of technical understanding based upon extensive research and development.

Simulation

Weight (10) Simulation techniques are extensively used to produce predictive analyses. Simulations can be quite complex when attempting to simulate dynamic events that change over time. Simulation technology will be critical to developing complex predictive tools that provide exploitable knowledge.

Risk (1) Technical risk is considered high. The drawback is the potential complexity in using the simulation of dynamic events over time with realistic constraints to reasonably ensure the results would be those expected from a real world event. Developing high value complex predictive simulation tools requires an in-depth understanding of the problem and the data requirements necessary to feed a simulation tool to produce accurate results. Developing that understanding can be problematic.

Statistical

Weight (10) Statistical analytics have been used for many years. Numerous analytic algorithms and techniques exist to develop predictive capabilities. These techniques and algorithms are continuously used every day with excellent results. As such, their importance to prediction can not be underestimated.

Risk (2) The risk is considered medium. As mentioned, a good number of algorithms and techniques are used today. But, often only a handful of the most common techniques are used due to unfamiliarity with the other algorithms in the statistical analysis tool box. Most of the risk would be due to fully understanding when to apply a specific statistical technique.

Data Mining

1. Weight (10) High weighted value is placed on this technology. Data mining techniques have been around for a number of year but they continue to evolve and grow in complexity. They have become very popular as a tool to look across various data dimensions within a business to look for obscure patterns that say something about business operations that are not easily determined with other analytic tools. Data mining techniques can be used to pull key data and knowledge elements for the purpose of producing a prediction.

2. Risk (2) The risk is considered moderate to medium. Data mining is a well established method and it continues to evolve. Most of the risk is likely to reside with problem understanding and application of data mining techniques for the purpose of prediction or to produce data to feed a predictive method.

v. Combinatorial Techniques

1. Weight (10) A high weighted value is given here because combining a variety of predictive methods (statistical, modeling, simulation, data mining) in novel ways often produces predictions that cannot be done any other way due to problem complexity.

2. Risk (1) The technical risk is also high because the ability to combine a number of predictive techniques together to address complex problems that are difficult to address requires a through understanding of the problem and a through understanding of predictive analytics. This often requires extensive research and development to achieve the objective.

b. Cost Drivers

All cost drivers in business process integration apply here.

Verification/Validation

1. Weight (10) A high weight is assigned to need for Verification/Validation. Predictive analytics would be of little value if the analytical tools do not produce reasonably verifiable prediction.

2. Risk (3) A high cost risk is also associated with verifying and validating prediction tools. Verification and validation of such toolscan be manpower intensive. This is particularly true with novel combinatorial prediction tools where novel approaches and methodologies are used to achieve predictive capabilities.

5. Web Technologies

WS			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Reaching Maturity			28		1.71
	1	Semantic Web	8	1	0.285714
	2	Service Oriented Architecture	10	2	0.714286
	3	Web Services	10	2	0.714286
Cost			32		2.28
	1	Software Technology	8	2	0.5
	2	Software Engineering	9	3	0.84375
	3	Network Topology/Infrastructure	8	2	0.5
	4	Skilled Military IT specialist	7	2	0.4375
Benefit to LPPC			142		2.54
	1	Losing the engagement (Mission) to the Enemy	9	2	0.13
	2	Soldiers dying or being wounded	6	2	0.08
	3	Running out of Ammunition	8	3	0.17
	4	Running out of Fuel	8	3	0.17
	5	Running out of Medical Supplies	8	3	0.17
	6	Running out of Water	8	3	0.17
	7	Running out of Batteries/Fuel Cells	8	3	0.17
	8	Breakdown of Equipment Not Due to Enemy	6	2	0.08
	9	Encountering Bad Weather	8	2	0.11
	10	Encountering Threat Forces	8	2	0.11
	11	Loss of Strategic Lift Assets and Their Cargo	6	2	0.08
	12	Loss of Theater Lift Assets and Their Cargo	6	2	0.08
	13	Closure of APODs and SPODs	6	2	0.08
	14	Closure of Sea Lanes	1	1	0.01
	15	Loss of LOCs	10	3	0.21
	16	Encountering Inaccessible Terrain with Convoys	8	2	0.11
	17	Untimely Delivery of Mission Critical Parts	8	3	0.17
	18	Loss of Comms w/log, intel and ops	10	3	0.21
	19	Loss of Common Operating Picture (COP)	10	3	0.21

The web has rapidly evolved in the medium of choice for communicating, exchanging critical information to do virtually everything. Web interfacing has evolved and now complex web interfaces guide users through complex processes to perform some very sophisticated queries for information. The web is so widely used that it is natural for most people to use on a daily basis on the job or at home. The usability features of the web is what attracts users to depend on it for most informational needs at home or on the job and is why this will be a critical technology for predictive analytics and exploitation of that predictive knowledge.

Technical Drivers

Semantic Web

Weight (8) A high weight is assigned. Concept is only now being worked but offers significant promise to improve usability and machine understanding of human requests made to it in a more natural way.

Risk (1) Risk is considered high as well. Significant research will be required to develop the algorithms to perform semantic interpretation of human input. It may even entail new forms of intelligent algorithms to be developed for this concept to be fully realized.

Service Oriented Architectures

Weight (10) The whole concept of services to improve Soldier usability of advanced information systems is considered a must. This is a technology still evolving but is critical to deploying, using and maintaining a predictive enterprise information capability that can be used for decision making.

Risk (2) Service Oriented Architectures are rapidly being embraced within the corporate business sector. This is still emerging technology, so architectural design and technical implementation has moderate risk associated with it.

Web Services

Weight (10) In a services oriented approach to an enterprise, a web services approach leads the way and is considered essential to meeting Soldier usability objectives in enterprise class information systems. This technology is critical to addressing Soldier usability with a predictive enterprise information system. Web services are a collection of technologies that allow web services to occur.

Risk (2) The web foundation technologies such as XML, AJAX, .NET, and others are still evolving. Governance rules and standards have yet to be agreed upon in some foundation technologies. Technical risk is considered medium.

Cost Drivers

All cost drivers in business process integration apply here which are associated with any type of software development.

Networking Topology/Infrastructure

Weight (8) A high weight value is given. Networking and its infrastructural architecture will be important to the implementation of a successful services oriented enterprise information system.

Risk (2) High technical risk is associated with the development of the necessary hardware and software to implement a high bandwidth, secure, mobile networking schema that will support the Army's information enterprises in the operating environment. Significant progress will be made, but the big question is, will it provide sufficient bandwidth to support the data flow in near real time in the 2020-2030 era and beyond? Research, development, and implementation costs are likely to be high.

6. Software Agents

SA			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Reaching Maturity			29		1.00
	1	Agent Technology	10	1	0.344828
	2	Networking Topology/Infrastructure	9	1	0.310345
	3	Security Implementation	10	1	0.344828
Cost			41		2.63
	1	Software Engineering	8	3	0.585366
	2	Software Testing	9	3	0.658537
	3	Networking Topology/Infrastructure	8	2	0.390244
	4	Skilled Military IT specialist	7	2	0.341463
	5	Security Implementation	9	3	0.658537
Benefit to LPPC			177		2.71
	1	Losing the engagement (Mission) to the Enemy	10	3	0.17
	2	Soldiers dying or being wounded	8	2	0.09
	3	Running out of Ammunition	10	3	0.17
	4	Running out of Fuel	10	3	0.17
	5	Running out of Medical Supplies	10	3	0.17
	6	Running out of Water	10	3	0.17
	7	Running out of Batteries/Fuel Cells	10	3	0.17
	8	Breakdown of Equipment Not Due to Enemy	3	3	0.05
	9	Encountering Bad Weather	10	3	0.17
	10	Encountering Threat Forces	10	3	0.17
	11	Loss of Strategic Lift Assets and Their Cargo	9	2	0.10
	12	Loss of Theater Lift Assets and Their Cargo	9	2	0.10
	13	Closure of APODs and SPODs	10	2	0.11

14	Closure of Sea Lanes	8	1	0.05
15	Loss of LOCs	10	3	0.17
16	Encountering Inaccessible Terrain with Convoys	10	3	0.17
17	Untimely Delivery of Mission Critical Parts	10	3	0.17
18	Loss of Comms w/log, intel and ops	10	3	0.17
19	Loss of Common Operating Picture (COP)	10	3	0.17

Software agent technologies are software entities that perform specific tasks. The software agents can migrate from system to system and communicate with other applications as well as other agents. They are designed to hide the technical nuts and bolts under the hood of the predictive enterprise information vehicle from the end user.

Technical drivers

Agent Technology

Weight (10) A high weight is associated with software agent technology. In order to implement an enterprise-wide prediction capability that is service oriented with Soldier usability being a key issue, software agents will be critical to the implementation of such a system that isolates the Soldier from the nuts and bolts technology. In a network-centric operating environment, software agents will need to seek and search for critical information with little help from the Soldier.

Risk (1) Developing software agents that will need to be autonomous, intelligent, communicative, and mobile to freely migrate to those systems where data repositories exist, initiate queries for information or store information is a major technical development challenge in and of itself. In addition, implementing a network security strategy that will provide adequate security and allow autonomous intelligent agents to move all about the network and data repository infrastructure in search of information will be a major technical challenge. Risk are considered high

Cost drivers

All cost drivers in business process integration apply here which are associated with any type of software development.

Security

Weight (9) A high weight value is given to security. Implementing a secure security methodology that allows software agents to migrate throughout the enterprise information system to perform push/pull data services as required is a major technical challenge which will drive development costs

Risk (3) Because of the technical challenge involved with security and software agents needing autonomy, the risk is considered high for development and implementation costs.

7. Virtual Reality

VR			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Reaching Maturity			27		1.00
	1	Virtual World Simulation Technology	9	1	0.333333
	2	Virtual World Immersion Technology	10	1	0.37037
	3	Virtual sensory technology, especially visual	8	1	0.296296
Cost			33		2.52
	1	Software Engineering	7	2	0.424242
	2	Software Testing	8	3	0.727273
	3	Network Topology/Infrastructure	9	2	0.545455
	4	Skilled Military IT specialist	9	3	0.818182
Benefit to LPPC			158		2.76
	1	Losing the engagement (Mission) to the Enemy	10	3	0.19
	2	Soldiers dying or being wounded	5	1	0.03
	3	Running out of Ammunition	10	3	0.19
	4	Running out of Fuel	10	3	0.19
	5	Running out of Medical Supplies	10	3	0.19
	6	Running out of Water	10	3	0.19
	7	Running out of Batteries/Fuel Cells	10	3	0.19
	8	Breakdown of Equipment Not Due to Enemy	6	3	0.11
	9	Encountering Bad Weather	10	3	0.19
	10	Encountering Threat Forces	10	3	0.19
	11	Loss of Strategic Lift Assets and Their Cargo	6	1	0.04
	12	Loss of Theater Lift Assets and Their Cargo	7	2	0.09
	13	Closure of APODs and SPODs	7	2	0.09
	14	Closure of Sea Lanes	1	1	0.01
	15	Loss of LOCs	8	3	0.15
	16	Encountering Inaccessible Terrain with Convoys	10	3	0.19
	17	Untimely Delivery of Mission Critical Parts	10	3	0.19
	18	Loss of Comms w/log, intel and ops	8	3	0.15
	19	Loss of Common Operating Picture (COP)	10	3	0.19

Virtual Reality – Virtual reality (VR) technology has been around for over 15 years. A desirable aspect for a technologist is to immerse a person into a virtual world such that the immersed person can participate in the virtual environment. The promise of this technology, when combined with very high bandwidth and high speed networking, has significant ramifications for not just collaborative planning over remote distances but collaborative planning on the move. For the first time, military commanders from a variety of domains (logistics, operations, intelligence) can come together in a virtual tactical operation center that is on the move. VR has great potential and direct application to a predictive enterprise information system. But, VR technology has a number of technical drawbacks that need resolution for VR's potential to be fully realized on the battlefield.

Technical drivers

Virtual World Simulation

Weight (9) The ability to simulate an environment close to reality requires not only high fidelity graphics, but also an understanding of physics so that virtual objects can react in a way that would be expected in the real world. The software to render a detailed virtual environment and to react in a way that would be expected in the real world is essential. A high weight value is assigned because the capability is critical to a successful virtual reality capability.

Risk (1) Technical challenges in hardware rendering capability and more particularly the software required to render and simulate a realist virtual world and the physics to make it react in a natural way is considered a major technical challenge. A high risk value is assigned

Virtual World Immersion Technology

Weight (10) A high weight is assigned. Immersion is considered critical to support a virtual collaboration tactical operation center on the move.

Risk (1) Technical risks associated with VR software are considered significant but more importantly, VR immersion has caused physiological problems to people immersed in virtual environments, primarily motion sickness. The causes and solutions must be resolved if VR is to have practical application on the battlefield.

Virtual Sensor Technology

Weight (8) A high weight is assigned to sensory technology across the board but especially visual. This technology is considered essential for VR immersion to be successful and to overcome the physiological affects associated with VR immersion.

Risk (1) Technological advancement continues particularly with very high resolution compact displays, fast rendering engines and research into the potential to directly paint images on the retina. Still understanding of the physiological affects caused by VR immersion will need to be understood in order to use technology to overcome it. Solutions are still problematic and so the risk is considered high.

Cost Drivers

All cost drivers in business process integration apply here including the networking cost drivers discussed in this paper, which are associated with any type of software development. VR applications have greatest promise for a predictive enterprise information system that can cut across all Army domains in a collaborative way. But the advanced hardware and software technologies required provide a truly immersive VR system that is mobile presents the most costly risk of any of the technologies discussed here.

8. Gaming Technology

GT			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Reaching Maturity			34		1.00
	1	Gaming Theory Development	7	1	0.205882
	2	Simulation Technology Development	9	1	0.264706
	3	Immersive VR technologies	9	1	0.264706
	4	Software Agent technology	9	1	0.264706
Cost			34		2.50
	1	Software Engineering	8	3	0.705882
	2	Software Testing	9	3	0.794118
	3	Network Topology/Infrastructure	9	2	0.529412
	4	Skilled Military IT specialist	8	2	0.470588
Benefit to LPPC			85		2.76
	1	Losing the engagement (Mission) to the Enemy	10	3	0.35
	2	Soldiers dying or being wounded	1	1	0.01
	3	Running out of Ammunition	4	3	0.14
	4	Running out of Fuel	4	3	0.14
	5	Running out of Medical Supplies	4	3	0.14
	6	Running out of Water	4	3	0.14
	7	Running out of Batteries/Fuel Cells	4	3	0.14
	8	Breakdown of Equipment Not Due to Enemy	1	3	0.04
	9	Encountering Bad Weather	8	3	0.28
	10	Encountering Threat Forces	8	3	0.28
	11	Loss of Strategic Lift Assets and Their Cargo	4	1	0.05
	12	Loss of Theater Lift Assets and Their Cargo	4	2	0.09

13	Closure of APODs and SPODs	4	2	0.09
14	Closure of Sea Lanes	1	1	0.01
15	Loss of LOCs	4	3	0.14
16	Encountering Inaccessible Terrain with Convoys	8	3	0.28
17	Untimely Delivery of Mission Critical Parts	4	3	0.14
18	Loss of Comms w/log, intel and ops	4	3	0.14
19	Loss of Common Operating Picture (COP)	4	3	0.14

Gaming technology has been around for some time, but advances in graphics and the push to immerse users directly into the game world opens up the door for gaming technology to be critical to support logistics operations from two points. One, as an advanced training tool to understand and recognize the consequences of courses of action developed based on predictions and secondly, to examine multiple course of action to assess the best course of action to take. For this to occur both gaming technology and theory will need to come together with simulation technology to realize this potential.

Gaming Theory

Weight (7) Advancements in Game Theory will need to occur in order to advance the technology. As noted in the discussion on this technology, the potential to support advanced training and learning has been noted by the military, but little focus has been directed in that area by the gaming industry. Some reservation exists as to just how important this technology will eventually become.

Risk (1) The risk is considered high because little has been done to push the theoretical envelope in a way that would advance the use of gaming for learning and training. Most of the focus on the gaming is for entertainment and until more effort is made to look at the learning and training potential, the development of theories associated with Gaming Theory and its application is considered a high risk.

Simulation Technology

Weight (9)

Risk (1) Application to gaming is critical and the risk specified in data visualization apply to simulation technology for the same reasons.

Immersive Technologies

Weight (9) A higher weight is given for gaming applications because a more robust immersive environment is needed compared to data walk through or fly through with some simple controls and responses. In immersed games, near real time responses will be essential. In many cases there will be adversaries that the immersed user will need to interact with.

Risk (1) At least one, if not two generation leaps in immersive technologies will be needed to realize gaming simulation applications over data visualization.

Software Agent Technology

Weight (9) Software agents technology will need to perform many complex tasks and pull data from all over the battlespace to examine courses of action or to have multiple players involved in complex learning/training scenarios.

Risk (1) The level of sophistication of the agents will need to be one or two generations above that used in data visualization.

Cost Drivers

As with all technology that has a heavy or predominant software component, the development and testing aspects are key as high risk drivers. Since data visualization depends on networking as well, network topology and infrastructure is a critical cost driver and although it has high risk associated with it, it is considered less of a risk than the software cost drivers. Skilled military IT specialists will be a cost driver, particularly in deploying and maintaining such systems on the battlefield. The technological skills required by the Soldiers to deploy and maintain such a system will pose a challenging problem for the Army.

9. Data Visualization

DV			(1-10)	1,2,3 =(L,M,H)	
Primary Criteria	Index	Pacing/sub-technologies	Weight	Score	Totals
Probability of Reaching Maturity			31		1.00
	1	Software Agent technology	7	1	0.225806
	2	Simulation Technology Development	9	1	0.290323
	3	Immersive VR technologies	7	1	0.225806
	4	Network Topology/Infrastructure	8	1	0.258065
Cost			34		2.50
	1	Software Engineering	8	3	0.705882
	2	Software Testing	9	3	0.794118
	3	Network Topology/Infrastructure	9	2	0.529412
	4	Skilled Military IT specialist	8	2	0.470588
Benefit to LPPC			169		2.88
	1	Losing the engagement (Mission) to the Enemy	10	3	0.18
	2	Soldiers dying or being wounded	9	3	0.16
	3	Running out of Ammunition	10	3	0.18

4	Running out of Fuel	10	3	0.18
5	Running out of Medical Supplies	10	3	0.18
6	Running out of Water	10	3	0.18
7	Running out of Batteries/Fuel Cells	10	3	0.18
8	Breakdown of Equipment Not Due to Enemy	7	3	0.12
9	Encountering Bad Weather	10	3	0.18
10	Encountering Threat Forces	10	3	0.18
11	Loss of Strategic Lift Assets and Their Cargo	7	2	0.08
12	Loss of Theater Lift Assets and Their Cargo	7	2	0.08
13	Closure of APODs and SPODs	8	3	0.14
14	Closure of Sea Lanes	3	1	0.02
15	Loss of LOCs	9	3	0.16
16	Encountering Inaccessible Terrain with Convoys	10	3	0.18
17	Untimely Delivery of Mission Critical Parts	10	3	0.18
18	Loss of Comms w/log, intel and ops	9	3	0.16
19	Loss of Common Operating Picture (COP)	10	3	0.18

This has elements of traditional display technology as well as virtual reality technology. A key element is the use of graphical displays to present complex multi-dimensional data in a way that knowledge and situational awareness can be presented for quick understanding and assessment by those viewing the data. The future holds the promise of leveraging advanced graphic technologies and virtual reality to immerse the logistician into a three dimensional rendering of the logistical and operating environment information to allow quick data mining that will generate instant situational awareness assessments. As discussed in the VR section above, a number of technical issues will need to be resolved to be fully implemented on the battlefield.

Technical drivers

Software Agent Technology

Weight (7) Software agent technology will be essential to finding and retrieving data in a natural manner in data sources that are going to be distributed across the operating environment.

Risk (1) All the technical issues associated with the discussion on software agents apply.

Simulation Technology

Weight (9) Simulation will be important in generating not only the virtual environment but in executing predictive simulations against data as part of the data mining and visualization process. It is a critical technology for data mining.

Risk (1) Developing complex simulations, particularly on multidimensional data, is very complex and requires highly skilled software engineers to implement complex simulations looking over more many dimensions of data.

Immersive Technology

Weight (7) This will be critical to visualizing and doing walk throughs or fly-bys of data repositories to visually data mine in a virtual data environment. Although this technology will revolutionize data visualization, it is not the only technological means to visualize multidimensional data.

Risk (1) As with virtual reality technology discussed above, the same risks apply.

Network Topology/Infrastructure

Weight (8) This is an essential technology since by 2030 most data sources will be distributed all over the operating environment. The ability to do data visualization and data mining will be heavily dependent on network capability and network topology to support the information enterprise.

Risk (1) Risk is considered fairly high because high speed and high bandwidth will be essential, along with sophisticated security protocols and networking protocols that will be needed to manage the push/pull requirements of data.

Cost Drivers

As with all technologies that are predominately software, the development and testing aspects are key high risk and cost drivers. Since data visualization depends on networking as well, network topology and infrastructure is a critical cost driver. Although networking has high risk associated with it, it is considered less of a risk than the software drivers.

5.3.1 Quadrant Chart

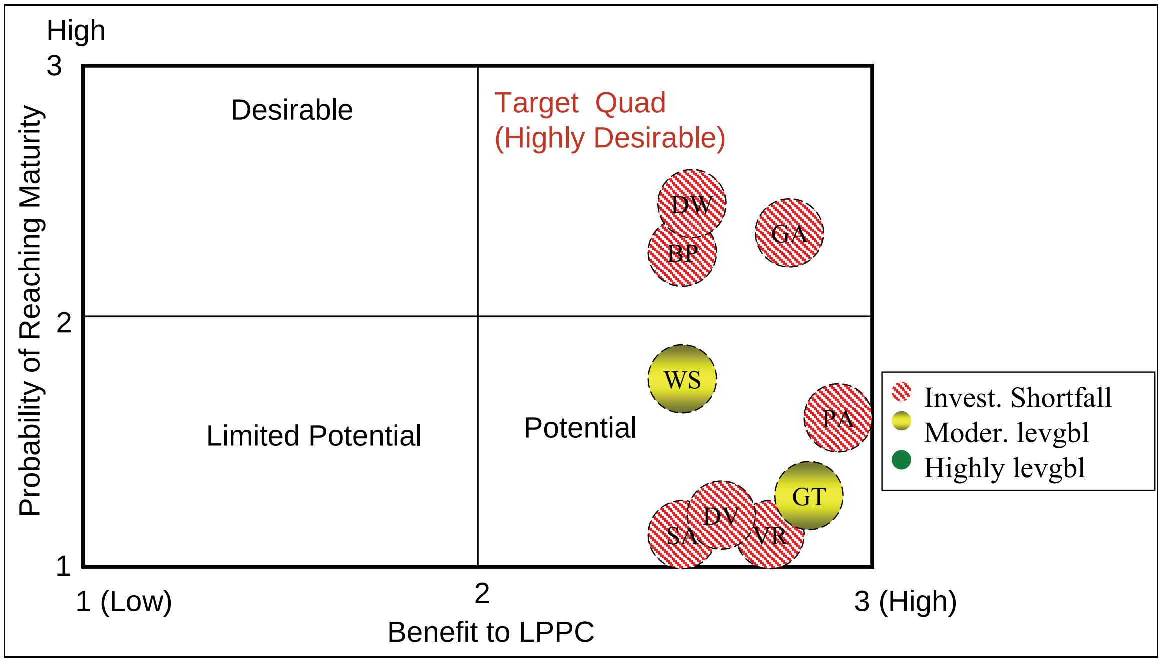


Figure 5.13. Exploitation and assessment quadrant chart.

Symbol	Technology	Section
BP	Business Process Integration	5.1.4
GA	Geospatial Analysis	5.2.
PA	Predictive Analytics	4.3.3
VR	Virtual Reality	5.2.1.1
WS	Web Technologies" Services (Service Oriented Architectures, Web Services, and Semantic Web)	5.1.4
SA	Software Agents	5.1.3
DW	Data Warehousing	5.1.6
DV	Data Visualization	5.2.1.2
GT	Gaming Technology	5.2.1.3

Semantic Web
Service Oriented Architecture
Web Services

5.4 The Way Forward

The way forward should be to establish a roadmap that develops an enterprise-wide prediction capability in a step-by-step process that always has the Soldier in mind. Prediction for Army logistics is a large and complex challenge. In order to properly address it, prediction requirements must be broken down into pieces that can be developed in a systematic way. The LPPC must be robust enough to allow change, new technologies, and new capabilities to be introduced iteratively and appropriately across the enterprise. The following steps show where early research efforts should focus to achieve successes that will provide quick returns on investment (ROI). They also demonstrate the need for a comprehensive long-term effort to develop prediction capabilities across the entire logistics domain in order to prevent or mitigate the critical events listed in table 5.1.

1. **Identify Critical Logistical Business Processes.** Decompose the Army's logistical functions into a fundamental set of business processes in order to identify those that directly impact the events listed in table 5.1. This will require a good amount of up-front research. A good analogy is the old Fram Oil filter commercial where it is said: "You can pay me now, or pay me later." And, the "pay me later" is always more expensive. This first step is essential to focusing on those critical processes that will have maximum impact.

2. **Designing an enterprise service oriented architecture that focuses on web technologies and business process integration.** Although this is often described in terms of near-term technologies, successful implementation on an enterprise-wide level is another issue. The Army must realize that the ability to attract, train, and retain the technological expertise to deploy, operate, and maintain complex information technology could end up being the Army's Achilles' heel. Army transformation depends on information technology, but only if the Army can keep this technology up and running, and Soldiers are able to use it to its fullest potential. The Army must seek emerging technologies that will help enable the enterprise system. This can mitigate some of the usability issues and training costs associated with complex technology, and it will be essential to Soldier use of predictive tools. A services approach to information technology applications in an enterprise information system is a leading candidate to address system usability issues and reduce training costs as discussed earlier in this section. Rather than trying to implement one solution across the entire logistical domain, it is recommended that new technologies be introduced sequentially. SOA technology and web portfolios lend themselves to this approach and allow the Army to "plug & play" specific prediction tools over time. Developing a departmental or unit level set of prediction capabilities could serve as a first step. This will demonstrate the potential that prediction capabilities can bring to logistical decision making, allows validation of prediction technology benefits, permits scalability, demonstrates early ROI, and will help bring to light a number of technical challenges that are likely to remain hidden until effort to implement such as system is attempted.

3. **Identify the required predictive capabilities needed for those critical business processes identified in step 1**. (Note: This step can be done in tandem with step 2.) Conduct research into identifying the required prediction capabilities needed to prevent or mitigate the identified critical events associated with the business processes identified in step one. Determine whether existing commercial technologies, emerging technologies from Army research programs such as those mentioned in this paper (e.g., ATLAS, LOGSPOT, and PDSM), or if extensive research is needed to develop, test, and verify new predictive capabilities. A steady research program that brings additional predictive capability online over time will continually enhance the existing capability of the enterprise system.

4. **Continually examine changes in Army doctrine and technology**. Army doctrine will change with time and this will result in business process change. Technology will also change with time and potentially dictate doctrinal changes as well. This could lead to obsolescence and require development of new prediction capabilities. Continual re-assessment will be required by the Army logistics community in collaboration with the Army research community to ensure that prediction capabilities are relevant and provide reasonably accurate actionable knowledge for decision making. Consequently, the need for continual examination and assessment of interdependent technology and doctrinal changes will synergistically work to maintain a robust set of prediction capabilities across the enterprise.

As described in this chapter, there are several efforts to develop new and unique cutting edge predictive capabilities focused on specific logistic problems (e.g., LOGSPOT – Predictive Planning, ATLAS – Maintenance Forecasting, PDSM – Predicting Manpower and Manpower skills required to maintain fielded software systems). Continued collaboration with scientists and engineers in efforts such as these is strongly recommended.

5.5 Conclusions

In doing the research, three key points became clear.

1. Technology is not the driver to a comprehensive prediction capability for exploitation and assessment in the 2020 – 2030 era. Advanced technology will be essential in achieving the objective of a comprehensive enterprise-wide prediction capability. There is no question about that. The key driver is the predictions themselves. In the process of conducting this research, it was discovered that for a required prediction, that prediction will drive the specific analytics necessary to realize that prediction. Those analytics will in turn drive the technologies necessary to realize the analytics (i.e., algorithms, models, simulation, data, network communications, sensors, etc). In other words, until you know what it is that you want to predict, you really do not know what specific technologies (i.e., algorithms, models, simulation, data, network communications, sensors, etc.) are going to be needed to realize that prediction. It is the specific predictions that will determine what technologies are needed to realize that prediction. This makes it extremely difficult to focus on any specific technology with any degree of certainty that it will be viable in meeting prediction objectives.

2. The predictions themselves are the key drivers to determining technologies needed. The second consideration, and probably the most important one, is *how* to determine what predictions are required. In conducting this research, it became clear that the Army's logistical operations are very complex across the entire logistical domain. Adding to that complexity is the fact that logistical business operations change gears (i.e., operational states) drastically as the Army transitions from a peacetime footing to a mission execution footing (war, etc.). These dynamic changes often cause changes in the Army's logistical business operations all across the supply chain. It also became evident that if problems or

disruptions occurred in logistical operations for any number of reasons, at any number of points along the supply chain, and for any number of sustainment commodities, they could have catastrophic impacts on sustainment objectives and mission success. The conclusion from this research was that critical prediction capabilities need to be identified that can provide knowledge that allows logisticians to take courses of action to prevent or minimize those events from occurring. It was also determined that a methodology needs to be established as a first step to segment the Army's logistical business across the entire logistics domain into a set of business processes with the expressed purpose of defining measures and metrics to identify which logistical business processes are critical to causing the events listed in table 5.1. From this, appropriate prediction requirements can be identified that are specifically tied to these critical logistical business processes – business processes that have been identified as impacting one or more of the critical events in table 5.1. This methodological approach allows for re-assessment of prediction requirements based on policy or technological change to ensure that the suite of prediction capabilities is valid and provides reasonably accurate knowledge.

3. Because research on this topic indicated that a suite of prediction capabilities would be required and that it would likely encompass the entire logistical domain, an enterprise information system comprising the requisite technologies described in this chapter would be appropriate direction to pursue. Since information systems are becoming increasingly complex, end-user usability and the manpower skills required to deploy, operate, and maintain such systems—including a prediction enterprise information system—will be key factors for full use of these systems. Research indicated that several classes of technologies are emerging (e.g., service oriented architectures, web services, geospatial analysis, software agents, and business process integration) that attempt to address the issues of usability, maintainability, and training required to own such systems. This is critical to any information technology system in order to get maximum use and benefits. A key point with usability is that it needs to be addressed up front in the design and development stages and not after the fact where it would be too costly to redesign.

4. In summary:

   a. Logistical business operations cause and effect audit trail drives the analytics required.

   b. Analytical cause and effect audit trail drives the technologies required.

   c. A Predictive Enterprise information system with a focus on end-user usability is a key part of the solution.

   d. Critical prediction capabilities need to be identified that can provide knowledge that allows logisticians to take courses of actions to prevent or minimize catastrophic events from occurring.

e. Business process integration is essential as both a provider and consumer of the increased data and knowledge emerging from the enterprise.

f. Software applications will help to clarify the specific predictive analytics and fusion algorithms. There will be a variety of tools (analytics) and the specific ones used for a given task will depend on both the task itself and echelon at which the prediction is being made.

g. The findings in this chapter support the conclusion of the Phase I paper that there is an urgent requirement for an enterprise-wide prediction and preemption capability. The capabilities necessary to implement an LPPC are currently being researched. Additional resources can accelerate this progress to meet the requirement for an enterprise-wide prediction and preemption capability.

---

[106] R. Scmelzer, Solving Information Integration Challenges in a Service-Oriented Enterprise, ZapThink, LLC. (2003, November).,pg 8.. Retrieved February 28, 2007, from http://hosteddocs.ittoolbox.com/Schmelzer022004.pdf
[107] A Roadmap for Web Services Adoption, (Feb 20, 2003), Netnumina Solutions, Web site: http://www.netnumina.com/Papers/cs/Web_Services.pdf
[108] Painter, Michael (2004, October). “Black Hawk Fleet Management Demonstration (FMD) HUMS/MMIS Condition Based Maintenance +”, (Briefing Slide), Knowledge Based Systems Inc., College Station, Texas.
[109] Williamson, B., Miller, L. (2003, June 21). The semantic web: A touch of intelligence for the internet? EducationGuardian.co.uk. Retrieved March 1, 2007, from http://education.guardian.co.uk/print/0,,4695866-108699,00.html
[110] Leslie, L.M. (2002, Dec 3 -12). Ensemble Prediction Methods for Tropical Cyclone Forecasting. Paper presented at the Fifth International Workshop on Tropical Cyclones. Paper retrieved February 28, 2007, from http://www.aoml.noaa.gov/hrd/iwtc/Leslie3-3.html
[111] Leipzig conference on the Future of Forecasting. (2005, June). The Oracle, p. 10. Retrieved March 1, 2007, from http://forecasters.org/filestore/oracle/Jun2005Oracle.pdf
[112] Forecasting: Why Some Mangers Outperform Statisticians at Forecasting, Christie Christelis, Technology & Management Perspectives, Vol. 1, No. 1, July 1998 http://www.tsicanada.com/documents/Forecast.pdf
[113] Technology Services International. (1998, July). Forecasting: Why Some Mangers Outperform Statisticians at Forecasting. Retrieved March 1, 2007, from http://www.tsicanada.com/documents/Forecast.pdf
[114] Zaptron Systems. (1998). Market Forecast Using DATAX – A Fuzzy Logic Approach to Time Series Analysis. Retrieved February 28, 2007, from http://www.zaptron.com/datax/forecast.htm
[115] Mobile Agents: Are they a good idea?, Colin G. Harrison, David M. Chess, Aaron Kershenbaum, Pg 11, IBM Research Division, T.J. Watson Research Center, Yorktown Heights, NY 10598, March 1995.
[116] ibid
[117] Franklin, S., Graesser, A. (1997). Is it an Agent, or just a Program? A Taxonomy for Autonomous Agents. Retrieved March 1, 2007 from the University of Memphis, Department of Mathematical Sciences Web site: http://www.msci.memphis.edu/~franklin/AgentProg.html
[118] Ammoura Ayman, DIVE-ON: From Databases to Virtual Reality. Retrieved May 2, 2007 from The Association of Computing Machinery, 2 Penn Plaza, Site 701, New York 10121-0701, Web site: http://www.acm.org/crossroads/xrds7-3/diveon.html
[119] Bonk, Curtis J., Dennen, Vanessa P., (March 2005), Massive Multiplayer Online Gaming : A Research Framework for Military Training and Education, Technical Report 2005-1, Office of the Secretary of Defense for Personnel and Readiness, Retrieved May 2, 2007 from Army War College, Strategic Experimental Education Group (SEEG), Web site: http://www.strategicleader.us/ExperientalLearningPapers/GameReport_Bonk_final.pdf

Chapter 6. An Integrated Perspective on Enabling Technologies for Prediction & Preemption

R. del Rosario

"The essence of flexibility is in the mind of the commander; the substance of flexibility is in logistics."

- Rear Admiral Henry Eccles, U.S. Navy

6.1 Revolutionary, Evolutionary, or Both?

Emergent capabilities result from the confluence of cross-cutting technologies. In all technical arenas, progress occurs in both revolutionary and evolutionary fashion at various points in their histories. The invention of the integrated circuit was very much a revolutionary advancement. Having established that fundamental device, the last several decades have seen steady, albeit impressive, decreases in the feature sizes of those same devices.

However, when crossed with advances in different fields such as multi-tasking operating systems, bit-level, object-oriented programming languages, and packet-transferred digital communication protocols, these evolutionary steps in individual fields have fused to initiate revolutionary advances from the user perspective. Figure 6.1 depicts just this paradigm of development with the example of the technologies that enable the present day web-based consumer supply chain.

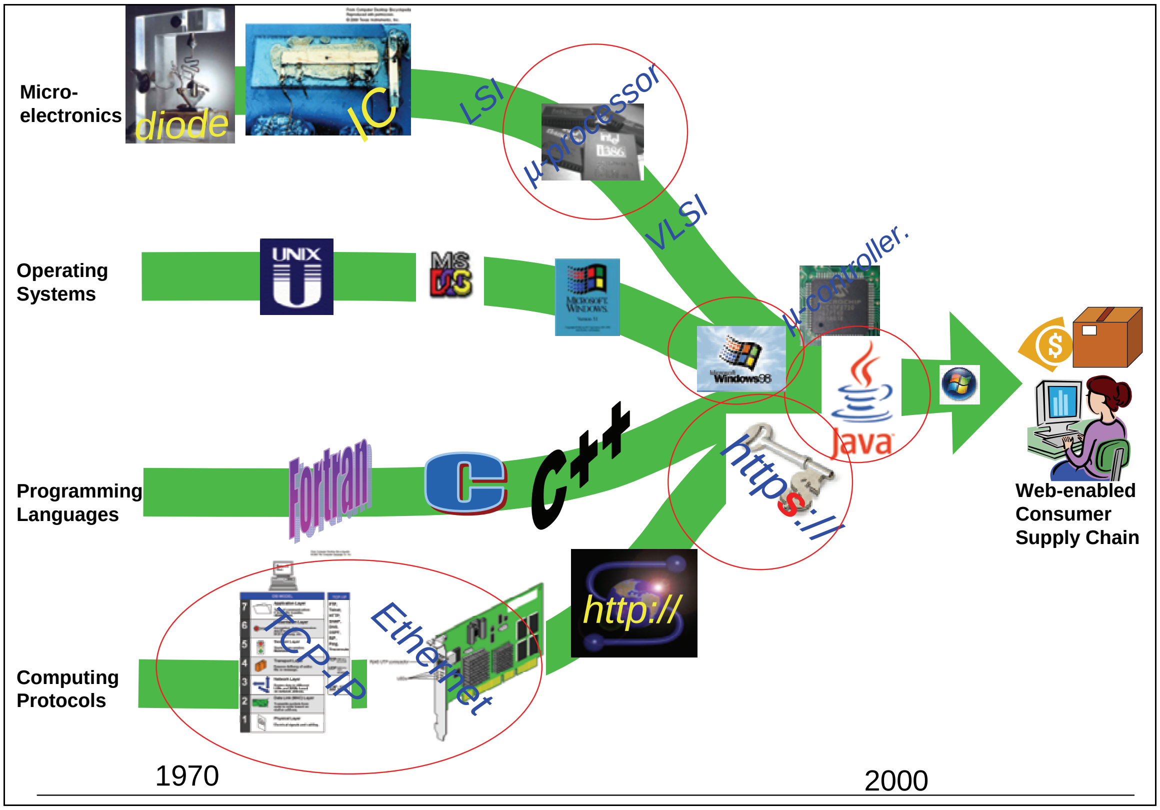


Figure 6.1. A rough and partial sketch of four of the major technology timelines that enabled the contemporary Web-enabled consumer supply chain as we know it today. Red circles indicate specific cross-cutting, enabling technologies.

Technologies circled in red indicate critical sets of technologies, without which, the consumer web could not exist. TCP-IP enabled robust, intermittent data communication, Java allowed retailers to place small client-software applications on a purchaser's computer to help expedite purchase and no one would ever have transmitted critical personal information or account numbers unless 128/256-bit encryption had been implemented.

6.1.1 Purpose of this Chapter

With this critical path-like methodology, we will "rack and stack" the underlying technologies, both from an individual technology area (performed primarily in the preceding chapters) and from an integrated perspective. This will enable a substantial down-select of the original 34 technologies, resulting in a more streamlined portfolio. The resultant portfolio will represent the forecast technologies recommended as critical investments.

6.2 Looking at the Technologies as a Whole

Chapters 2 through 5 delved into the four technical areas considered essential to establishing an enterprise Logistical Prediction and Preemption Capability. The material therein was presented, discussed and evaluated from a focused perspective within those subject areas. We now consider the interplay of those technologies with others outside of their respective area. (What data collection technologies hold high synergistic potential with fusion algorithms? Which data transmission technologies will expedite the exploitation of the simulated COAs?) While the recommendations made thus far emphasize the major building blocks of the enterprise, we will now turn our attention to those that offer the greatest benefits from a synergistic point of view. We now consider the set of 34 technologies as a whole group and evaluate their impact upon each other.

6.3 Cumulative Quadrant Model

We preface this discussion of the integrating or cross-cutting nature of these technologies with a brief look at the overall picture formed thus far from chapters 2 through 5. Figure 6.2 displays all of the technologies discussed in chapters 2 through 5 in a single quadrant chart.

This overall version of the quadrant model includes an additional *border key* to distinguish the 4 technology areas by the line-type. The table that immediately follows the figure lists the abbreviations next to the names of the technologies and the sections in which they are discussed in detail. The table also adds an overall index of the 34 technologies discussed throughout the technical chapters. This index will be used as a reference for the cross correlation matrix discussion that immediately follows.

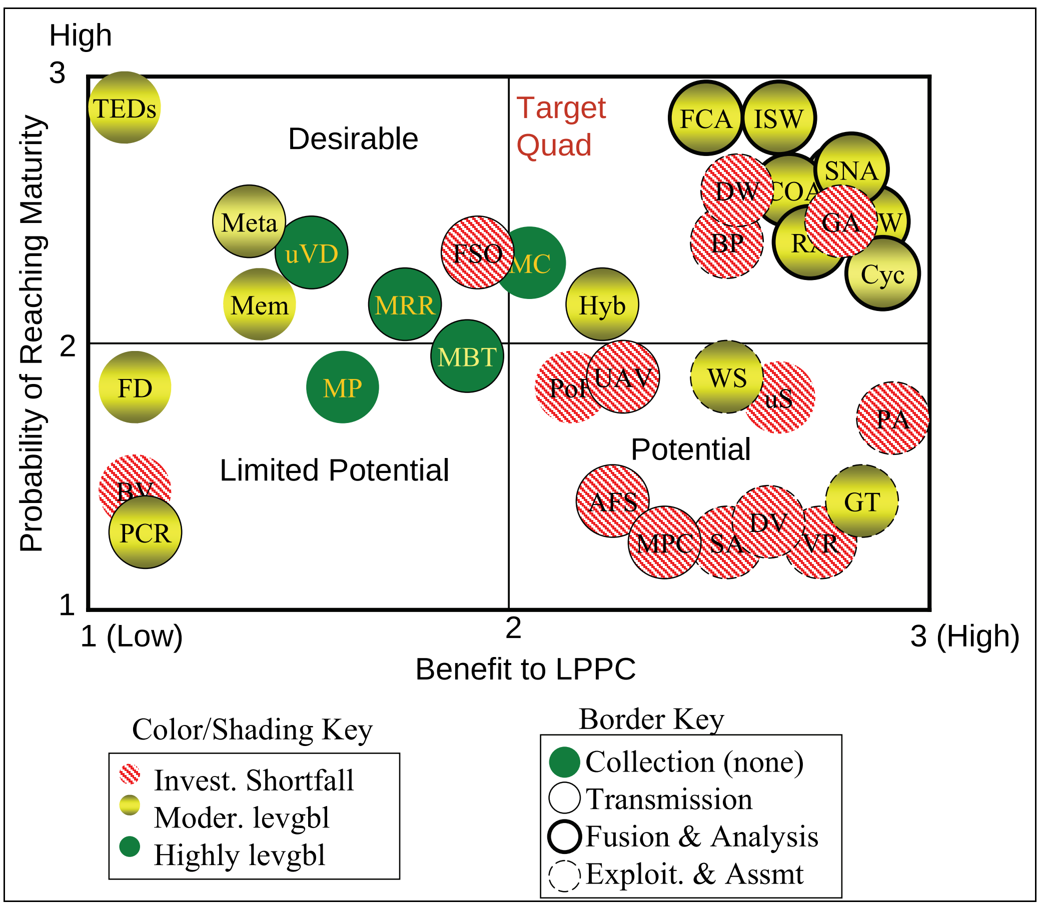


Figure 6.2. Summary quadrant chart of all technologies.

Index	Symbol	Data Collection Technologies	Section
1	MP	Multi-core Processors	2.3.3.2
2	MC	Microcontrollers	2.3.3.3
3	BV	Betavoltaics (parasitic vibr, RF)	2.3.6
4	Mem	Memory (Memory stickers,)	2.3.4.1
5	uS	Microscale sensors (MEMS, Nano)	2.3.2
6	FD	Flexible Displays	2.3.7
7	PoF	Physics of Failure (Prognostic) Algorithms	2.6.1
8	TEDS	Transducer Electronic Data Sheets (Standards)	2.3.1
Index	**Symbol**	**Data Transmission Technologies**	**Section**
9	FSO	Free Space Optical Communication	3.2.1
10	PCR	Photon Counting Receivers	3.2.2
11	AFS	Adaptive Free Space Optical Communication	3.2.3
12	MRR	Modulating Retro Reflector	3.2.4
13	Hyb	Hybrid RF Optical Communication	3.2.5
14	UAV	UAV Relayed Communication	3.2.5.3
15	Meta	Meta-materials	3.5.2
16	uVD	Microfabricated Vacuum Electronic Devices	3.5.3
17	MBT	Multi-band Tunable Antennas	3.5.4
18	MPC	Multi-Platform Common Data Link (MP-CDL)	3.5.5.1
Index	**Symbol**	**Fusion & Analysis Technologies**	**Section**
19	ISW	Intelligent Sensor Webs	4.5.1
20	ASW	Adaptive Sensor Webs	4.5.2
21	FCA	Formal Concept Analysis	4.5.3
22	sCOA	Simulations Based Course of Action	4.5.4
23	SNA	Social Network Analysis	4.5.5
24	RA	Reflexive Analysis	4.3.5
25	Cyc	Cyc-Based Virtual Logistician	4.5.7
Index	**Symbol**	**Exploitation & Assessment Technologies**	**Section**
26	BP	Business Process Integration	5.1.4
27	GA	Geospatial Analysis	5.2.
28	PA	Predictive Analytics	4.3.3
29	VR	Virtual Reality	5.2.1.1
30	WS	Web Services	5.1.4
31	SA	Service Oriented Architectures	5.1.3
32	DW	Data Warehousing	5.1.6
33	DV	Data Visualization	5.2.1.2
34	GT	Gaming Technology	5.2.1.3

6.4 Cross Correlation Matrix

Using a methodology analogous to the scoring tables used for the individual technology area chapters, we have scored and ranked the 34 technologies. However, in this case rather than scoring against various sub-technologies or logistical tenets, only one tenet is used:

Potential for integrating technology N with technology M, where M is any of the 34 technologies other than N.

As with the evaluations in chapters 2 through 5, scores were assigned as either low (1), medium (2), or high (3). Hence, a high score rating between two technologies indicates high potential for integration of the two. A low score indicates limited correlation between the two.

The matrix produced is shown in Figure 6.3. This table shows all 34 technologies scored against each other with regard to their potential for being integrated together for increased capability. Rankings of the technologies were determined by summing the total scores (i.e., a technology's total score = the sum of its correlations to all of the other technologies). Note that the matrix is diagonally symmetric, the diagonal is zero (i.e., self-correlations not counted), and the sums are observable in both the bottom row and the right-most column.

A second matrix has also been produced, figure 6.4. This table provides the reader with a complete picture of the 34 technologies and their dependences. The column labeled "Target of Opportunity" does not represent the proposed six "Roadmap" technologies; rather it is a simple representation of nice-to-have technologies if additional funding became available. By advancing and coupling those technologies identified as Targets of Opportunity to the six Roadmap technologies, the LPPC would recognize a more robust capability.

Score	1Rank	MP	MC	BV	Mem	uS	FD	PoF	TEDS	FSO	PCR	MRR	AFS	Hyb	UAV	Meta	MBT	uVD	MPC	ISW	ASW	FCA	sCOA	SNA	RA	Cyc	BP	GA	PA	WS	SA	DW	DV	VR	GT	Total
61	2 MP	0	1	1	1	1	3	3	1	1	1	1	2	1	1	1	1	1	1	1	2	3	3	3	2	3	2	3	3	2	2	1	3	3	3	61
53	11 MC	1	0	3	3	3	1	1	3	1	1	1	2	2	2	1	1	2	2	3	3	1	1	1	1	1	1	2	1	1	1	1	1	1	3	53
43	23 BV	1	3	0	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43
61	2 Mem	1	3	3	0	3	2	2	3	1	1	1	2	2	1	1	1	1	3	3	3	1	1	1	1	1	3	2	1	1	1	3	2	3	3	61
54	9 uS	1	3	3	3	0	1	3	3	1	1	1	1	1	1	2	2	1	1	3	3	1	1	1	1	1	2	3	1	1	1	1	1	1	3	54
53	11 FD	3	1	1	2	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	3	2	2	2	3	3	3	3	53
47	21 PoF	3	1	1	2	3	1	0	3	1	1	1	1	1	1	2	2	2	1	2	2	1	1	1	1	1	2	1	1	1	1	2	1	1	1	47
61	2 TEDS	1	3	1	3	3	1	3	0	2	1	2	2	2	2	2	3	3	2	3	3	1	1	1	1	1	2	3	1	1	1	1	1	1	3	61
49	18 FSO	1	1	1	1	1	1	1	2	0	1	1	1	1	1	3	1	1	3	2	2	1	1	1	1	3	1	3	1	1	1	2	2	2	3	49
33	34 PCR	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	33
37	32 MRR	1	1	1	1	1	1	1	2	1	1	0	2	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	37
41	30 AFS	2	2	1	2	1	1	1	2	1	1	2	0	1	1	1	2	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	41
42	28 Hyb	1	2	1	2	1	1	1	2	1	1	1	1	0	1	1	3	1	3	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	42
43	23 UAV	1	2	1	1	1	1	1	2	1	1	1	1	1	0	1	3	1	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	43
41	30 Meta	1	1	1	1	2	1	2	2	3	1	1	1	1	1	0	2	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	41
49	18 MBT	1	1	1	1	2	1	2	3	1	1	1	2	3	3	2	0	1	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	49
42	28 uVD	1	2	1	1	1	1	2	3	1	1	1	1	1	1	1	1	0	3	1	1	1	1	1	1	1	3	2	1	1	1	1	1	1	1	42
68	1 MPC	1	2	1	3	1	1	1	2	3	1	3	3	3	3	3	3	3	0	3	3	1	1	1	1	3	3	3	1	1	1	1	3	3	2	68
56	7 ISW	1	3	3	3	3	1	2	3	2	1	1	1	2	3	1	3	1	3	0	1	1	1	1	1	2	3	1	1	1	2	1	1	1	1	56
57	6 ASW	2	3	3	3	3	1	2	3	2	1	1	1	2	3	1	3	1	3	1	0	1	1	1	1	1	3	1	2	1	2	1	1	1	1	57
43	23 FCA	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	3	1	1	3	2	2	2	2	1	1	43
43	23 sCOA	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	3	1	1	2	2	3	3	1	1	1	43
43	23 SNA	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	3	1	1	3	2	3	2	1	1	1	43
37	32 RA	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	3	1	1	1	2	1	1	1	1	1	37
54	9 Cyc	3	1	1	1	1	3	1	1	3	1	1	1	1	1	1	1	1	3	2	1	3	3	3	3	0	1	1	1	2	2	1	1	2	2	54
58	5 BP	2	1	1	3	2	3	2	2	1	1	1	1	1	1	1	1	3	3	3	3	1	1	1	1	1	0	3	3	3	1	2	2	2	1	58
50	16 GA	3	2	1	2	3	3	1	3	3	1	1	1	1	1	1	1	2	3	1	1	1	1	1	1	1	3	0	1	1	1	1	1	1	1	50
49	18 PA	3	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	2	3	2	3	1	1	3	1	0	3	2	3	1	1	1	49
47	21 WS	2	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	3	1	3	0	3	2	1	1	1	47
52	14 SA	2	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	3	3	1	2	1	1	2	3	0	2	2	3	3	52
53	11 DW	1	1	1	3	1	3	2	1	2	1	1	1	1	1	1	1	1	1	1	1	2	3	2	1	1	2	1	3	2	2	0	3	3	2	53
50	16 DV	3	1	1	2	1	3	1	1	2	1	1	1	1	1	1	1	1	3	1	1	2	1	1	1	1	2	1	1	1	2	3	0	3	3	50
52	14 VR	3	1	1	3	1	3	1	1	2	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	2	2	1	1	1	3	3	3	0	3	52
56	7 GT	3	3	1	3	3	3	1	3	3	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	2	1	1	1	1	3	2	3	3	0	56
	Total	61	53	43	61	54	53	47	61	49	33	37	41	42	43	41	49	42	68	56	57	43	43	43	37	54	58	50	49	47	52	53	50	52	56	

Figure 6.3. Detailed scoring matrix.

Index	Symbol		Required	Target of Opportunity	Dependencies	Section
		Data Collection Technologies				
1	MP	Multi-core Processors	√		28,19-25	2.3.3.2
2	MC	Microcontrollers	√			2.3.3.3
3	BV	Betavoltaics (parasitic vibr, RF)				2.3.6
4	Mem	Memory (Memory stickers,)	√			2.3.4.1
5	uS	Microscale sensors (MEMs, Nano)	√		26,28	2.3.2
6	FD	Flexible Displays		√		2.3.7
7	PoF	Physics of Failure (Prognostic) Algorithms		√		2.6.1
8	TEDS	Transducer Electronic Data Sheets (Standards)	√			2.3.1
		Data Transmission Technologies				
9	FSO	Free Space Optical Communication	√			3.2.1
10	PCR	Photon Counting Receivers				3.2.2
11	AFS	Adaptive Free Space Optical Communication				3.2.3
12	MRR	Modulating Retro Reflector				3.2.4
13	Hyb	Hybrid RF Optical Communication	√			3.2.5
14	UAV	UAV Relayed Communication				3.2.5.3
15	Meta	Metamaterials				3.5.2
16	uVD	Microfabricated Vacuum Electronic Devices				3.5.3
17	MBT	Multi-band Tunable Antennas				3.5.4
18	MPC	Multi-Platform Common Data Link (MP-CDL)	√		9,13	3.5.5.1
		Fusion & Analysis Technologies				
19	ISW	Intelligent Sensor Webs	√		2,5,8	4.5.1
20	ASW	Adaptive Sensor Webs	√		19	4.5.2
21	FCA	Formal Concept Analysis	√			4.5.3
22	sCOA	Simulations Based Course of Action	√		21	4.5.4
23	SNA	Social Network Analysis	√			4.5.5
24	RA	Reflexive Analysis	√		21	4.3.5
25	Cyc	Cyc-Based Virtual Logistician	√		21,22,24	4.5.7
		Exploitation & Assessment Technologies				
26	BP	Business Process Integration	√			5.1.4
27	GA	Geospatial Analysis				5.2.
28	PA	Predictive Analytics	√		26,28,19-25	4.3.3
29	VR	Virtual Reality		√		5.2.1.1
30	WS	Web Services	√			5.1.4
31	SA	Software Agents		√	30	5.1.3
32	DW	Data Warehousing				5.1.6
33	DV	Data Visualization		√	30	5.2.1.2
34	GT	Gaming Technology		√	30	5.2.1.3

Figure 6.4. Technology Dependencies.

6.4.1 Integrated Technology Rankings

Having scored and ranked the cross-cutting aspect of the whole set of technologies, six particular technologies that show high promise for increased synergy stand out. (As expected, there is some overlap with the recommended technologies from the individual technical chapters.)

6.4.1.1 Multicore Processors

The rationales for the high scores for some of the technologies are straightforward to justify. For example, multi-core processors will present orders of magnitude advantage for the ones applied to any of the highly complex data fusion algorithms. In this case, the sheer computing horsepower is exactly what is needed as one of the enablers for quick response to simulated COAs. The resulting high scores across the board for data fusion algorithms make it a very clear example of a technology with multiple applications in the overall capability (prognostics algorithms and distributed requirements for exploitation also benefit).

An early example of this type of impact has recently been observed in the biophysics arena. The *Folding@home* (figure 6.5) project at Stanford University allows the general public to *loan* their CPU time to the problems of unfolding complicated protein structures as part of the search for cures to various types of cancer, Alzheimer's and other diseases.

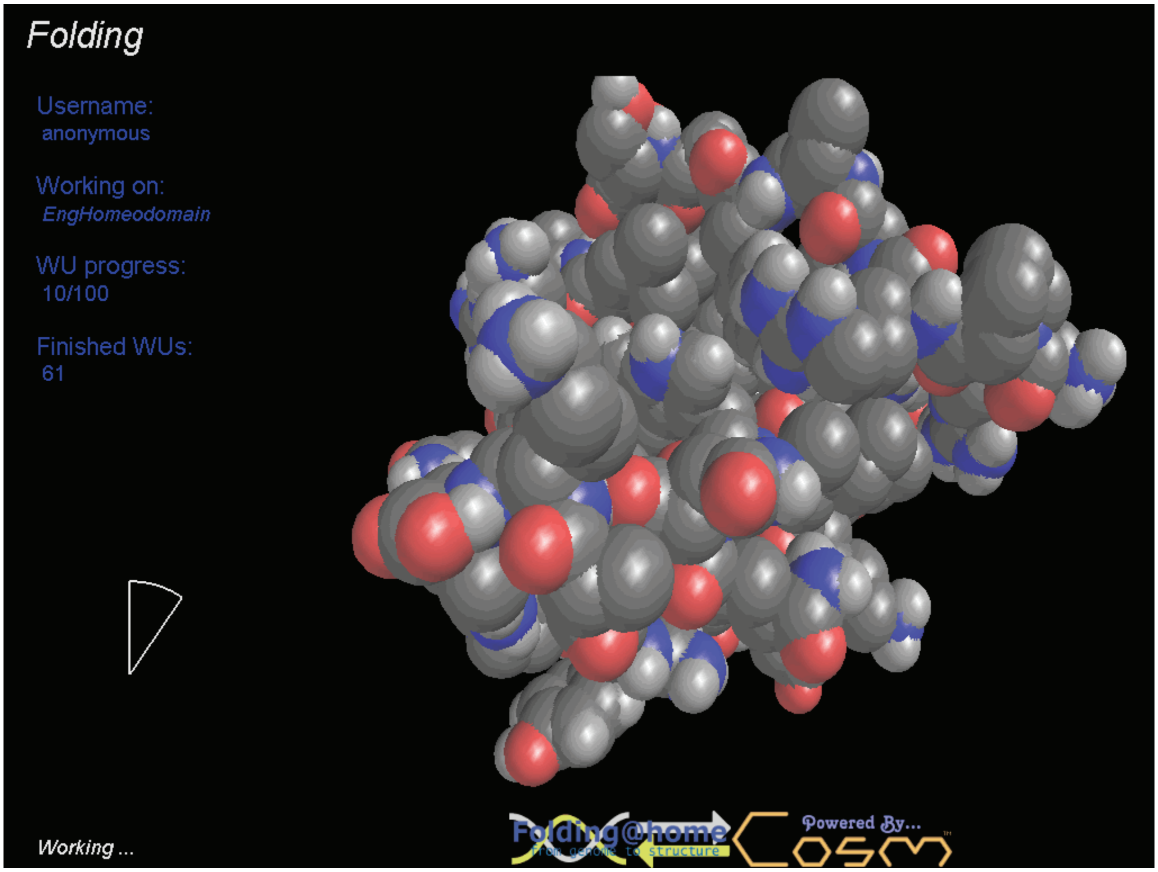


Figure 6.5. Protein folding application for multicore processors.

While the effort has been under way since 2000, the release of a version of the client software to the multicore Playstation 3 enabled a tripling of the total computing power with a relatively small number of users.[120]

6.4.1.2 Memory (Pre-positioned)

Solid state memory represents arguably the most ubiquitous technology today and this utility will only grow as applications including LPPC mature. Regardless of the underlying materials or devices upon which it is based (DRAM, SRAM, MEMS, magneto-optical and so forth), memory will proliferate to the point that it is located on individual parts and pieces in readily readable forms. To the casual user, it will serve as an enormous improvement in commodity item tracking (1/100 the size of a bar code but with the storage capacity of a CD). To the LPPC user, it enables a host of the other requisite technologies, particularly Transducer Electronic Data Sheets and micro/nanosensors, and extensions to microcontrollers. The addition of memory to these other technologies represents the most fundamental underpinning to intelligent sensor webs and ultimately, autonomous sensor networks.

6.4.1.3 TEDS/Standards

Although the TEDS (transducer electronic data sheets) and standards described in chapter 2 appear to be very easily leveraged, and lacking in direct impact (with regard to the list of 19 events to be avoided), they are absolutely critical in enabling the intelligent sensor webs (ISW) listed as one of the top data fusion technologies.

Similarly, because of the comprehensive nature of logistics, technological advances will demonstrate fusion, not just in data sources, but in the hardware technologies as well. Multi-modal storage conditions: stationary, transport, and hostile environments, will present challenges that will be met by equally adaptive solutions. Concepts such as the universal energy harvester[121] will integrate thermoelectric, photovoltaic, and micro-electro-mechanical systems (MEMS)-based vibrational elements in order to parasitically extract power to fuel ubiquitous sensors.

However, without what engineers call a “well defined interface,” it will be substantially more difficult to capitalize on device level breakthroughs. At the ground level, TEDS or other similar standards will provide the essential “glue” to scale device level improvements up to the system level with shorter development times.

6.4.1.4 Multi Platform – Common Data Links (MP-CDL)

MP-CDL represents the “Holy Grail” of communication. It entails the hardware, protocols, and most importantly the transitions, to enable multi-mode communication between the entire set of underlying technologies: RF, microwave, millimeter-wave, free space optical, and hybrids. The significant strength of the MP-CDL is that it can support an extremely mobile force. Interoperability will mean that airborne, WAN, LAN, PAN, satellite, and fiber-optic networks can all communicate with each other, allowing for real-time information transfer. This type of connectivity is illustrated in the idea of the Global area network. Likewise, it includes all of the potential node hardware: UAVs, man-portable and vehicular ground terminals, and satellites.

6.4.1.5 Intelligent/Autonomous Sensor Webs

A network of distributed multi-modal sensors that fuse data in a decentralized manner is capable of sensing, recognizing, and then reporting acquired entities and objects. Intelligent sensor web (ISW) technology will be capable of servicing the LPPC by allowing spatially distributed sensors mounted on networked platforms to dynamically collect, transmit, fuse, and analyze data and location of existing logistics and operation nodes. By cooperatively tracking the status of the logistics nodes as a function of time, intelligent sensors webs will provide real-time aggregated knowledge.

Adaptive Sensor Web (ASW) technology, although similar to ISW, has a distinct advantage. ASW will dynamically collect and transmit data, similar to ISW, however, it will provide superior data fusion and analysis. This will be evidenced by an ASW capability to recursively modify the logistics common operating picture (LCOP) by prioritizing available asset quantity/location data as a function of data confidence. This will allow the ASW to selectively fuse the best data to generate the most reliable collective description of exiting supplies and assets distributed across the area of operations as a function of time.

6.4.1.6 Business Process Integration

Business Process Integration is essential as both a provider and consumer of the increased data and knowledge that will flow through the LPPC. From the hardware technology perspective, having a cohesive BPI as a first step enables optimal placement of novel devices. For example, the use of micro sensors and pre-positioned memory “stickers” will be aided substantially by knowing exactly what needs to be monitored. Likewise, more expensive but more capable items such as intelligent sensor web nodes and micro fabricated vacuum devices can be used effectively via judicious placement, resulting from business process integration. For the software applications, the results of the integration will clarify the specific predictive analytics and fusion algorithms required.

6.5 Cumulative Quadrant Model Revisited

Figure 6.6 illustrates the reexamination of the original cumulative quadrant model. In this case however, we have grayed out many of the technologies. This down-selection was determined by the results of the scoring in chapters 2 through 5 and the cross-correlation matrix in chapter 6. Thus, these results represent the technologies recommended as critical investments for the logistics community in order to affect a prediction and preemption capability.

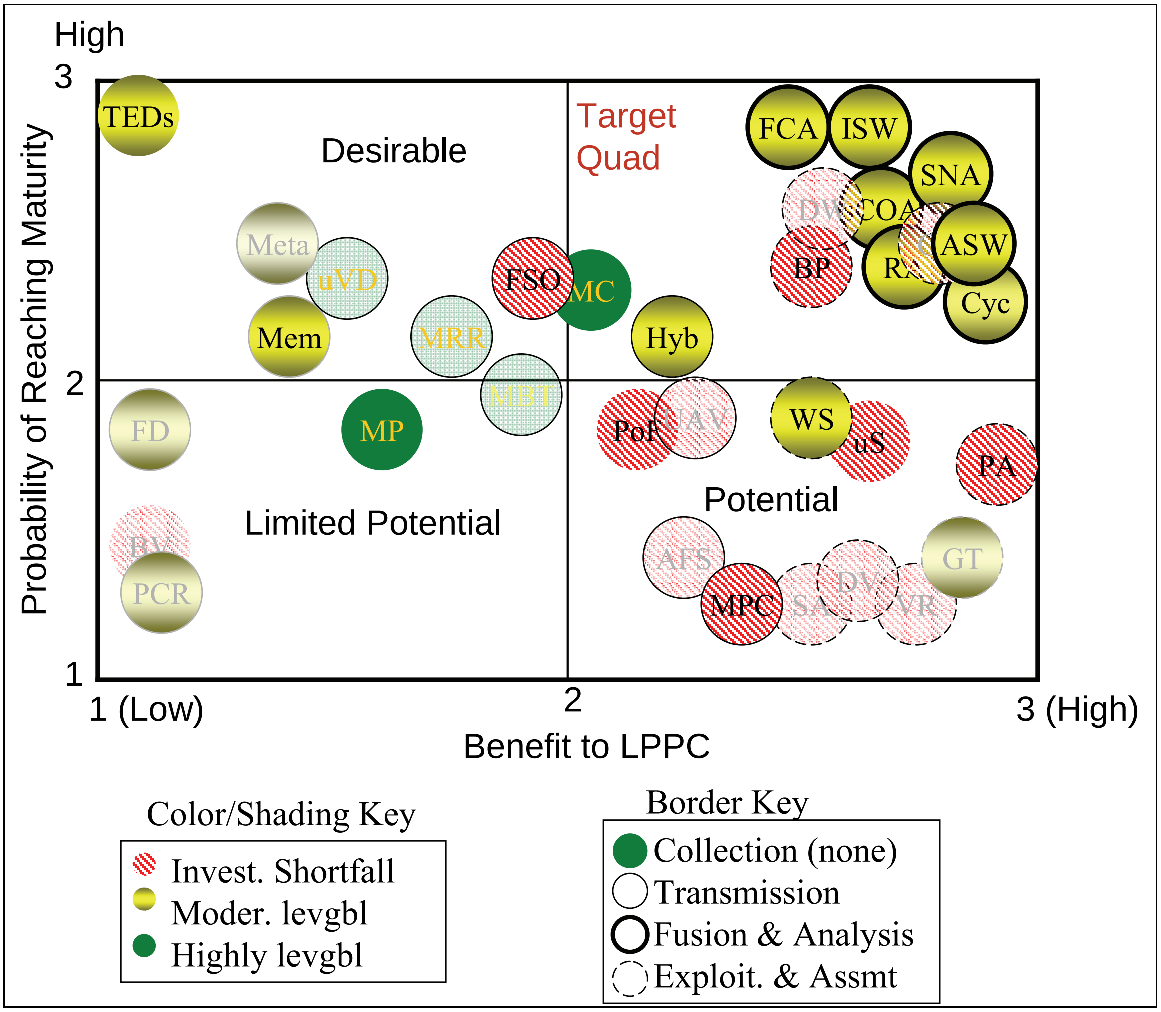


Figure 6.6. Full quadrant model with down selects from technical and integration authors.

6.6 Observations

In plotting the entire ensemble of technologies from all areas together, several observations are immediately noticeable:

1. The first key observation is the clustering of the technologies:

    a. The vast majority of Data Collection technologies do <u>not</u> appear in the upper right (most desirable quadrant).

    b. Similarly, most of the Data Transmission technologies do not appear prominently in positions in the upper right quadrant.

    c. For Data Collection and Data Transmission, there are a few *Desirable* (upper left quadrant) technologies.

d. Data Fusion algorithms appear exclusively in the upper right corner, which means that the concepts will have reached a high state of maturity at the conceptual level; they will have maximum benefit to the LPPC.

e. Exploitation technologies are split between the upper right and lower right corners, implying that they will all have high positive impact but that some are significantly more likely to reach maturation.

2. Cost of Proliferation:

a. The Data Collection technologies that are *Desirable* will also be easily leveraged from the commercial sector. (Microcontrollers, Multicore Processors).

b. Of the Data Transmission technologies, hybrid (of RF & optical), will be the most straightforward to leverage.

c. For Fusion & Analysis and Exploitation & Assessment, nearly all of the high benefit technologies, the upper and lower right quadrants, will require moderate (yellow) to high (red) levels of investment from the logistics community in order to proliferate those technologies toward a prediction and preemption capability. (This is perhaps the most significant but least surprising observation.)

3. Integrating Technologies:

a. Business Process Integration is listed as the most critical of the Exploitation and Assessment technologies.

b. TEDS (& other standards based technologies): Although the other integrating technologies either fall in the upper right quadrant or at least the lower right, standards based technologies fall in the upper most left corner. This position indicates a very high probability of maturation yet does not score very highly on its own with regard to Benefit to LPPC.

c. Only in cross-referencing figure 6.3 do we see that the ultimate benefit of such technologies is realized when used as the glue between the other technologies. In that sense, they will expedite the development of advanced sensors into viable systems, finally culminating in intelligent and autonomous sensors webs.

d. Sensor webs: Intelligent and Autonomous sensor webs represent a "killer-application." Though dependent on the device and materials advances (Micro sensors) and some portion of the Fusion algorithms, they represent a pinnacle technology with substantial ramifications.

1. Additional valuable technologies: Although we have highlighted a small subset of the 37 technologies described in chapters 2 through 5, this is not meant to imply that all of the others lack value to the LPPC. In particular, the human interface technologies, Data

Visualization, Virtual Reality, and Gaming Theory all indicate very high scores for benefit to LPPC.

2. Updates and additions to *Signposts*: In addition to the technical breakthroughs listed in the Future Logistics Innovation Themes, the monitoring of the following signposts is suggested:

   a. Development of leakage current reducing materials or techniques, consistent with standard silicon semiconductor fabrication processes. Affects multiple data collection technologies namely, multi-core processors, Memory stickers, and micro-controllers.

   b. Novel techniques for energy scaling of betavoltaics: While proof of principles designs are readily achievable, additional work is needed to increase both energy density and peak power (vice average power) output.

   c. Larger library of prognostic algorithms for increased overall robustness and platform applicability.

   d. Development of robust extensible hardware architectures for prognostics on new platforms.

   e. Implementation of complex prognostic algorithms and predictive analytics on multi-core processors.

   f. Low cost vibration remediation and pointing system advances for Free space optical communication systems.

   g. Transitions electronics for the high to low density data rate in hybrid FSO systems.

   h. Co-site/co-channel interference remediation for MP-CDL. Although the adoption of additional optical links helps reduce this issue, for the foreseeable future, the continued proliferation of RF links for communication, radar, sensing, combat ID, and countermeasures will need to be addressed.

   i. Development of robust data fusion models capable of supporting Distributed Blackboard Fusion. These include adaptation of Social Network Analysis and Omnibus models to Logistical applications.

   j. Maturation of a Distributed Blackboard Fusion Architecture for Logistic application. This will pave the way for the more advanced fusion models and is a prerequisite for intelligent sensor webs.

   k. Development of specific predictive analytics exemplars such as JTIMS, agent-based models, and space/world line analyses.

6.7 Conclusions

Several key points became clear from the research. Technology alone will not drive a comprehensive prediction and preemption capability. Rather, the difficult homework of preparing infrastructure, both real and virtual, must occur in parallel.

1. While the hardware-centric R&D initiatives pertinent to an LPPC tend to have much in common with Operations and Intelligence, the majority of investment from Logistics will be needed in Fusion & Analysis and Exploitation & Assessment, where current R&D is limited.
2. Commercial, University, DOE, and DoD research and development could be exploited to achieve an Army LPPC. These areas include:
    a. Advanced Computing
    b. MEMS/NEMs
    c. Nanoscience and nanomaterials
    d. Alternative energy sources re photovoltaics, advanced batteries, fuel cells, etc.
    e. Heavy vehicle reliability and power
3. Exploitation of these sources of advanced R&D and their ensuing products will be required in order to achieve and field an Army LPPC. Partnerships, CRADAs, Interagency Agreements, and interagency technology transfers will need to be established and exploited to achieve an Army LPPC.
4. The technologies and resulting advanced products that are required to achieve an Army LPPC are:
    a. Data Collection
        i. Memory “Stickers” Mem*
        ii. Multi-Core microprocessors*
        iii. Physics of Failure (POF)
        iv. Transducer Electronic Data Sheets (TEDS*)
        v. Microscale/Microfabricated Sensors
    b. Data Transmission
        i. Multi-Platform Common Data Link (MPCDL)*
        ii. Hybrid Free Space Optical Communication (Hyb)
        iii. Free Space Optical Communication (FSO)

c. Data Fusion and Analysis
    i. FCA
    ii. Intelligent / Adaptive Sensor Networks (ISW/ASW)*
    iii. Simulations-based Course of Action (SCOA)
    iv. Reflexive Analysis
    v. SNA
    vi. Cyc-based Virtual Logistician

d. Exploitation and Assessment
    i. Web Services (e.g. Service Oriented Architectures)
    ii. Business Process Integration (BP)*
    iii. Predictive Analytics (PA)

NOTE: * For an LPPC, these technology areas/products require Logistics domain intervention to achieve desired end-state technology/products for insertion into the logistics enterprise. These are the areas that Phase III should focus on as they assess technology development issues.

5. Regarding Cost:

a. Data Collection technologies stand to leverage the most from the commercial sector. This is not surprising since substantial investment is included in the areas of microelectronics, sensors, and portable power.

- This means that much of the hardware will be available for use in logistics applications and that the primary investment required from the Logistics community lies in the area of maintaining technical cognizance and—where possible—influence in the early development of standards in order to better reflect the Army's need to significantly reduce the life cycle costs of platforms.

- For platform health management, Physics of Failure algorithms will be critical and available for many of the platforms of interest. Complexity of programming, and verification & validation, will keep it from being proliferated as a commodity, unlike memory.

b. Data Transmission will be an essential area for LPPC's relationship to the Operational and Intelligence communities. Unlike the Data Collection, Fusion, and Exploitation technologies, which will have many features unique to Logistics (the data elements may be unique to log but the analytical logic in fusion and analysis tools is often identical to that required by other users), Transmission technologies will an imperative for co-development since that one capability will connect all three communities and be most visible in the MP-CDL.

c. For Fusion & Analysis and Exploitation & Assessment, the underlying mathematics for prediction represents the most technically challenging subject. It is clear that when we are discussing supply-side Predictive Analytics or Distributed Blackboard Fusion, a substantial effort will be required to bring these types of algorithms to fruition for a dynamic military environment. The sets of technologies ascribed here will also enable this to be performed in a distributed architecture that minimizes data payload and centralized processing.

   - Dependencies of the Fusion & Analysis algorithms: In the case of Fusion & Analysis, although all of the technologies are recommended, several of the more far reaching ones are dependent on the others. Hence, in the short term, the investment should not be evenly distributed, but, rather, focused on the early enablers.

6. Integrating Technologies:

   a. Business Process Integration is the key to capitalizing on all of the other technologies. It represents all of the "homework" that needs to be done to appropriately digitize the necessary information that serves as inputs to the LPPC.

   b. Standards based technologies (e.g., TEDS): While not ostensibly the most thrilling "technology" aspect of LPPC, users need to participate in the development of collection, transmission, and fusion standards (e.g., industrial working groups and committees) in order to ensure that their vision and needs are met as the technologies evolve. Early participation is more important than heavy participation (i.e., relegating oneself to a pure consumer will leave that consumer unrepresented in the final set of capabilities). The investment advantage is that relatively few resources are necessary to maintain this type of technical cognizance.

7. As the final interface between the end-user and the data, developments in the human interface technologies will be highly formative to the development of an LPPC. In this case they represent more than just the user interface; rather, they also entail the first opportunity to digitize the data collection, expediting all portions of the process that follow. They will exhibit maximum benefit when the other (highlighted) capabilities are in place. For example, Virtual Reality will provide significant benefit to the logistics enterprise. That capability will in turn be expedited for large displays with the advent of Flexible Displays. Their full potential will be fulfilled when the underlying business processes and analytics are in place.

8. The Soldier: Regardless of the technical advances that will be made on all of these fronts, the Soldier will still be the most critical enabler. Intuitive use of the resulting tools will remain the most valuable practical aspect for enabling prediction. In order to ensure

efficient use, the interfaces must be intuitive enough to obviate the need for instruction manuals. A large effort must be spent in developing system interfaces that can quickly and intuitively learn in order to obtain value and meaning from LPPC actionable knowledge. Without an aggressive prediction and preemption program, the Army's combat capability will be sub-optimized and warfighters will be subjected to increased uncertainties on the operating environment.

In some cases, the requirements will indeed drive development. For others, though, it will make the most sense to leverage ongoing commercial advances. While it is one thing to delineate where the Army logistical model departs from the commercial (linear), it is quite another to determine how best to construct a predictive logistical enterprise that is consistent with both operating regimes (linear and nonlinear). In the end, the effort will result in what might be described as an engineering control loop. Each prediction will drive the specific analytics that are necessary to realize the prediction; those analytics will in turn cyclically drive the technologies necessary to realize the analytics (i.e., algorithms, models, simulation, data, and network communications).

Thus, the end state will be a toolbox of hardware, software, and algorithms that continually updates with each new prediction, based on assessment. The end result of this paper is to recommend a first set of those tools that will enable such a prediction capability.

6.8 Recommendations to Phase III Team

Figure 6.1 described representative cross-cutting technologies (products) that eventually led to a substantial supply capability for the consumer at-large. In this same fashion, we summarize the results of this paper in figure 6.7, "The Roadmap of Essential Prediction Technologies." It represents the LPPC roadmap with the substantial technical milestones that will be achieved within the 2020-2030 timeframe displayed within the context of the four components of an LPPC covered in chapters 2 through 5. The technologies circled in red, and discussed in paragraphs 6.4.1-Integrated Technologies Rankings, specify those that have substantial cross-cutting aspects such that investment in that one technology provides benefit to more than just one component of an LPPC. Hence, the circled areas are those that we recommend that the Phase III focus their efforts on. The other areas are driven by the commercial sector, the national labs, academia, or other parts of the federal sector and will happen without the Logistic Domain's intervention. Underlying all of the technology areas is an implicit requirement for standards and open architectures for any LPPC project, procurement or R&D effort. Finally, these technologies form the basis of the Phase III effort.

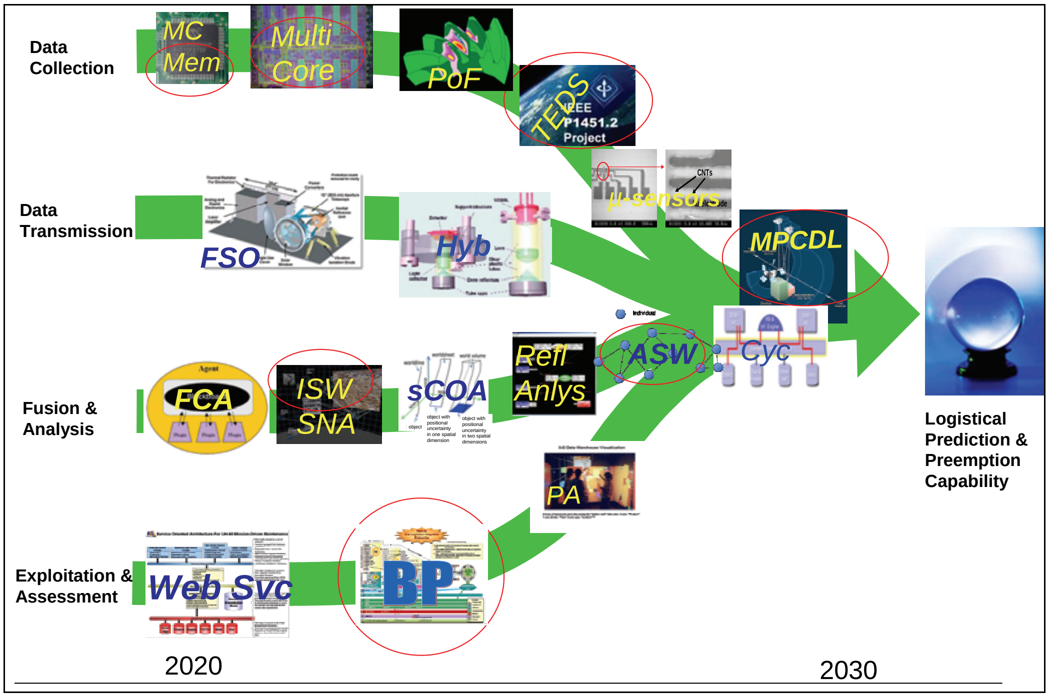


Figure 6.7. Roadmap of essential prediction technologies.

In support of an LPPC, based upon the technologies discussed in this Phase II document, the following recommendations are made:

1. The LIA in coordination with the Army and Joint Logistic Domain should establish methodology to determine business relationships and processes for obtaining the data, information, and knowledge elements listed in appendix B as a matter of routine.

2. The LIA in coordination with the Army and Joint Logistic Domain should identify those specific Army/Joint Logistical Business Processes (i.e., logistical business ontologies) that directly affect the 19 undesirable events/situations and the associated data elements that must be provided by those business processes to the LPPC.

3. Phase III should focus its efforts on developing and fielding an LPPC that mitigates the list of 19 events in table 1.1.

4. The LIA CLOE Project should document the baseline requirements for an enterprise service oriented architecture that focuses on web technologies and business process integration.

5. The LIA in coordination with the Army and Joint Logistic Domain should identify the research and development initiatives required to develop, test, and verify new predictive analytics needed for an LPPC. Agent Based Modeling and Distributed Blackboard Fusion architecture are recommended as starting points to initiate definition of the tradespace between the types of predictions needed, algorithm appropriateness, and extensibility.

Collaboration with Army Research Laboratory subject matter experts is also recommended in this area.

6. As part of the Prediction demonstration, LIA should develop a departmental or unit level set of prediction capabilities using open architectures and standards such that an LPPC can be built in a modular fashion.

7. To increase the visibility of the LPPC requirements LIA in coordination with the Army and Joint Logistic Domain should attended standards and technical meetings pertinent to prediction. While subject matter expertise may be an initial concern, presenting an informational presence as a customer for the emerging technologies in transmission and collection would likely be welcome input. These meetings should include but are not limited to, the technologies discussed in chapters 2 and 3: IEEE 1451.4 for Transducer Electronic Data Sheets, emerging communication standards, e.g. 802.15.4, and Multi-Platform Common Data Link.

8. LIA should increase its collaboration with the Army R&D Community in an effort to get new R&D initiatives resourced and producing technologies and advanced products that are not currently be driven by outside forces i.e., industry. This will require active participation in the Army's R&D process from research initiative formulation through the review and approval process to the SDD Phase and eventual fielding. Areas for the Phase III to focus on are:

   a. ARL: advanced sensors and materials

   b. CERDEC: data fusion and analysis for both on-platform and off-platform)

   c. TARDEC and AMRDEC: embedded physics of failure prognostics (on-platform sensors, data collection, fusion, analysis, and transmission of analysis findings off board the platforms)

9. The LIA in coordination with the Army and Joint Logistic Domain should assist and facilitate cooperative exploitation of R&D and technology transfers from the DoD and DOE laboratories. Discussions between the Phase III and Phase II teams could lead to a high level listing of current performers.

10. LIA in coordination with the Army and Joint Logistic Domain should assist and facilitate an active dialog with the Army S&T community and Acquisition Corps in developing an Army strategy for eventual acquisition and fielding of the Army LPPC.

---

[120] http://folding.stanford.edu

[121] J. B. Posthill, D. E. Dausch, C. B. Watkins, M. L. Lee, J. Lewis, M. Mantini, R. Venkatasubramanian, "Assessment of Micro-components for Energy Harvesting from Thermal Gradients, Light, and Mechanical Vibrations," Government Microcircuit Applications and Critical Technology Conference 2007

INTENTIONALLY LEFT BLANK.

Appendix A. Vignette

Concept of Operations. The following vignette illustrates in a future notional operational environment the desired functional capabilities relating to prediction and preemption through the use of advanced planning and decision support systems/tools. It relies heavily on the Modular Force Logistics Concept (MFLC) and Operational Level Logistics Command (OLLC) for the operational context through 2024.

Overview. There is political and social unrest between the sovereign nations of Ageori and Janazer. (See figure A-1) Ageori is a secular state with close ties to the west, especially the U.S. Janazer, however, is an extremist state. Extremist organizations have instigated anti-U.S. sentiment in the region and have sponsored insurgencies into Ageori. Deterioration of political and diplomatic approaches is imminent. Ageori is expected to officially request help from its western partners. As a result and viewed as a possible area of deployment, SOF have been inserted into the area of operations through and with the support of the government of Ageori. Conditions continue to deteriorate, as insurgents resort to political assassinations and the use of improvised explosive devices throughout Ageori to instill fear and destabilize the Ageori government. Insurgent forces have quickly established a foothold in the east and continue to use their informational and military power in their efforts to gain control of the eastern region of Ageori. Ageori finally requests assistance in restoring its territorial integrity and the rule of law.

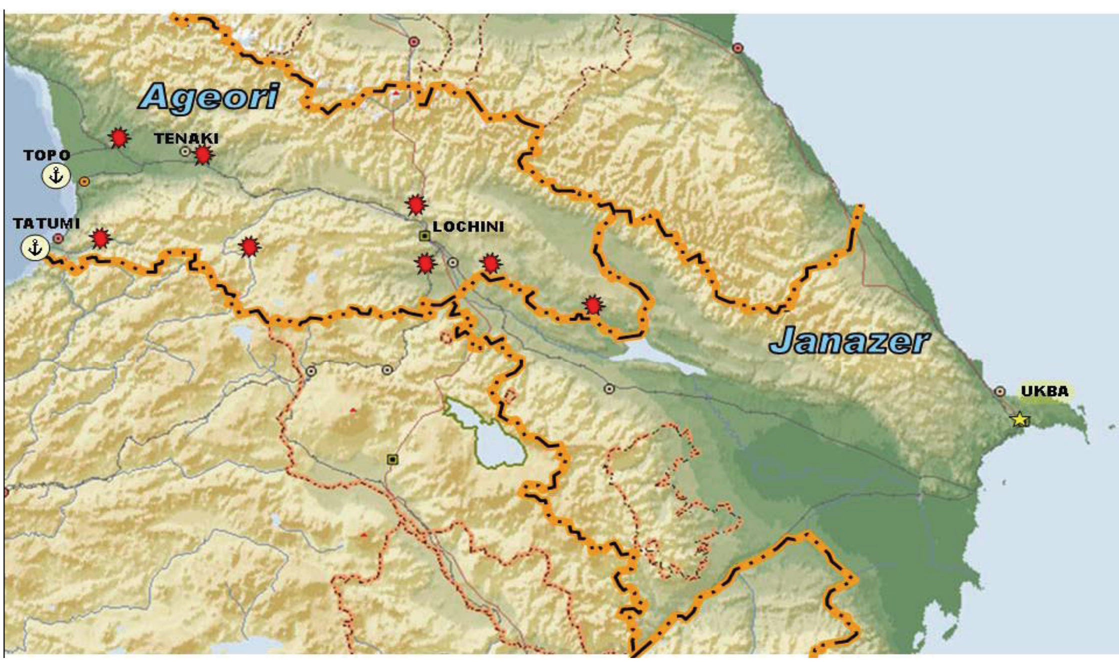


Figure A-1. Depiction of the nations Ageori and Janazer

Pre-Deployment

While tensions increase in Ageori, planners tailor the force using predictive deployment, employment and sustainment (DES) tools as part of their mission analysis. The JFC, through the DES tools, has already alerted the TSC of the critical information regarding the operation. Force sustainment requirements have been modeled for multiple force employment options against the forecasted RDDs. Risk Assessment based on each mode of travel and critical supply category is calculated based on the commander's concept of operation, support and intent. Units to deploy are notified and begin preparations for movement.

The Logistics Common Operating Picture (LCOP) and associated software applications are also providing visibility of data and decision support tools needed by the key logistics community of interest players to manage the end-to-end logistic and distribution system that will support the force, including coalition units, during all phases of the operation. This will be especially important during operations to seize the initiative as well as during stability operations. Focus is on predicting consumption and equipment status based on expected operations tempo, historical trends for similar missions, and actual platform data that is being posted to the network on a continuous basis. There is also focus on establishing priorities and assessing the availability and capacity of assets to sustain and support continuous operations after 72 hours. Beyond this time, forces will require tactical resupply using a combination of replenishment operations orchestrated by the Brigade Support Battalions as well as direct aerial resupply as appropriate and available from CONUS, sea based assets, or intermediate staging bases, if used. Planning tools will fuse disparate data into meaningful and actionable information used to develop viable concepts of support that are flexible enough for dynamic restructuring during mission execution.

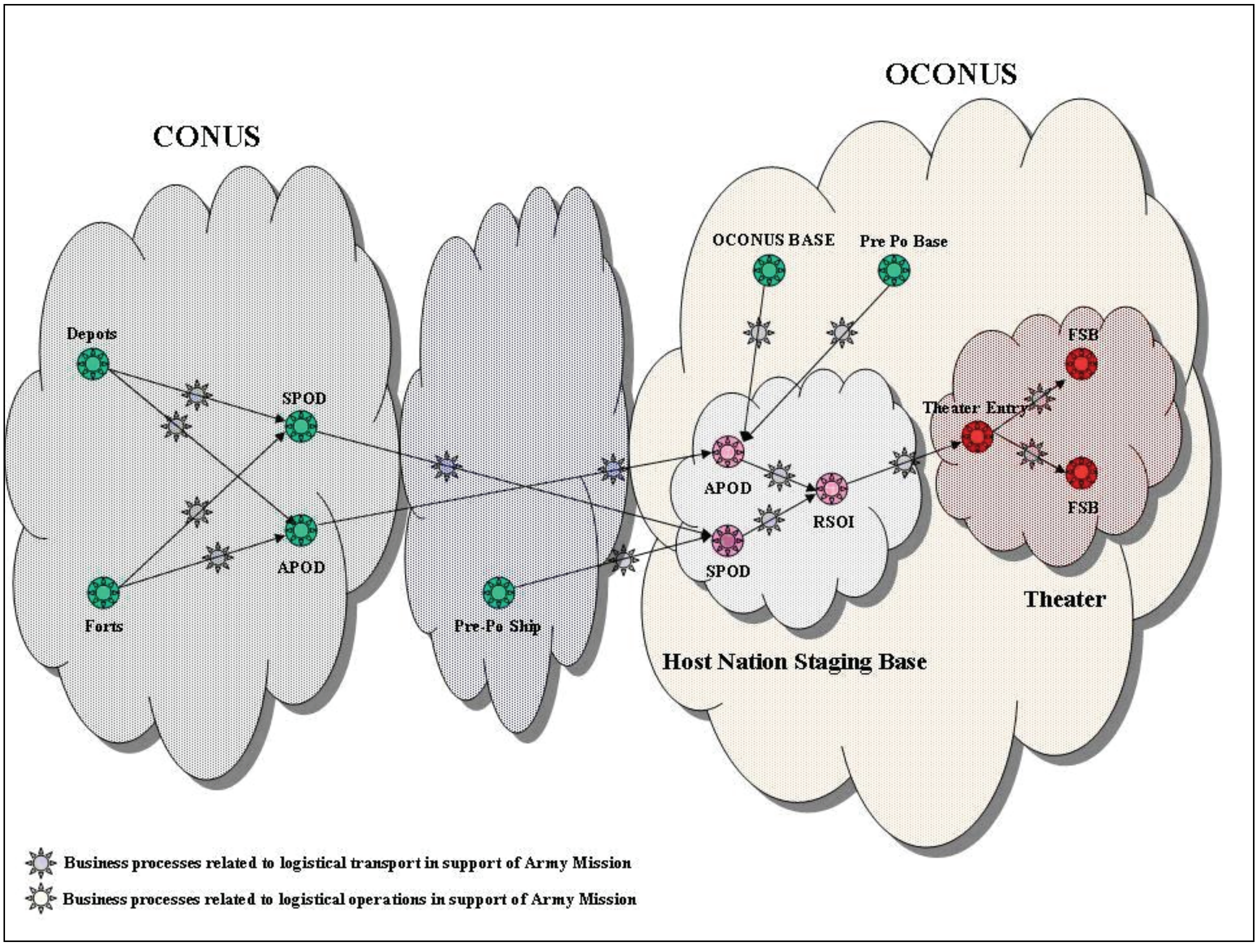


Figure A-2. Business processes in support of an Army mission

SOF have been inserted into the area of operations. With the support of the government of Ageori they have established a Joint JSOTF in the vicinity of Lochini. The JFC has directed the TSC to provide support to deployed SOF units. Points of entry have been identified and reconnoitered by SOF teams already in theater and the TSC has directed one of its Expeditionary Sustainment Command (ESC) HQ to deploy along with a sustainment brigade to conduct sustainment and initial port opening operations. The Theater Opening package, along with its mission, has been identified and is given priority of movement.

Operational Construct

Shaping Operations.

Deployment Execution. SOF operations continue and, as events develop, it becomes apparent that diplomatic and political efforts to quell differences will fail. Ageori requests military and financial assistance from its western partners; the U.S. assumes responsibility as the lead nation. This aggravates the extremist faction and raises the number of hostile incidents dramatically.

ESC deploys into the theater and establishes command and control of logistic operations and theater opening functions. The ESC is an advanced C2 element of its parent TSC headquarters that may or not fully deploy into theater. It provides the same range of capabilities but not to the scale of the TSC Main. It maintains connectivity with the TSC Main in order to receive assistance in such areas as planning, distribution management, and materiel management. The ESC commands those logistic units deployed until or if the TSC main deploys. It finalizes planning for the distribution hubs and convoy support centers to ensure concept of maneuver supportability.

Deter and Engage. Allies continue to seek political solutions to prevent aggression in the region but have also increased deployment preparations. Coalition/interagency teaming as well as mission/force requirement identification is taking place as force leaders use this time to unify purpose and effort.

Seize the Initiative. Early entry operations begin in theater beginning with a Marine Expeditionary Unit (MEU) to deploy in and around the ports of Topo and Tatumi to provide local security for support operations. Because the Marine systems are compatible with Army systems—the result of decades of efforts at interoperability—their logistics status is available through the Logistics Services portion of the GIG, portaled through LandWarNet, the Army contribution to the GIG. Logistic services, originally a loosely-coupled enterprise service of the GIG, and not on par with the real-time capability of the GIG's warfighter grid, were given equal status in 2016 when FCS was fielded. Real-time sustainment data is now provided within and across Service domains.

A proliferation of platform on-board sensor data is made available immediately in the Net-Centric Operational Environment (NCOE), and routed to the subscribed participants in the-theater. COP application functionality fuses various sensor reports as received, into actionable track entities by using sophisticated software that adjusts the time and geospatial bases of the disparate information into a common reference frame to be displayed for JTF user's situational awareness. Raw data is available on demand for analysis as required. This is enabled by the proliferation of on-board sensors that provides trend data on platform and force readiness for all major combat systems.

By 2012 the Army's Condition Based Maintenance Plus (CBM+) Program achieved enterprise-wide predictive maintenance and anticipatory logistics capabilities by connecting self-reporting, self-diagnosing platforms to the logistics enterprise, enabled by the end-to-end architecture, an expansion of the Common Logistics Operational Environment effort begun early in the millennium.

Small, embedded, data collection systems have been developed with sensors that monitor the environmental and operational conditions of its platform. Through the collection and processing of the data through prognostic algorithms, the health/operational condition of the platform is reported through a mobile–adaptable mesh network using a combination of optical and RF links *back to a central location for the fusion of the data to provide an overall situational awareness of the operational condition of the platforms.*

The MEU, initially supported from a sea-base during initial entry, will receive support during subsequent operational phases from the Army in fulfillment of its mandate to provide support to other components of the joint force. The MEU is followed in theater by the 3rd Division and Coalition Brigade forces. The Division comprises 1 FCS unit, 3 conventional HBCTs, and an SBCT. After these units close on the various points of entry, they begin preparation for movement to their forward positions in Tactical Assembly Area (TAA) LIBERTY. The TSC engages with the COCOM staff to develop logistic plans, coordinate support for JTF and coalition units, and establish linkages to and relations with coalition and HN organizations.

Innovative improvements in COP applications have solved earlier problems wherein sensor reporting of vehicle platform positions resulted in multiple representations of the same platform with differing fidelity and time basis causing confusion and mistrust of COP visualizations and data fusion.

However, of forward positioned land and afloat assets scheduled for movement and distribution to Divisional units before onward movement from the APOD present an unresolved issues. Taking into account Leave Behind Equipment (at home station) by the individual BCTs, requirements were determined by HQDA G3/G4 in coordination with the Army Sustainment Command (ASC) prior to deployment. Expected shortages were matched against forward positioned assets whose locations and equipment serviceability status are continuously transmitted to the Common Operating Picture (COP) via advanced RFID/AIT technologies. However, actual equipment deployed does not exactly match planned deployments for a variety of reasons. There were also some maintenance failures in deployed equipment prior to out loading.

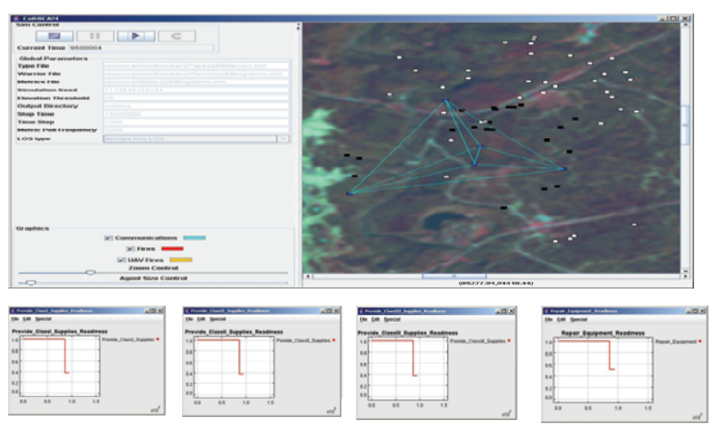


Figure A-3. Complex Reactive Behavior Combat Agent Model (CoRBCAM) is an agent-based software suite that was developed as a tool for fusion and analysis of information in order show the interaction relationship of independent actions.

Catastrophically, many of the vehicles/equipment sustained serious damage when the ship hit a mine while approaching the port. Using decision support tools with advanced analytical capabilities, in combination with dynamically transmitted platform prognostics data, the ESC fuses data from both Divisional and newly delivered platforms to determine precisely what shortages exist, calculates current readiness rates for each weapon system, and then provides alternative courses of action to repair and/or replace critical equipment- examining in-theater, as well as reachback options.

An operational capability of the Net-Centric Operational Environment (NCOE) is to provide real-time or near-real-time data, information, and knowledge supported by applications and services. This is accomplished by employing a variety of options, including forward deployment of small footprint applications capable of delivering instantaneous information, and a "reachback" capability to centralized centers for a more detailed and thorough analysis.

Embedded data collection systems have been incorporated into the vehicles/equipment over the last decade. This system is capable of monitoring and prognosticating the health and operational situation on its platform. A quick survey of the damage is conducted over a local mesh network to assess the damage. With an FSO link, the information is quickly provided to the JFC. Additional information on other assets are communicated through a wide area network in order to establish the impact of the ship-mine incident.

Existing guidance from the JFC is 96% equipment readiness (EOH and ES) prior to leaving the TAA. Complicating this is the fact that the Division includes a mix of FCS, conventional BCT and SBCT units- making cross leveling of critical platforms impractical. This automated analysis reveals that current readiness is only 92%. Further, Stryker operational availability is only at 90%.

This is a problem, as the Stryker is critical to the main effort. Further, OPTEMPO and METT-TC factors are expected to further decrease readiness- more reason to start as close to the mandated 96% as possible. PREPO platforms and intelligent-agent technology enablers embedded in each platform enable real-time identification of vehicle and equipment failures that are picked up by both local Divisional (and Brigade) as well as enterprise IT applications.

Decision support applications deployed with BCT, Division, and TSC provide the means to analyze readiness of platforms and units quickly, albeit without the full robustness provided via reachback. Courses of action that recommend precisely what platforms can be shifted between or amongst units to achieve desired levels of readiness based on priority of unit missions are presented for decision. Corresponding impacts on units giving up equipment is known as well. Instantaneous what-if analyses are used to make quick decisions on internal division transfers. Since this is only useful for units with similar equipment, namely the HBCTs, recommended solutions for the Stryker Brigade are being worked up via reachback capabilities.

The Knowledge Management Cell of the CONUS-based TSC is alerted and reacts. Within one hour, courses of action that address total asset shortfalls with associated predicted levels of confidence are complete. Worldwide asset locations, status, and availability as well as air and sea transportation options are explored autonomously using software agent technology- perfected with the end of FCS fielding in 2017. Trade-off and what-if analyses are conducted with emphasis in meeting a not-to-exceed time-definite delivery of 72 hours- beyond which increased operational risk threatens mission objectives. The completed analysis results in 3 recommended courses of action:

COA 1: 100% of FCS platforms and Stryker shortages will be available NLT 80 hours with 93% confidence. Accomplishment is dependent on both C17 airland delivery to the AO plus arrival of additional Joint High Speed Vessels operating in a contiguous theater.

COA 2: 100% of pacing items available NLT 71 hours with 86% confidence. Dependent on 3 additional C17s.

COA 3: 100% pacing items delivered NLT 56 hours with 65% confidence.

Each COA is dependent not only on "time drivers" but a number of other variables e.g., ground transportation, weather, sea state, enemy activity etc., all of which have distinct probabilities of success. The JFC believes COA 1 is viable and plans accordingly. Achievement of predicted time-definite delivery is of paramount importance to the JFC's ability to plan and make decisions about the upcoming operation. Equal in importance to the prediction of delivery is meeting this schedule, and thus, preempting mission failure that might occur without introduction of this solution.

Decisive Operations.

Offensive Operations. Responding to the Ageori request, the U.S. leads a coalition force to assist Ageori in actions against extremist insurgents. The ARFOR, comprising one division and a coalition brigade conducts a two-axis offensive operation into Janazer. Convoy force protection issues and mountainous terrain are expected to make it difficult for combat service support convoys to keep up with the SBCT. Alternate route planning is deemed critical.

As such, the entire 120 hours of the operation is constructed in a geospatial COP view and collaboratively distributed via the network to all planners and operators. Each planning domain has opportunity to modify the plan based on their requirements to support it. Reachback capability is used to run each version of the plan through powerful planning algorithms in the decision support system to identify plan shortfalls based on current conditions provided in real-time. What-if analyses are run and based on predicted results, alternate routes are selected, analyzed and folded into course of action recommendations for route selection.

The attacks begin along two major road systems leading east. The FCS, 1 BCT and the SBCT conducts the main attack along the southern axis to ORANGE, while the Coalition Brigade and 2 BCT conduct a supporting attack on the northern axis, followed by the 3rd BCT in reserve.

As the plan is being executed, a JTF plan simulation is initialized, and updated by Blue Force Tracking (BFT) for the COP, as well as inputs from operators based on emergent voice and other communications. The plan is made available simultaneously on the network, and progress is monitored by all echelons in the COP real time view. One convoy, hauling critical fuel and ammunition, makes a major navigation error, jeopardizing the rate of the SBCT advance. Alert systems that detect deviations from the planned route feed adaptive decision support applications that begin analysis of alternative COA. Automatic notifications are passed to the JTF and to the effected units.

The convoy receives re-direction orders suggested by the plan decision support application for a previously analyzed route that allows it to make the planned rendezvous with the SBCT. The overall effect of this change in operational play is evaluated by net-centric planning applications, an alternate course of action for the operation is proposed, collaboratively accepted by the JTF HQ and subordinate units and disseminated via the network.

HBCT1 has an intermediate objective, from which they will mount the final assault on OBJ Orange. To reach the objective the HBCT has to move through the Ja Fajan escarpment. The escarpment, a natural shelf nearly 250 feet high running roughly east to west, can only be negotiated via a lone road. On the approach to the escarpment, the road forms a single-lane causeway between a marsh on one side and an inland lake on the other. The climb up the hill is at a 12 percent grade in some areas. Because the terrain confines the brigade to the causeway that skirts the lake through soft ground, the commander expects a sharp fight at the escarpment. Intelligence places paramilitary forces in battalion size at the escarpment.

Figure A-4. As part of the Intelligent Sensor Web, the UAS detection network surveys the Ja Fajan escarpment & detects paramilitary forces in place. With its multi-communication modes, the information is relayed simultaneously to the HBCT1 battalion & JFC. Due to the integration of the JTIMS tool, an agent- based model, and Reflexive theory based simulation, a COA is developed in real-time for alternate deploy of supplies to support the mission.

The HBCT commander determines the need to ensure supportability of a plan that is modified based on new and current intelligence. All logistics support plans are checked for viability to support the operational plan enroute to the escarpment using decision aids and predictive analysis tools. Requirements for transportation assets, especially those for fuel, and ammunition are validated. Availability and employment of Heavy Lift Vertical Takeoff and Landing (HLVTOL) and/or fixed-wing precision aerial resupply options are evaluated against possible missions.

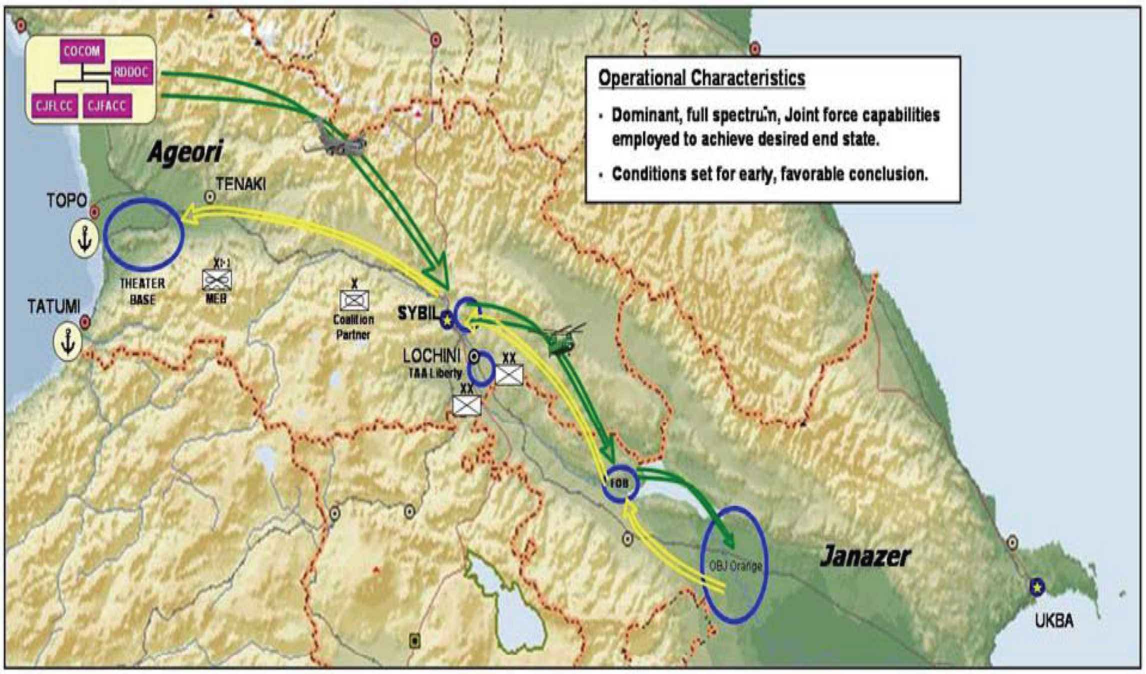


Figure A-5. Depiction of possible aerial resupply missions

Courses of action for resupply during heavy engagement are developed. All of this is completed on-the-move, as the HBCT approaches the escarpment. All indications point to complete readiness to undertake the mission without pause—a prime goal of the predictive and decision support capabilities developed for the modular force of 2025. All attacks are successful and all allied forces consolidate on the objective and conduct preparation to continue follow-on attacks to seize the capital city Ukba.

INTENTIONALLY LEFT BLANK.

Appendix B. Tables Describing Requisite Prediction Data Elements

Table B-1. Mission information.

Requisite Data/Information/Knowledge Elements		Source of Data/Information/Knowledge Elements
Mission Task Force (Blue Force)		G3 Plans Cell
Mission Start Time		G3 Maneuver and Support
Mission Duration		G3 Maneuver and Support
Mission Terrain		G3 Intel/Surveillance Section
	Terrain Impedance to Land Convoys	G3 Engineer Cell
	Terrain Impedance to Air Operations ("convoys")	G3 Maneuver and Support/Sustainment Section

Table B.2. Enemy information.

Requisite Data/Information/Knowledge Elements		Source of Data/Information/Knowledge Elements
Enemy Size		G2 and G3 Intel Surveillance Maneuver and Support
Enemy Location		G2 and G3 Intel Surveillance
Enemy Intent		G2 and G3 Intel Surveillance
Enemy Tactics		G2 and G3 Intel Surveillance/Maneuver and Support
Enemy Threat to Land Convoys		G2 and G3 Maneuver and Support
Threat to Air Operations		G2 and G3 Intel Surveillance
Projected Combat Losses		G2 and G3 Plans
	Combat Equipment	"
	CSS Equipment	"
	CS Equipment	"
	Fuel	"
	Water	"
	Ammunitions	"
	Portable Energy Sources	"

Table B-3. Weather (Wx) information.

Requisite Data/Information/Knowledge Elements		**Source of Data/Information/Knowledge Elements**
Weather (Wx)		G3 and Air Force
	Current	Intel
	Prior Seven Days	Intel
	Forecast Now through Mission Duration Plus 48 Hours	Intel
	Wx Impedance to Land Convoys	Intel & Engineer Sections
	WX Impedance to Air Operations ("convoys")	Intel & Tac AirController

Table B-4. Munitions information.

Requisite Data/Information/Knowledge Elements		**Source of Data/Information/Knowledge Elements**
Preferred Munitions		G3 Plans Cell
	Number Required Initial Load of Preferred Munitions	G3 Maneuver and Support
	Location(s) of Preferred Munitions	G4 Maneuver and Support
	Number Required for Resupply of Preferred Munitions	G3 Maneuver and Support/Plans Cell
	Location(s) for Resupply of Preferred Munitions	G4 Sustainment/Plans Cell
	MHE Requirements	G4 Sustainment Section
	Transportation Requirements	G4 Sustainment Section
Substitute Munitions		G3 Sustainment Section/Plans
	Number Required Initial Load of Substitute Munitions	G3 Plans Cell
	Location(s) of Substitute Munitions	G4 Maneuver and Support
	Number Required for Resupply of Substitute Munitions	G3 Maneuver and Support/Plans Cell
	Location(s) for Resupply of Substitute Munitions	G4 Sustainment/Plans Cell
	MHE Requirements	G4 Sustainment Section
	Transportation Requirements	G4 Sustainment Section/Plans

Table B-5. Fuel information.

Requisite Data/Information/Knowledge Elements		**Source of Data/Information/Knowledge Elements**
Fuel Quantity Required for Mission		Plans Cell/Sustainment
	Fuel Quantities Required for Initial Fueling	G4 Sustainment Section
	Fuel Location(s)	G4 Maneuver and Support/Sustainment Sections
	Fuel Quantities Available	G4 Sustainment Section
	Fuel Quantities Required for Resupply	G4 Sustainment/Plans Sections
	Location(s) for Fuel Resupply	G4 Sustainment/Maneuver and Support
	MHE Requirements	G4 Sustainment Section
	Transportation Requirements	G4 Sustainment Section/Plans

Table B-6. Sustenance information.

Requisite Data/Information/Knowledge Elements		**Source of Data/Information/Knowledge Elements**
Water Quantity Required for Mission		Plans Cell/Sustainment Section
	Water Quantities Required for Initial Issue	G4 Sustainment Section
	Water Location(s)	G4 Sustainment/Maneuver and Support
	Water Quantities Available	G4 Sustainment
	Water Quantities Required for Resupply	G4 Sustainment Section/Plans Cell
	Location(s) for Water Resupply	G4 Sustainment/Maneuver and Support
	MHE Requirements	G4 Sustainment
	Transportation Requirements	G4 Sustainment
Rations Quantity Required for Mission		Sustainment Section/Plans Cell
	Ration Quantities Required for Initial Issue	G4 Sustainment Section/Plans Cell
	Ration Location(s)	G4 Sustainment/Maneuver and Support
	Ration Quantities Available	G4 Sustainment
	Ration Quantities Required for Resupply	G4 Sustainment/Plans Cell
	Location(s) for Ration Resupply	G4 Sustainment/Maneuver and Support
	MHE Requirements	G4 Sustainment
	Transportation Requirements	G4 Sustainment/Plans Cell

Table B-7. Medical information.

Requisite Data/Information/Knowledge Elements		**Source of Data/Information/Knowledge Elements**
Medical Supplies		Sustainment
	Medical Supplies Quantities Required for Initial Issue	G4 Sustainment/Plans Cell
	Medical Supplies Location(s)	G4 Sustainment
	Medical Supplies Quantities Available	G4 Sustainment
	Medical Supplies Quantities Required for Resupply	G4 Sustainment/Plans Cell
	Location(s) for Medical Supplies Resupply	G4 Sustainment/Maneuver and Support
	MHE Requirements	G4 Sustainment
	Transportation Requirements	G4 Sustainment/Plans Cell
	Environmental Protection Requirements	Medical Corps/Sustainment

Table B-8. Portable energy sources (batteries & fuel cells).

Requisite Data/Information/Knowledge Elements		**Source of Data/Information/Knowledge Elements**
Portable Energy Sources Required for Mission		
	Portable Energy Sources Quantities Required for Initial Issue	G4 Sustainment/Plans Cell
	Portable Energy Sources Location(s)	G4 Sustainment/Maneuver and Support
	Portable Energy Sources Quantities Available	G4 Plans Cell
	Portable Energy Sources Quantities Required for Resupply	G4 Plans Cell/Sustainment
	Location(s) for Portable Energy Sources Resupply	G4 Sustainment/Maneuver and Support
	MHE Requirements	G4 Sustainment
	Transportation Requirements	G4 Sustainment / Plans Cell

Table B-9. Lift resupply information.

Requisite Data/Information/Knowledge Elements		Source of Data/Information/Knowledge Elements
Strategic Lift Resupply Required for Mission		
	Air – TPFDD Flow	G3, USTRANSCOM, Air Force/Sustainment/Plans Cell/Engineer
	Sea – TPFDD Flow	G3, USTRANSCOM Sustainment/Plans Cell
	Threat to Strategic Airlift	G2, G3, USTRANSCOM, Air Force/Sustainment/Plans Cell
	Threat to Strategic Sea Lift	G2, G3, USTRANSCOM/Sustainment/Intel and Surveillance
	Location(s) for Fuel Resupply	G4 Sustainment/Maneuver and Support
	MHE Requirements	G4 Sustainment
	Transportation Requirements	G4 Sustainment
Theater Level Lift Resupply Required for Mission		
	Air	G3 Sustainment/Intel/Maneuver and Support
	Land	G3 and G4 Sustainment/Intel/Maneuver and Support
	Sea	G3 Sustainment/Intel/Maneuver and Support
	MHE Requirements	G4 Sustainment
	Transportation Requirements	G4 Sustainment/Plans Cell

Table B-10. Equipment status information.

Requisite Data/Information/Knowledge Elements		Source of Data/Information/Knowledge Elements
Projected Status of Equipment To be Used In Mission		
	Combat Equipment	G3 and G4 Sustainment/Plans Cell
	CSS Equipment	G3 and G4 Sustainment/Plans Cell
	CS Equipment	G3 and G4 Sustainment/Plans Cell
Number and Type Parts Required (Projected)		G4 Sustainment/Intel/Plans
Requisite Tools (Projected)		G4 Sustainment/Plans Cell
	Location(s), number, and type	G4 Sustainment
	Transportation Requirements	G4 Sustainment/Plans Cell
	MHE Requirements	G4 Sustainment
	Location(s), number, and type	G4 Sustainment
Requisite Special Tools (Projected)		G4 Sustainment/Plans Cell
	Location(s), number, and type	G4 Sustainment
	Transportation Requirements	G3 Sustainment
	MHE Requirements	G4 Sustainment
Requisite MOS(es) (Projected)		G4 Plans/Maneuver and Support/Intel / Sustainment
	Location(s), number, and type	G4 Sustainment/Plans Cell
	Transportation Requirements	G4 Sustainment/Plans Cell

Appendix C. Glossary

1-4-2-1 Strategy. Calls for four levels of priority; 1-Defend the homeland against direct attack; 4-Assure, dissuade, deter in and from four forward regions; 2-Surge jointly to swiftly defeat adversaries in two overlapping focused campaigns; 1-Preserve the President's option to decisively defeat one of these adversaries in a conclusive campaign

10-30-30. 10 days to Seize the Initiative, 30 days to Decisively Defeat, 30 days to Redeploy

Acquisition Strategy. A plan that documents the acquisition planning process and provides a comprehensive approach for achieving goals established in materiel requirements. It summarizes other management planning documents (including the supportability strategy), Government-furnished materiel to be provided, the acquisition strategy, organizational resources (money, time, people), and schedule. (AR 700-127, 19 Jan 06)

Action. A structured behavior of limited duration.

Active Badges. A battery powered badge worn by a person that transmits in the infrared portion of the electromagnetic spectrum. The active badge is used to provide information about the location of people. (LIA Future Logistics Innovation Themes Document, 2006)

Activity. A structured behavior of continuous duration.

Air Interdiction. The ability to conduct operations to destroy, neutralize, or delay the enemy's military potential before it can be brought to bear effectively against friendly forces at such distance from friendly forces that detailed integration of each air mission with the fire and movement of friendly forces is not required. (Modified JP 1-02)

Air & Space Defense. The ability to detect, deter, prevent, and defeat air, missile, and space threats against the Homeland. [Homeland Security (HLS) Joint Operating Concept (JOC), Feb 04]

Agile Sustainment. The ability to provide materiel, facilities, services, and other support to maintain readiness and enable operations until successful accomplishment of the defined mission or national objective. (Derived from JP 1-02).

Ambipolar Field-Effect Transistors. A field-effect transistor, more commonly referred to as a FET, is a transistor that has a channel of semiconductor material with a resistance that can be controlled by an applied voltage to one or more input terminals (known as gates). FETs depend on one type of charge carrier (electron or hole) for their operation and are typically called unipolar FETs. An ambipolar FET is a transistor that depends on types of charge carrier (electrons and holes) for its operation. (LIA Future Logistics Innovation Themes Document, 2006)

Analytical Information Technologies (AIT). Information technologies that facilitate tasks like predictive modeling, data assimilation, planning or decision-making, through automated data driven methods, numerical solutions of physical or dynamical systems, human-computer interaction, or a combination. AIT includes DMT, DSS, BI, OLAP, GIS, and other supporting tools and technologies. (Extracted from the Encyclopedia of Data Warehousing and Mining)

Analysis and Production. The ability to convert processed information into intelligence through the integration, analysis, evaluation, and interpretation of all source data and the preparation of intelligence products in support of known or anticipated intelligence needs. (Modified from JP 2-01).

Anti-matter. Matter that is composed of the antiparticles of those that constitute normal matter. If a particle and its antiparticle come in contact with each other, the two annihilate and produce a burst of energy, which results in the production of other particles and antiparticles or electromagnetic radiation. (LIA Future Logistics Innovation Themes Document, 2006)

Application (Financial or Mixed System). A group of interrelated components of financial or mixed systems which supports one or more functions and has the following characteristics: a common data base, common data element definitions, standardized processing for similar types of transactions, common version control over software. (U.S. Army PEO EIS and Software Engineering Center, The Enterprise Solutions Competency Center, ERP/SOA Resource Center)

Architecture. The structure of components, their relationships, and the principles and guidelines governing their design and evolution over time. (DOD Integrated Architecture Panel, 1995, based on IEEE STD 610.12)

Army and Joint Integration. Any approach to the description of themes, analysis of capabilities and eventual fielding of innovative solutions to the warfighter must be tied to the Joint Capabilities Integration and Development System (JCIDS). Themes, Experimentation and demonstration plans all develop and provide information to the logistics community and the JCIDS process. LIA innovation products could assist the Functional Capabilities Board and others in making JCIDS assessments. Results from theme documents, Experimentation plans and demonstrations can impact the Functional Needs Analysis (FNA), Functional Solution Analysis (FSA) and Post Independent Analysis (PIA), informing them on current and future concepts and supporting capabilities. Currently, the Joint Logistics (Distribution) Joint Integrating Concept (JIC) provides the clearest articulation of desired logistics capabilities for the 2015-2025 timeframe. Describing tasks, metrics, conditions, standards, and attributes, the JL(D) JIC provides a JCIDS-compliant basis to articulate themes for logistics innovation and provides illustrative examples that will inform the process of selecting technology areas and the appropriate means by which to conduct conceptual development and assessment. (LIA, 2006)

Army Battle Command. Battle command is the art and science of applying leadership and decision making to achieve mission success. Battle command encompasses the functions of leadership (providing purpose, motivation, and direction) and decision making. Enabled by command, control, communications, and computers (C4) and intelligence, surveillance, and reconnaissance (ISR), battle command enhances the commander's ability to gain information and decision making advantages over any adversary. Fully networked battle command capabilities are the bridge from the Current to Future Forces and enable the JFC to conduct fully interdependent, network-centric warfare. The Army views battle command as the essential operational capability that fundamentally enables the conduct of future joint operations. To implement the JOpsC and JOCs and achieve decision superiority, the Future Joint Force will exercise battle command within an inherently joint, top-down network that provides common situational awareness. (U.S. Army PEO EIS and Software Engineering Center, The Enterprise Solutions Competency Center, ERP/SOA Resource Center)

Army Materiel Command (AMC). Army's provider of materiel readiness -- technology, acquisition support, materiel development, logistics power projection, and sustainment.

(Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Assessment Rating Definitions. Department of the Army definitions to be used Army-wide in assessing ILS elements that will contribute to the successful cost-effective acquisition, type classification, production, fielding, sustainment, and repair of operationally ready, mission-essential systems are as follows: (Any substitution for or deviation from the following definitions is prohibited.)

a. GREEN (G): No problems. All actions on schedule.

b. AMBER (A): Significant or minor problems identified, with a solution or work-around plan expected to be completed by the next major milestone date.

c. RED (R): Major problems identified (show stopper) with no solution identified or solution being implemented with less than satisfactory results projected by the next major milestone date. (AR 700-127, 19 Jan 06)

Assumption. A supposition on the current situation or a presupposition on the future course of events, either or both assumed to be true in the absence of positive proof, necessary to enable the commander in the process of planning to complete an estimate of the situation and make a decision on the course of action.

Attribute. A testable or measurable characteristic that describes an aspect of a system or capability

Attrition-based. Based on reduction of the effectiveness of a force caused by loss of personnel and materiel. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Automated Ontology Extraction. A means to read standard text documents, perform semantic analysis on those documents, and generate a useful ontology for the set of documents with little human intervention. (LIA Future Logistics Innovation Themes Document, 2006)

Automatic Identification Technology (AIT). A suite of technologies that enables the automatic capture of source data, thereby enhancing the ability to identify, track, document, and control materiel, maintenance processes, deploying forces, equipment, personnel, and cargo. It encompasses a number of read-and-write data-storage technologies that capture asset identification information. The devices are interrogated by using several means, including direct contact, laser, and radio frequency. Digital information obtained from the interrogations can be provided to automated information systems that support the Army's logistics operations. (AR 700-127, 19 Jan 06)

Automatic Test Equipment (ATE). Equipment that measures functional or static parameters to evaluate system performance. May be designed to perform fault isolation to piece-part level. The decision-making, control, or assessment functions are performed with minimal human intervention. (AR 700-127, 19 Jan 06)

Avatar. A two or three-dimensional human representation of a person's self which can explore the virtual universe. It can conduct conversations with other users, and can be customized by the user. An icon representing a user. The Metaverse representations of a user in virtual-reality. (LIA Future Logistics Innovation Themes Document, 2006)

Basic Research. Research that advances knowledge and theoretical understanding that is exploratory in nature. Through theory generation, basic research provides the foundation for further applied research. (LIA Future Logistics Innovation Themes Document, 2006)

Basic Services Restoration. The ability to establish or reestablish the critical infrastructure necessary to ensure the immediate safety and security of the local populace. These activities, most likely military led, must ensure the functioning of basic services to include emergency response capabilities such as internal security forces, medical, fire, and the restoration of basic services such as power, communications, water and the reopening of critical local businesses. Restoration operations become the starting point for the international community to support reconstruction efforts. (Paraphrased from Stability Operations JOC, para 2.d.3, p 23.and 2.d.4 p 26, and JP 3-57 CMO)

Basic Sustainment Materiel. Materiel consumed in initial fielding, in follow-on training, and in performing the system-stated mission for a specified time. Includes such items as ammunition, petroleum, oils, and lubricants, batteries, and bulk supplies. (AR 700-127, 19 Jan 06)

Battlefield Damage Assessment and Repair. A wartime procedure to rapidly return disabled equipment to the operational commander by expediently fixing, by-passing, or jury-rigging components to restore the minimum essential components required for performing a specific combat mission or to enable the equipment to self-recover. (AR 700-127, 19 Jan 06)

Bio-Feedstock. Any plant-derived organic matter used as a feedstock to produce an array of energy-related products, including liquid, solid, and gaseous fuels; electricity; heat; chemicals, and other materials. (LIA Themes Document, 2006)

Built-in Test Equipment (BIT). Any identifiable device that is a part of a system whose purpose is used in testing the system. (AR 700-127, 19 Jan 06)

Business Rules. Statements that define or constrain some aspect of the mission or the architecture. What the business must do, or what it cannot do. The rules under which the architecture or its nodes behave under specified conditions. For example, "If (these conditions) exist, and (this event) occurs, then (perform these actions)." (DOD Architecture Framework Version 1.0, Volume 2, 30 August 2003)

Business and Scientific Applications. End-user modules which are capable of using AIT along with domain specific knowledge (e.g., business insights or constraints, process physics, engineering know-how). Applications can be custom built or pre-packaged and are often distinguished form other information technologies by their cognizance of the specific domains for which they are designed. This can entail the incorporation of domain specific insights or models, as well as pre-defined information and process flows. (Extracted from the Encyclopedia of Data Warehousing and Mining)

Business Intelligence (BI). Broad set of tools and technologies that facilitate management of business knowledge, performance and strategy, through automated analytics or human-computer interaction. (Extracted from the Encyclopedia of Data Warehousing and Mining)

Business Transformation. Transformation is a process that shapes the changing nature of military competition and cooperation through new combinations of concepts, capabilities, people, and organizations that exploit the Nation's advantages and protect against asymmetric vulnerabilities to sustain strategic position, which helps underpin peace and stability in the world. The Army will transform its culture, capabilities, and processes as an integral component of Defense Transformation. The Army frames transformation through the interaction of the continuously evolving capabilities of the Current to Future Force. The Current Force is today's operational Army. The Future Force is the operational force the Army continuously seeks to become. The Army possesses and refines capabilities to enable the Current Force to conduct joint operations in the near term while it simultaneously develops transformational capabilities for the Future Force. Army Transformation leverages Current Force operational experience, the insights from innovative joint and Army concept development and experimentation processes, and science and technology to enhance the responsiveness, readiness and capabilities of the Future Force. (U.S. Army PEO EIS and Software Engineering Center, The Enterprise Solutions Competency Center, ERP/SOA Resource Center)

Capabilities-based Approach (CBA). A capabilities-based approach focuses more on how the United States can defeat a broad array of capabilities that any adversary may employ rather than who the adversaries are and where they may engage joint forces or U.S. interests. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Capabilities Based Maintenance Plus (CBM+). The application and integration of appropriate processes, technologies, and knowledge-based capabilities to increase operational availability and reduce total life cycle costs by improving maintenance effectiveness and responsiveness. CBM+ is based on performing maintenance upon evidence of need obtained from real-time assessments, embedded sensors, and external measurements. CBM+ uses a systems engineering approach to collect data and feed the decision-making process for operations, and weapon system acquisition and sustainment. (Draft DOD CBM Guidebook August 2006)

Capabilities-based Planning (CBP). Planning, under uncertainty, to provide capabilities suitable for a wide range of modern-day challenges and circumstances while working within an economic framework that necessitates choice. It emphasizes flexibility, adaptiveness, and robustness of capability. That implies a modular, building-block approach to force design and operations. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Capability. A capacity or ability to be developed, used or treated for a specific purpose. Example: Development of the neutron bomb, which provided the capability to kill armored crews with little collateral damage.

Carbon Nanotubes. Cylindrical carbon molecules with novel properties that make them potentially useful in a wide variety of applications in nanotechnology, electronics, optics, and other fields of materials science. Carbon nanotubes exhibit extraordinary strength and unique electrical properties, and are efficient conductors of heat. (LIA Future Logistics Innovation Themes Document, 2006)

Carcasses. Unserviceable Principle End Items (PEI), usually, but not always, indicates PEI has been stripped or partially stripped and will need to be evacuated to a major repair facility

Centers of Gravity (COG). Those characteristics, capabilities, localities from which a military force derives its freedom of action, physical strength or will to fight. In the context of this CCP, it denotes those characteristic, capability, or localities that must be a constant or the OBJ TSC will fail to effectively execute the effects based approach to logistics from the source of support to the point of effect. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

C Levels

C-1: The C-1 level indicates that the unit possesses the required resources and is trained to undertake the full wartime mission(s) for which it is organized or designed. The status of resources and training will neither limit flexibility in methods for mission accomplishment nor increase vulnerability of unit personnel and equipment. The unit does not require any compensation for deficiencies.

C-2: The C-2 level indicates that the unit possesses the required resources and is trained to undertake most of its wartime mission(s) for which it is organized or designed. The status of resources and training may cause isolated decreases in flexibility in methods for mission accomplishment, but will not increase the vulnerability of the unit under most envisioned operational scenarios. The unit would require little, if any, compensation for deficiencies.

C-3: The C-3 level indicates that the unit possesses the required resources and is trained to undertake many, but not all, portions of the wartime mission(s) for which it is organized or designed. The status of resources or training will result in a significant decrease in flexibility for mission accomplishment and will increase the vulnerability of the unit under many, but not all, envisioned operational scenarios. The unit would require significant compensation for deficiencies.

C-4: The C-4 level indicates that the unit requires additional resources or training to undertake its wartime mission(s), but it may be directed to undertake portions of its wartime mission(s) with resources on hand.

C-5: The C-5 level indicates that the unit is undergoing a service-directed resource action and is not prepared, at this time, to undertake the wartime mission(s) for which it is organized or designed. HQDA employs the force development process with the goal of "standing-up" units at the overall level of C-3 or higher. In many cases, actions impacting on unit status can be synchronized so that transitioning units can shorten the time period in C-5 status or avoid C-5 status entirely. (Refer to paragraph 1-6 c.) C-5 units are restricted to the following:

(1) Units undergoing activation, inactivation or conversion.

(2) Units manned or equipped below ALO-3 level.

(3) Units that are not manned or equipped but are required in the wartime structure (i.e., COMPO 4 units).

(4) Units placed in cadre status by HQDA.

Level 6 indicates that one or more of the individual resource areas are not measurable, or by Service direction are not measured. (For example, the equipment serviceability [ES] of a unit cannot be measured because a civilian contractor performs maintenance for the unit or the unit is an Opposing Force (OPFOR) unit at a training center that has no organic reportable equipment). Level 6 is not used as an overall category level. Although unmeasured resource areas are not reportable for USR purposes, commanders remain responsible for accountability and management of any Army personnel and equipment. (CJCSM 3150.02)

Collect. As an information management activity, to collect is to continuously acquire relevant information by any means, including direct observation, other organic resources, or other official, unofficial, or public sources from the information environment. Commanders set priorities for collecting by establishing CCIR. They continuously revise them throughout the operations process, as the situation changes.

Collecting Takes Two Forms. Information push and information pull. (FM 6-0)

Collective Training. Training either in an institution or in units to prepare a group (crew, team, squad, or platoon) for tasks required of the group. (AR 700-127, 19 Jan 06)

Combat Developer (CBTDEV). The command or agency responsible for concepts, doctrine, organization (excluding Army wholesale logistics), and system objectives and requirements. (AR 700-127, 19 Jan 06)

Combined Joint Task Force (C/JTF). Comprised of a combined force - A military force composed of elements of two or more allied nations - and a joint task force - A joint force that is constituted and so designated by the Secretary of Defense, a combatant commander, a sub-unified commander, or an existing joint task force commander. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Computer Network Operations (CNO). The ability to conduct computer network attack (CNA), computer network defense (CND), and related computer network exploitation (CNE) enabling operations. (Derived from DRAFT DODD 3600.1)

Common Relevant Operational Picture (CROP). A presentation of timely, fused, accurate, and relevant information that can be tailored to meet the requirements of the joint force commander and the joint force and is common to every organization and individual involved in a joint operation. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Command and Control (C2). The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission.

Commander's Intent. A concise expression of the purpose of an operation and the desired end state that serves as the initial impetus for planning.

Command/Internal Information. The ability to communicate with service members, civilian employees, contractors and family members of the joint force, both deployed and at home stations to create an awareness of the joint force's goals and significant developments affecting deployed forces. (Derived from JP 1-02).

Communicate Commander's Intent and Guidance. The ability for a Commander to concisely express the operational purpose and desired end state. As the impetus for the planning process, it may also include the commander's assessment of the adversary commander's intent and an assessment of acceptable operational risk. In the net-centric collaborative environment, the commander's intent must be shared early and often to enable parallel planning and self-synchronized execution. (C2 JIC)

Communities of Interest. Groups formed to replace Special Interest Groups and to provide a forum for members to network and exchange ideas. Often found within the DOD Command and Control community, although not limited to same.

Community Relations. The ability to plan and synchronize programs to enhance interaction and communication among U.S. Joint Forces, and select domestic and foreign stakeholders throughout all operational phases to support commanders' strategic and operational objectives. (Derived from JP 1-02 and JP 3-61).

Component. (In the context of the DOD Enterprise Architecture Service Component Reference Model). A self contained business process or service with predetermined functionality that may be exposed through a business or technology interface. (Federal Enterprise Architecture SRM v1.0, 12 June 2003)

Computer Resources Support. Facilities, hardware, software, and manpower needed to operate and support embedded and stand-alone computer systems, including post-deployment software support requirements and planning. (AR 700-127, 19 Jan 06)

Concept. A general idea or understanding, especially one derived from specific instances or occurrences. Example: The capabilities afforded by the neutron bomb enabled the realization of the concept of using tactical nuclear weapons to halt a Soviet armor onslaught, which theretofore had been unviable due to collateral effects in a highly urbanized Germany.

Concept Capability Plan (CCP):

Condition. A variable of the environment that affects performance of a task.

Conduct Operational Movement and Maneuver. The ability to dispose joint forces to impact the conduct of operations by either securing positional advantages or a mobility differential before battle is joined, or exploiting tactical success to achieve operational or strategic results. Operational Mobility includes Land Force Movement, Operational Maneuver from Strategic Distances and Intra-theater operational maneuver. (Revised from UJTL, CJCSM 3500.04C)

Conduct Decisive Maneuver. The ability to apply ground forces supported by air, sea, and space to conduct simultaneous, distributed operations against enemy critical vulnerabilities and centers of gravity. It is characterized by continuous operations and controlled operational tempo that seeks to decisively resolve the outcome of battles and engagements through close combat with enemy forces. The ability to close with, and destroy the enemy. (Derived from TRADOC Pamphlet 525-3-0)

Configure. To arrange, construct or build, as in "scalable, modular forces" with a known degree of sustainment, allowing immediate engagement/support of the JTF upon arrival at a designated theater POA (point-of-action).

CONOPS (Concept of Operations or Commander's Concept). The overall picture and broad flow of tasks within a plan by which a commander maps capabilities to effects, and effects to end state for a specific scenario.

Contingency Basing. The ability to station forces or supplies for varying periods of time at land-based overseas facilities. (Modified "Forward Deployed" definition from MCRP 5-12)

Contingency Plan. A plan for major contingencies that can reasonably be anticipated in the principal geographic subareas of the command. (JP1-02)

Contingency. An emergency involving military forces caused by natural disasters, terrorists, subversives, or by required military operations. Due to the uncertainty of the situation, contingencies require plans, rapid response, and special procedures to ensure the safety and readiness of personnel, installations, and equipment. (JP1-02)

Control Territory, Populations, and Resources. The ability and desired end state of controlling territory, populations, and resources during offensive or defensive operations, or as part of Stability Operations (SSTRO), includes management of EPWs, detainees, indigenous displaced persons, and/or refugees. (JCA Working Group definition; derived from Army FM 3-0, Dominant Land operations, pg. 1-6)

Conduct Detainee Operations. The ability to detain certain categories of persons, including unlawful enemy combatants and security internees. It includes the management of Detention facilities, Joint Interrogation and Debriefing Centers, and detainee reporting requirements within the Joint Area of Operations. (Derived from JP 3-63, Joint Doctrine for Detainee Operations, in final coordination)

Conduct Refugee Operations. The ability to mange persons seeking refuge in another country to escape persecution. (JCA Working Group Definition, 14/15 Mar 06)

Contractor Logistics Support (CLS). Use of a commercial source to provide support for materiel employed by Army field units in the form of maintenance, supply and distribution, training, software support, and rebuild/overhaul. (AR 700-127, 19 Jan 06)

Counter Operational Mobility. A belligerent operation to prevent vessels and/or aircraft of all nations, enemy as well as neutral, from entering or exiting specified ports, airfields, or coastal areas belonging to, occupied by, or under the control of an enemy nation. (Modified NWP 1-14M)

Crisis. An incident or situation involving a threat to the United States, its territories, citizens, military forces, possessions, or vital interests that develops rapidly and creates a condition of such diplomatic, economic, political, or military importance that commitment of U.S. military forces and resources is contemplated in order to achieve national objectives. (JP1-02)

Crisis Action Planning. 1. The Joint Operation Planning and Execution System process involving the time-sensitive development of joint operation plans and orders in response to an imminent crisis. Crisis action planning follows prescribed crisis action procedures to formulate and implement an effective response within the time frame permitted by the crisis. 2. The time-sensitive planning for the deployment, employment, and sustainment of assigned and allocated forces and resources that occurs in response to a situation that may result in actual military operations. Crisis action planners base their plan on the circumstances that exist at the time planning occurs. (JP1-02)

Criterion. A critical, threshold, or specified value of a measure.

Critical Infrastructure Protection (CIP). The ability to identify, assess, and enhance the security of physical assets, cyber assets, and associated infrastructures essential to the execution of the National Military Strategy. (Derived from Homeland Security (HLS) Joint Operating Concept (JOC), Feb 04)

Data. The lowest level of information on the cognitive hierarchy. Data consist of unprocessed signals communicated between any nodes in an information system, or sensings from the environment detected by a collector of any kind (human, mechanical, or electronic). Data is rarely useful until it is processed to give it meaning. The exception is combat information. Combat information is unevaluated data, gathered by or provided directly to the tactical commander which, due to its highly perishable nature or the criticality of the situation, cannot be processed into tactical intelligence in time to satisfy the user's tactical intelligence requirements (JP 1-02). Because of its nature, collectors often amass a lot of unimportant data. Until data is processed, it is often difficult to tell if it is relevant. However, as with all information, collectors should focus, as much as possible, only on data needed to determine the information required to build the common operational picture (COP). (FM 6-0)

Data Assimilation. Statistical and other automated methods for parameter estimation, followed by prediction and tracking. Decision Support Systems (DSS): Broadly defined, these include technologies that facilitate decision-making. These can embed DMT and use these through automated batch processes and/or user-driven simulations or what-if scenario planning. The tools for decision support include analytical or automated approaches like data assimilation and operations research, as well as tools that help the human experts or decision-makers manage by objectives or by exception like OLAP or GIS. (Extracted from the Encyclopedia of Data Warehousing and Mining)

Data Collection. The means by which raw facts are gathered for transmission, interpretation, fusion, processing, exploitation and/or assessment.

Data Fusion and Analysis. The combination of raw facts gathered from multiple sources. Once the data are fused, they need to be analyzed using qualitative and quantitative measures to yield actionable knowledge. The resulting actionable knowledge is used to develop potential courses of action (COAs). Realistic quantified uncertainties must be provided.

Data Mining Technologies (DMT). Broadly defined, these include all types of data-dictated analytical tools and technologies that can detect generic and interesting patterns, scale (or can be made to scale) to large data volumes and help in automated knowledge discovery or prediction tasks. These include determining associations and correlations, clustering, classifying and regressing, as well as developing predictive or forecasting models. The specific tools used can range from .traditional. or emerging statistics and signal or image processing to machine learning, artificial intelligence and knowledge discovery from large databases, as well as econometrics, management science and tools for modeling and predicting the evolutions of nonlinear dynamical and stochastic systems. (Extracted from the Encyclopedia of Data Warehousing and Mining)

Data Transmission/Flow/Distribution/Exchange. The transfer of raw facts between functional elements over or through a medium according to a protocol.

Defense Support to Public Diplomacy (DSPD). The ability to understand, engage, influence and inform key foreign audiences through words and actions to foster understanding of U.S. policy and advance U.S. interests, and to collaboratively shape the operational environment. This ability can include public information activities as well as information operations to assist selected host nations and the Department of State in reaching foreign target audiences through communication channels such as websites, radio, print, and television." DSPD comprises DOD's support to USG public diplomacy, which are defined as those overt international public information activities of the USG designed to promote U.S. foreign policy objectives by seeking to understand, inform, and influence foreign audiences and opinion makers, and by broadening the dialogue between American citizens and institutions and their counterparts abroad. (Derived from Draft DSPD DODD xxxx.x; (still in Draft and unnumbered) IO EXCOM brief 27 Jun 05; NMSP-WOT Annex H Appx 1; and JP 1-02).

Defense Logistics Agency (DLA). Responsible for the worldwide logistics support throughout the Department of Defense. Supports the procurement, management, storage and, and distribution of items for U. S. military customers, other federal agencies, and allied forces. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Defense Planning Guidance (DPG). Document, issued by the Secretary of Defense, provides firm guidance in the form of goals, priorities, and objectives, including fiscal constraints, for the development of the Program Objective Memorandums by the Military Departments and Defense agencies. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Deliberate Planning. 1. The Joint Operation Planning and Execution System process involving the development of joint operation plans for contingencies identified in joint strategic planning documents. Deliberate planning is accomplished in prescribed cycles that complement other Department of Defense planning cycles in accordance with the formally established Joint Strategic Planning System. 2. A planning process for the deployment and employment of apportioned forces and resources that occurs in response to a hypothetical situation. Deliberate planners rely heavily on assumptions regarding the circumstances that will exist when the plan is executed. See also Joint Operation Planning and Execution System; Joint Strategic Planning System. (JP1-02)

Designer Materials. The condition that encompasses the design of materials both at the molecular and macro levels as well as the supporting processes used to give items unique qualities and attributes. (LIA Future Logistics Innovation Themes Document, 2006)

Develop and Maintain Shared Situational Awareness and Understanding. The ability to share and access a "common operational picture" (COP) with mission partners as necessary, presenting current and forecast information on adversary and friendly forces, neutral elements, the environment and geospatial information. The "picture" is built through access to both processed and raw data from sensors, analysts and other sources, and through collaborative analysis and assessment of this data. If, transformed into knowledge through synthesis, experience and collaboration, enables situational understanding. (C2 JIC).

Develop Skills. The ability to develop doctrine and to educate, train, and exercise personnel and units to enhance their ability to conduct military operations. (Derived from CJCSI 1800.01B/Joint Doctrine Encyclopedia)

Defense Support of Civil Authorities. Often referred to as Civil Support, DSCA is the ability to provide DOD support, including Federal military forces, the Department's career civilian and contractor personnel, and DOD agency and component assets, for domestic emergencies and for designated law enforcement and other activities. The Department of Defense provides defense support of civil authorities when directed to do so by the President or Secretary of Defense. (Strategy for Homeland Defense and Civil Support, Jun 05)

Demonstration. The presentation of either materiel prototypes that incorporate mature, promising technologies and/or new business processes designed to improve logistics operations. The purpose is to determine whether the capabilities of the demonstrated prototypes or business process changes are sufficiently beneficial to warrant fielding to Army organizations. (LIA Future Logistics Innovation Themes Document, 2006)

Deployable Command Post (DCP). Forward deployed element of the OBJ TSC, and is the "on-the-ground" manager, decision maker and command and control authority for all logistics functions in the area of operations. By design, the DCG for Support has command oversight authority for external support operations as the "forward" commander and has delegated authority and responsibility as the OBJ TSC commander in the area of operations. As such, his responsibility covers the full range of command and control responsibilities for all subordinate logistics forces in the AO. The requirement to have a single logistics commander is executed through this DCP and staff elements. The OBJ TSC Main is where the OBJ TSC commander resides. The DCPs are commanded by the Deputy Commander for Support and the Deputy Commander for Port of Debarkation. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Deployability. The capability of the force (personnel and materiel) to be moved anywhere in the world to support a military operation. (AR 700-127, 19 Jan 06)

Deployment. The relocation of forces and materiel to desired areas of operations. Deployment encompasses all activities from origin or home station through destination, specifically including intra-continental United States, intertheater, and intratheater movement legs, staging, and holding areas. (JP 1-02)

Deployment and Distribution Operations Center (DDOC). Joint initiative that will deploy trained information technology-equipped logistics specialists into a theater of operations to improve command and control of the distribution process. The DDOC will synchronize deployment and distribution, while optimizing strategic and operational capabilities for the combatant commander. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Directive Authority for Logistics (DAFL). Combatant commander authority to issue directives to subordinate commanders, including peacetime measures, necessary to ensure the effective execution of approved operation plans, personnel, weapon systems, equipment, and necessary support, or combination thereof. Essential measures include the optimized use or reallocation of available resources and prevention or elimination of redundant facilities and/or overlapping functions among the Service component commands. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Discovery. The identification of new areas of research, scientific breakthroughs, new technologies, new patents and products. It supports the identification of capability deficiencies and the articulation of possible logistics solution sets. (LIA Future Logistics Innovation Themes Document, 2006)

Displaced System. A system that is redistributed from one MACOM to another because of the fielding of a new or improved system. (AR 700-127, 19 Jan 06)

Display. As an information management activity, display is to represent relevant information in a usable, easily understood audio or visual form tailored to the needs of the user that conveys the common operational picture for decision-making and exercising command and control functions. There are three ways to display information: graphic displays, written reports, and verbal narrative reports. (FM 6-0)

Dissemination and Integration. The ability to make information and intelligence available to support the development of an accurate, complete and timely User-Defined Operational Picture (UDOP). (JCA CRC, 28 Apr 05; modified from JP 2-01).

Disseminate. As an information management activity, disseminate is to communicate relevant information of any kind from one person or place to another in a usable form by any means to improve understanding or to initiate or govern action. It takes two forms: broadcast dissemination and point-to-point dissemination. Effective IM combines broadcast and point-to-point dissemination based on the situation and available INFOSYS. (FM 6-0)

Distribution Operations Center (DOC). The DOC capability is resident in the OBJ TSC. It is an essential part of the Deployable Command Post. It provides an expeditionary capability to the operational level commander in the execution of distribution operations to supported forces.

Distribution Operations Package (DOP). DOC portion of the DCP. Brain stem of the DCP in support of expeditionary operations. It operates in the same manner and has the same fundamental capabilities as the full DOC. The DOP operates as a fully resourced package, but is tailorable to support the expeditionary force.

Distribution. The operational process of synchronizing all elements of the logistic system to deliver the "right things" to the "right place" at the "right time" to support the geographic combatant commander. (JP1-02)

Distribution Based Logistics. Logistics system which provides certainty of support by concentrating on transportation effectiveness and information precision versus inventories.

Doctrine, Organization, Training, Materiel, Leadership, Personnel and Facilities (DOTMLPF). DOTMLPF is a joint methodology. It refers to the full range of solutions to advance joint warfighting, and field the capabilities required to deter and defeat the adversaries. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

DOD Architecture Framework (DODAF). Defines a common approach for DOD architecture description, development, presentation, and integration for both warfighting operations and business processes. The DODAF is intended to ensure that architecture descriptions can be compared and related across organizational and mission area boundaries, including Joint multi-national boundaries and DOD warfighting and business domains. (DOD Chief Information Officer Memo, the Department of Defense Architecture Framework (DODAF), 9 February 2004)

Early-entry Command Post (CP). That part of the deployable command post that deploys early into the JOA, to establish command and control of logistics. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Effect. An outcome (condition, behavior, or degree of freedom) resulting from tasked actions.

Effects-based Approach (EBA). Seeks to understand the battlespace as integrated, adaptive systems and the key relationships that exist between systems. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Effects-based Operations (EBO). Effects-based operations are actions that change the state of a system to achieve directed policy aims using the integrated application of the diplomatic, informational, military, and economic (DIME) instruments of national power. The SJFHQ and other near term capabilities now in prototyping will help the joint force commander (JFC) conduct EBO. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Effects-based Approach to Logistics (EBAL). Effects Based Approach to Logistics (EBAL) is a combined logistics and C2 community effort initiated by the U.S. Army Logistics Innovation Agency (USALIA) to create and demonstrate a true multi-echelon distribution and deployment prioritization schema based on the supported commander's intent. (EBAL Team, Sept 06)

Effects-based Planning (EBP). An operational planning process to conduct EBO within RDO. EBP is results-based vice attrition-based. EBP closely mirrors the current joint planning process, yet focuses upon the linkage of actions to effects to objectives. EBP changes the way we view the enemy, ourselves, and what is included and emphasized in the planning process. EBP uses a flexibly-structured battle rhythm that leverages a collaborative knowledge environment and capitalizes on the use of fewer formal joint boards. It employs virtual, near-simultaneous planning at all echelons of command. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Electroactive Polymers. Polymers whose shape is modified when subjected to an applied voltage. Electroactive polymers can be used as actuators as they can undergo a large amount of deformation while sustaining large forces. Due to the similarities with biological tissues in terms of achievable stress and force, they are often called artificial muscles, and have the potential for application in the field of robotics, where large linear movement is often needed. (LIA Future Logistics Innovation Themes Document, 2006)

Electronic Warfare (EW). The ability of the military to use electromagnetic energy and directed energy to control the electromagnetic spectrum or to attack the enemy. The three major subdivisions within electronic warfare are: electronic attack, electronic protection, and electronic warfare support. (Derived from DRAFT DODD 3600.1 and JP 1-02)

Embedded Diagnostics. Determination and reporting the cause of a failure by detection of failure symptoms through the use of sensors, central processing unit, and a user interface which are integrated (or embedded) into the design of the system. (AR 700-127, 19 Jan 06)

Embedded Instrumentation. Data collection and processing capabilities, integrated into the design of a system for one or more of the following uses: diagnostics, prognostics, testing, or training. (AR 700-127, 19 Jan 06)

Embedded Prognostics. The detection and reporting of component degradation prior to failure through the use of sensors, central processing unit and a user interface which are integrated (or embedded) into the design of the system. (AR 700-127, 19 Jan 06)

Embedded Training. Training involving simulation or stimulation of operational equipment performance in addition to the equipment's primary operational function(s). Training provided by capabilities not specifically required for mission completion, but that are built into or added onto operational systems, subsystems or equipment to enhance or maintain user's skill proficiency. (AR 700-127, 19 Jan 06)

Emergency Preparedness (EP). The ability to ensure DOD and U.S. Government processes, procedures, and resources are in place to support the President and Secretary of Defense in a designated National Security Emergency. These missions consist of Continuity of Operations (COOP), Continuity of Government (COG), and other missions as directed by the President. (Strategy for Homeland Defense and Civil Support, Jun 05; Homeland Security JOC, Feb 04)

End State. The set of conditions, behaviors, and freedoms of action that defines achievement of the commander's objectives.

End-to-End. Boundaries of the JDDE applicable to force deployment and movement of materiel to support the operational requirements of a JFC/COCOM.

Force deployment boundaries originate at unit origin or home station and terminate when units are located at their JFC designated point of need. Inclusive are intra-continental, inter-theater, intra-theater movement, and reception/assembly activities as required. Materiel movement commences at the source of supply and terminates with commodity receipt by the consuming unit.

Energy-on-Demand. The condition that provides instant usable energy and power systems at the point of effect when needed.

Enterprise. Any significant undertaking united by a set of common and fully integrated processes, standards, systems, people, organizations, shared-knowledge, and technical connectivity to accomplish a broad, enduring mission.

Enterprise Architecture. The explicit description and documentation of the current and desired relationships among business and management processes and information technology. (OMB Circular A-130, Management of Federal Information Resources, 8 February 1996)

Enterprise Integration. The vertical and horizontal alignment of plans, business processes, and information systems across organizations and functional boundaries to provide competitive advantage. (SA Memo, Establishment of the Army Enterprise Integration Oversight Office (AEIOO), 16 April 2003)

Enterprise Services. The ability to provide well-defined, enterprise network functions that accept a request and return a response through an interface with a user or another service such as collaboration, messaging, or information discovery and storage. (Derived from NCOE JIC)

Environmentally Preferable. Products or services that have a lesser or reduced effect on human health and the environment when compared with competing products or services that serve the same purpose. This comparison may consider raw materiel acquisition, production, manufacturing, packaging, distribution, reuse, operation, maintenance, or disposal of the product or service. (AR 700-127, 19 Jan 06)

Establish/Adapt Command Structures and Enable Both Global and Regional Collaboration. The ability for Commanders to quickly establish or adapt command structures across the force, with all mission partners and within the staff tailored to the mission, and to create the processes that will enable horizontal and vertical collaboration. They must have a menu of alternative schemes for organizing the components and defining command relations, with associated guidance on when and how to apply them. It is essential that the infrastructure be in place to enable rapid reaction to new crises. (C2 JIC)

Equip. The ability to acquire and integrate materiel to meet Service and Joint requirements. (Derived from JP 1-02)

Evaluation and Feedback. The ability to continuously assess and improve the information and processes used to provide battlespace awareness. (Modified from JP 2-01, 7 Oct 04)

Exercise Command Leadership. The ability to exercise authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of a mission. Commanders must be able to exercise effective leadership of an interdependent joint force in rapidly changing scenarios involving complex distributed, simultaneous or sequential operations, often with other agencies and nations. Unity of effort and the authority and accountability of the commander must be preserved. (C2 JIC)

Expeditionary Distribution. The operating process in an unimproved, austere environment of synchronizing all elements of the logistics system to deliver the “right things” to the “right place” at the “right time” to support the geographic combatant commander.

Experimentation. The formulation and development of new logistics concepts and proposed innovative solution sets that fill identified and documented deficiencies in current capabilities and/or entirely new capabilities not yet perceived or documented by others. (LIA Future Logistics Innovation Themes Document, 2006)

Exploitation and Assessment. The implementation of knowledge-generated COAs to preempt the adverse affects of situations that would otherwise occur without predictive preemption intervention. As decisions are implemented and COAs are applied to missions and tasks supporting sustained combat operations, the assessment process identifies events that occurred but were not predicted, adverse affects that were preempted due to predictive preemption intervention, and COA successes and failures.

Facilities. The permanent or semipermanent real property assets specifically required to support the system, including facilities for training, equipment storage, maintenance, contractor, ammunition storage, mobile shop storage, classified storage, troop housing, fuels and lubricant storage, and special facility requirements. (AR 700-127, 19 Jan 06)

Facility Planning. An early, systematic evaluation of the effect of the introduction of a new materiel system on fixed facilities in the peacetime scenario. This is required because of the long and constrained MCA process (5 to 7 years from requirements determination to having a usable facility). (AR 700-127, 19 Jan 06)

Federated Structure. A management and organizational construct that governs by virtue of a compact between the affected entities that surrender their individual sovereignty to a central authority but retain limited residual powers. (U.S. Army PEO EIS and Software Engineering Center, The Enterprise Solutions Competency Center, ERP/SOA Resource Center)

Financial Management System. The financial systems and the financial portions of mixed systems necessary to support financial management. (U.S. Army PEO EIS and Software Engineering Center, the Enterprise Solutions Competency Center, ERP/SOA Resource Center)

Financial System. An information system comprised of one or more applications that is used for any of the following: collecting, processing, maintaining, transmitting, and reporting data about financial events; supporting financial planning or budgeting activities; accumulating and reporting cost information; or supporting the preparation of financial statements. A financial system supports the financial functions required to track financial events, provide financial information significant to the financial management of the agency, and/or required for the preparation of financial statements. A financial system encompasses automated and manual processes, procedures, controls, data, hardware, software, and support personnel dedicated to the operation and maintenance of system functions. A financial system may include multiple applications that are integrated through a common database or are electronically interfaced, as necessary, to meet defined data and processing requirements. (U.S. Army PEO EIS and

Software Engineering Center, The Enterprise Solutions Competency Center, ERP/SOA Resource Center)

First Unit Equipped Date. The first scheduled date for handoff of a new materiel system in a MACOM. (AR 700-127, 19 Jan 06)

Force. 1. An aggregation of military personnel, weapon systems, equipment, and necessary support, or combination thereof. 2. A major subdivision of a fleet. (JP 1-02)

Force Closure. The point in time when a supported JFC determines that sufficient personnel and equipment resources are in the assigned operational area to carry out assigned tasks. (JP 1-02)

Force Health Protection or Joint Force Health Protection. Represents all services performed, provided, or arranged by the Services (or joint elements) to promote, improve, conserve, or restore the mental or physical well-being of personnel. These services include, but are not limited to, the management of health services resources, such as manpower, monies, and facilities; preventive and curative health measures; evacuation of the wounded, injured, or sick; selection of the medically fit and disposition of the medically unfit; blood management; medical supply, equipment, and maintenance thereof; combat stress control; medical, dental, veterinary, laboratory, optometry, medical food, and medical intelligence services. (JP 1-02)

Forcible Entry. The ability to conduct a military operation in the face of expected armed opposition to gain entry of ground forces into an operational area in order to establish a lodgment to enable the conduct of follow-on operations. (Modified JFEO CBA)

Form Factor. Physical dimensions and weight

Forward Processing. A condition where incoming data is instantly stored and then processed as opposed to processed and then stored. Distributing data instantly to storage for processing may allow other optimized devices to parse data more efficiently. (LIA Future Logistics Innovation Themes Document, 2006)

Freedom of Navigation. The ability to provide required forces to conduct operations to demonstrate U.S. or international rights to navigate the global commons (air, sea, space, and cyberspace routes). (Modified JP1-02)

Fuel Cell. An electrochemical energy conversion device similar to a battery, but differing from the latter in that it is designed for continuous replenishment of the reactants consumed, i.e., it produces electricity from an external supply of fuel and oxygen as opposed to the limited internal energy storage capacity of a battery. (LIA Future Logistics Innovation Themes Document, 2006)

Functional Logistics Brigade. At the theater level (Transportation Groups, Petroleum Groups, and Ammunition Groups) control the bulk of the operational level GS supplies. (Operational

Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Future Capability Identification. The ability to identify capabilities needed to meet joint force requirements in the future to inform Force Generation activities. (Derived from FCB responsibilities as described in CJCSI 3170.01E dtd 11 May 2005)

Geographical Information Systems (GIS). Tools that rely on data management technologies to manage, process and present geo-spatial data, which in turn can vary with time. (Extracted from the Encyclopedia of Data Warehousing and Mining)

Global Force Management. The ability to align force apportionment, assignment, and allocation methodologies in support of the National Defense Strategy and joint force availability requirements; present comprehensive insights into the global availability and operational readiness of U.S. military forces; globally source joint force requirements, provide senior decision makers a vehicle to quickly and accurately assess the impact and risk of proposed allocation, assignment and apportionment changes. (From Annex A (Glossary) "Global Force Management Guidance FY 2005")

Global Information Grid (GIG). The globally interconnected, end-to-end set of information capabilities, associated processes and personnel for collecting, processing, storing, disseminating, and managing information on demand to warfighters, policy makers, and support personnel. (DOD Directive 8100.1, Global Information Grid (GIG) Overarching Policy, 19 September 2002)

Global Posture. The ability to position forces and their supporting infrastructure in order to execute U.S. defense strategy today and in the future. Key elements of global posture are facilities/infrastructure, activities and host nation relationships/agreements. (Derived from OSD/Policy brief to Strategic Planning Council, 26 May 04).

Global Strike. The ability to rapidly plan and deliver limited-duration attacks using the full range of kinetic (conventional and nuclear) and non-kinetic capabilities to achieve a range of desired effects against highly valued adversary assets regardless of range or access. (Derived from Strategic Deterrence JOC, Feb 04)

Governance. How and by whom business transformation will be implemented within the Army. Specifically, governance is a management vehicle designed to ensure efficient execution, guidance, and oversight for Army business transformation and compliance activities. It is achieved through organizational structure and performance measurement, which define boundaries, authorities, responsibilities, and tasks. (U.S. Army PEO EIS and Software Engineering Center, The Enterprise Solutions Competency Center, ERP/SOA Resource Center)

Haptic. Pertaining to the technology of touch. (LIA Future Logistics Innovation Themes Document, 2006)

High Speed Intra-theater Connector. Term normally only applied to water craft capable of traveling at least 40 knots and certified to travel intra-theater distances.

Human Factors Engineering. The systematic application to system design and engineering of relevant factors concerning human characteristics. These factors include skill capabilities, performance, anthropometric data, biomedical factors, and training implications to system development, design, acquisition strategy, and manning. (AR 700-127, 19 Jan 06)

Humanitarian Assistance. The ability to support those programs conducted to relieve or reduce the results of natural or manmade disasters (to include war) or other endemic conditions such as human pain, disease, hunger, or privation that might present a serious threat to life or that can result in great damage to or loss of property. Foreign humanitarian assistance (FHA) provided by U.S. forces is limited in scope and duration. The foreign assistance provided is designed to supplement or complement the efforts of the host nation civil authorities or agencies that may have the primary responsibility for providing humanitarian assistance. FHA operations are those conducted outside the United States, its territories, and possessions. (JP 3-07.6)

Individual Training. The instructions given to qualify an individual for a needed skill or to increase a skill through practice. (AR 700-127, 19 Jan 06)

Inducements. The ability to influence or mitigate an adversary’s consequences of restraint. It includes the analytic capability to measure or model the effects of various courses of action and select the best options. For example, shared early warning provided by the U.S. to a potential adversary could influence them to restrain themselves from taking an unconsidered (or inappropriate) reaction to U.S. or third-party activity. Shared early warning would mitigate the adversary’s risk of being pre-empted. Another example may be an adversary’s decision to forgo WMD ownership in response to U.S. Global Deterrence efforts. To mitigate the adversary’s consequences of restraint, the U.S. can provide assistance in safely transporting, securing, deweaponizing or neutralizing WMD. (Strategic Deterrence JOC, Feb 2004)

Information. In the context of the cognitive hierarchy, information is data that have been processed to provide further meaning. Processing includes filtering, fusing, formatting, organizing, collating, correlating, plotting, translating, categorizing, and arranging. Information is useful for immediate application. It can be used to avoid threats, acquire targets, or take other immediate actions. Information forms the basis of the COP. (FM 6-0)

Information System. The organized collection, processing, transmission, and dissemination of information in accordance with defined procedures, whether automated or manual. Information systems include non- financial, financial, and mixed systems as defined in this document. (U.S. Army PEO EIS and Software Engineering Center, The Enterprise Solutions Competency Center, ERP/SOA Resource Center)

Information Transport. The ability to provide the physical communications media over which assured connectivity takes place, supported by switching and routing systems, and the computing infrastructure. (Derived from NCE JFC)

Information Assurance. The ability to provide the measures that protect and defend information and information systems by ensuring their availability, integrity, authentication, confidentiality, and non-repudiation. This includes providing for restoration of information systems by incorporating protection, detection, and reaction capabilities. (DOD Directive 8500.1, Information Assurance)

Initial Operational Capability. The first attainment by a MTOE unit of the capability to operate and support effectively in the operational environment a new, improved or displaced Army materiel system. (AR 700-127, 19 Jan 06)

Innovation. The creative thinking that puts pieces together in ways that others have not envisioned or pursued and therefore changes the way the capability is realized. (LIA Future Logistics Innovation Themes Document, 2006)

Innovation Process. Theme development is the beginning of the innovation process. This effort consists of gathering available knowledge, and categorizing it into manageable areas of logistics interest and applicability. The themes themselves describe imaginable and plausible future advancements in technology, organization, and/or business processes that provide the means by which logistics functions are significantly improved. Theme development commits G-4 resources to a specified effort and outcome: the gathering of information for experimentation that is imperative to our ability in demonstrating that it will deliver a required capability. Properly developed themes support the goal of informing experimentation plans by providing concept developers useful knowledge. This initial information allows the researcher to appropriately build the theme ensuring a satisfactory outcome. The theme build process focuses on items of impact throughout a specified time period, working from an unconstrained view of all possible factors impacting the problem. (LIA, 2006)

Installation Units. Mounts, cables, brackets, and other hardware required to physically interface a device (such as a radio, weapon, smoke generator, decontamination device/detector) with an Army vehicle. The vehicle may be for air, land, or water use. The IU may be installed by a contractor or depot, during vehicle production or overhaul/rebuild, or may be installed by a field unit. (AR 700-127, 19 Jan 06)

Integrated Diagnostics. A structured process that maximizes the effectiveness of diagnostics by including pertinent elements such as testability, automatic and manual testing, training maintenance aids, and computer-aided engineering as a means of providing a cost-effective capability to detect and unambiguously isolate all faults known or expected to occur. (AR 700-127, 19 Jan 06)

Integrated Logistics Support (ILS). A unified and iterative approach to the management and technical activities needed to influence operational and materiel requirements and design specifications, define the support requirements best related to system design and to each other, develop and acquire the required support, provide required operational phase support at lowest cost, seek readiness and LCC improvements in the materiel system and support systems during the operational life cycle, and repeatedly examine support requirements throughout the service life of the system. (AR 700-127, 19 Jan 06)

Intelligent Agents/Systems. A software agent that exhibits some form of artificial intelligence. Software agents are often used for data mining, often based on fixed pre-programmed rules, and they have the ability to adapt and learn. (LIA Future Logistics Innovation Themes Document, 2006)

Inter-Agency. A broad generic term that describes the collective elements or activities of the Department of Defense and other U.S. Government agencies, regional and international organizations, nongovernmental organizations, and commercial organizations engaged in a common effort.

Interim Contractor Support (ICS). A method of support used in compressed or accelerated acquisition programs, or when design is not sufficiently stabilized. Provides all or part of a materiel system support by contract for a specified interim period after initial deployment to allow organic support capability to be phased in. A support acquisition technique rather than a support concept. (AR 700-127, 19 Jan 06)

Intergovernmental Organization Coordination. The ability to effectively coordinate with key intergovernmental organization to ensure unity of effort and support of U.S. objectives (e.g., United Nations, European Union, Organization of American States). (Modified JP3-08)

Irregular Warfare. The ability to conduct warfare that has as its objective the credibility and/or legitimacy of the relevant political authority with the goal of undermining or supporting that authority. Irregular warfare favors indirect approaches, though it may apply the full range of military and other capabilities to seek asymmetric approaches, in order to erode an adversary's power, influence and will. Also called IW. (QDR Execution Roadmap for Irregular Warfare)

Joint Air Operations. The ability to employ joint forces to achieve military objectives within and through the air domain. Such operations include those to establish local air superiority, provide missile defense, assault support operations and execute strikes. (JP 1-02, derived from "Air Control Operations")

Joint Access & Access Denial Operations. The ability to conduct military operations across any domain, opposed or unopposed, to gain or deny freedom of action within a given battlespace. (Modified JFEO JIC)

Joint Command & Control. The ability to exercise authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. A commander performs command and control functions through an arrangement of personnel, equipment, communications, facilities, and procedures to plan, direct, coordinate, and control forces and operations in the accomplishment of the mission. (Derived from C2 JFC, Feb 04 and JP 1-02)

Joint Deployment/Rapid Distribution. The ability to deliver mission ready, tailored forces and sustainment globally and on time for the full range of military operations. (Derived from Focused Logistics Joint Functional Concept; Campaign Plan for Integrating Joint Deployment and Global Distribution, version 2.3)

Joint Force Generation. The ability of DOD to man, equip, and organize resources and to develop Joint Force skills necessary to ensure the Joint Force Commander has the capabilities to fulfill the National Military Strategy. Personnel and equipment are resourced through recruiting and acquisition programs, and are implicitly linked to Joint requirements. Developing personnel and unit skills to perform military tasks and functions are accomplished through Service and Joint education, training, and exercise programs. (Derived from NMS, 2004)

Joint Force Management. The ability to integrate existing and future human and technical assets from across the Joint Force to make the right capabilities available at the right time and place in support of the National Defense Strategy. (Derived from Force Management Joint Functional Concept dtd 2 June 2005)

Joint Functional Concepts (JFC). A description of how a future JFC will integrate a set of related military tasks to attain capabilities required across the range of military operations. Joint functional concepts derive specific context from the joint operating concepts and promote common attributes in sufficient detail to conduct experimentation and measure effectiveness. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Joint Global Deterrence. The ability to prevent aggression or coercion threatening vital interests of the United States and/or our national survival. It involves activities to convince adversaries not to take courses of action that have grievous results by means of decisive influence over their decision making. (Derived from the Strategic Deterrence JOC, Feb 04)

Joint Homeland Defense. The ability to protect U.S. sovereignty, territory, domestic population, and critical defense infrastructure against external threats and aggression, or other threats as directed by the President. (Strategy for Homeland Defense and Civil Support, Jun 05)

Joint Information Operations. The ability to conduct operations using the integrated employment of the core capabilities of Electronic Warfare (EW), Computer Network Operations (CNO), Psychological Operations (PSYOP), Military Deception (MILDEC), and Operations Security (OPSEC), in concert with specified supporting and related capabilities*, to influence, disrupt, corrupt or usurp adversarial human and automated decision-making while protecting our own. (Derived from DRAFT DODD 3600.1)

Joint Interagency/IGO/MN/NGO Coordination. The ability to coordinate between elements of the DoD, engaged U.S. Government agencies, intergovernmental organizations, nongovernmental organizations, multinational entities (e.g., partnership states) for the purpose of accomplishing an objective. (Derived from JP 3-0800)

Joint Land Operations. The ability to employ joint forces to achieve military objectives within the Land Domain. Such operations include offensive operations, defensive operations, and/or stability operations. Joint Land operations will require the Regional Component Commander (RCC) to employ joint forces to engage adversaries across the spectrum of traditional, irregular, catastrophic, and disruptive challenges. They are conducted as part of a campaign or major joint operation and extend across the full range of military joint operations (ROMO). Joint land operations can include operational maneuver from strategic and operational distances to directly attack centers of gravity in order to achieve the joint force commander's desired objectives. Close combat is a fundamental capability for successful joint land operations across the greater part of the ROMO. Joint Land Operations can include maneuver and engagement in order to destroy opposing forces, secure key terrain, control vital lines of communications, or to establish local or regional military superiority. Ultimately, Joint Land Operations seek to control territory, populations, and resources, which may require a long term commitment, in order to achieve national objectives. (Modified from JP 1-02)

Joint Logistics. The ability to provide effective, responsive, and efficient movement and sustainment capacity; exercise control from end to end; and provide certainty to the supported Joint force commander that forces, equipment, sustainment, and support will arrive where needed and on time in all domains. (Derived from the Focused Logistics Joint Functional Concept, December 2003)

Joint Maritime/Littoral Operations. The ability to employ joint forces through the maritime/littoral domain to achieve military objectives. Such operations may include destruction of enemy naval and coastal forces, expeditionary/amphibious operations and support, control of strategic approaches, establishment of local military superiority, control of maritime commerce, and the conduct and support of operations throughout the theater. (Modified JP 1-02)

Joint Net-Centric Operations. The ability to exploit all human and technical elements of the joint force and its mission partners by fully integrating collected information, awareness, knowledge, experience, and decision making, enabled by secure access and distribution, to achieve a high level of agility and effectiveness in a dispersed, decentralized, dynamic and/or uncertain operational environment. (Derived from Net-Centric Environment JFC)

Joint Protection. The process, set of activities, or use of capabilities by which the Joint Force prevents/mitigates adverse effects on personnel (combatant/non-combatant), physical assets, and information of the United States, allies and friends, required to ensure fighting potential can be applied at the decisive time and place against the full spectrum of threats. The Joint Force will achieve this through the tailored selection and application of multi-layered, active and passive, lethal and non-lethal, offensive and defensive measures, within all domains, across the range of military operations, based on assessment of acceptable level of risk. (Modified from Protection Joint Functional Concept (JFC), Jun 04)

Joint Public Affairs Operations. The ability to plan, coordinate and synchronize U.S. military public information activities and resources in order to support the commander's operational and strategic objectives through the communication of truthful, timely and factual unclassified information about joint military activities within the area of operation (AO) to foreign, domestic, and internal audiences. This capability includes advising the commander on the effects of public information activities on operations, and the effects of operations on foreign, domestic and internal audiences. (Derived from JP 3-61)

Joint Shaping. The ability to support Joint Force, Interagency and Multinational operations - inclusive of normal and routine military activities – performed to dissuade or deter potential adversaries and to assure or solidify relationships with friends and allies. Shaping is executed continuously with the intent to enhance international legitimacy and gain multinational cooperation in support of defined military and national strategic objectives and national goals. These activities are designed to assure success by shaping perceptions and influencing behavior of both adversaries and allies. Each capability supporting Shaping Operations, to include Information Operations, must adapt to a particular theater and environment and may be executed in one theater in order to achieve effects in another. (Derived from 3 Jan 05/18 April OPSDEPs TANK on "Standardizing Campaign Phases and Terminology")

Joint Space Operations. The ability to employ joint forces across all domains to achieve national objectives in, from and/or through space. (Derived from JP 3-14)

Joint Special Operations & Irregular Warfare. The ability to conduct operations that apply or counter means other than direct, traditional forms of combat involving peer-to-peer fighting between the regular armed forces of two or more countries. The ability to conduct operations in hostile, denied, or politically sensitive environments to achieve military, diplomatic, informational, and/or economic objectives employing military capabilities for which there is no broad conventional force requirement. These operations may require low visibility, clandestine, or covert capabilities that are applicable across the range of military operations. They can be conducted independently of or in conjunction with operations of conventional forces or other government agencies, and may include operations through, with, or by indigenous or surrogate forces. (Derived from JP 1-02)

Knowledge. In the context of the cognitive hierarchy, knowledge is information analyzed to provide meaning and value, or evaluated as to implications for the operation. (FM 6-0)

Land Defense. The ability to detect, deter, prevent, and defeat land threats against the Homeland. [Homeland Security (HLS) Joint Operating Concept (JOC), Feb 04]

Level of Repair Analysis (LORA). An analytical methodology used to assist in developing maintenance concepts and establishing the maintenance level at which components will be replaced, repaired, or discarded based on economic/non-economic constraints and operational readiness requirements. Also known as Repair Level Analysis (RLA). (AR 700-127, 19 Jan 06)

Leverage Mission Partners. The ability for commanders to achieve/maintain unity of effort and to leverage the capabilities of mission partners not under his command. Mission partners may include other DOD units, non-DOD agencies, coalition and international organizations. This is accomplished through coordination, collaboration, influence, persuasion, negotiation and diplomacy as appropriate. (C2 JIC)

Logistician. A command or agency other than the MATDEV, CBTDEV, trainer, or user representative, responsible for ILS program surveillance and evaluation in the acquisition process. (AR 700-127, 19 Jan 06)

Logistic Brigade (LOG BDE). Works for the theater logistic commands irrespective of service affiliation, to facilitate sustained support across the JOA. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Logistics Management Information (LMI). Logistics management information comprises the support and support-related engineering and logistics data acquired from contractors for use in materiel management processes such as those for initial provisioning, cataloging, and item management. Depending upon specific program requirements, this information may be in the form of summary reports, a set of specific data products, or both. (AR 700-127, 19 Jan 06)

LOC Protection. The ability to conduct activities or operations to protect land, sea, air, space, and cyber routes that connect an operating military force with its source of sustainment. (Modified JP1-02)

Maintainability. A characteristic of design and installation that provides inherently for the system to be retained or restored to a specified condition within a given time when the maintenance is performed using prescribed procedures and resources. (AR 700-127, 19 Jan 06)

Maintenance Planning. Establishing a maintenance structure for a system. Source selection authority (including RCM) and maintenance engineering are used to provide an effective and economical framework for the specific maintenance requirements of the system. (AR 700-127, 19 Jan 06)

Man. The ability to recruit personnel to meet Service and Joint requirements. (Derived from JP 1-02)

Manage Indigenous Displaced Persons. The ability to manage persons who have been forced to leave their home for reasons such as religious or political persecution of war, but have not crossed an international border. (JCA Working Group Definition, 14/15 Mar 06)

Manage Enemy Prisoners of War. The ability to manage detained persons, as defined in Articles 4 and 5 of the Geneva Convention, who are captured while engaged in combat under orders of their government. (JP 1-02)

Manpower. The personnel strength (military and civilian) as expressed in terms of the number of men and women available to the Army. (AR 700-127, 19 Jan 06)

MANPRINT. The entire process of integrating the full range of human-factor engineering, manpower, personnel, training, health hazard assessment, system safety, and Soldier survivability throughout the materiel development and acquisition process to ensure optimum total system performance. (AR 700-127, 19 Jan 06)

Maritime Defense. The ability to detect, deter, prevent, and defeat maritime threats against the Homeland. [Homeland Security (HLS) Joint Operating Concept (JOC), Feb 04]

Maritime Interdiction. The ability to conduct operations by other than air or missile means to divert, disrupt, delay or destroy the enemy's military potential and/or infrastructure before it can be used effectively against friendly forces or noncombatants. (Modified JP 3-03)

Maritime/Littoral Expeditionary Operations. The ability to conduct operations requiring immediate deployment/employment of forces into remote or austere environments. Characteristics of expeditionary operations are tailored forces, forward deployed, rapid deployment, expeditionary basing at sea and ashore, forcible entry, and sustainment. (Modified USMC Warfare Publication)

Maritime/Littoral Fires. The ability to provide fires by maritime gun, missile, and electronic warfare systems in support of a unit or units tasked with achieving the commander's objectives

Materiel Change. All efforts to incorporate a hardware or software change to a system or end item in production and/or in the field, involving engineering, testing, manufacture, acquisition, and application to improve or enhance its capability to perform its mission, to be produced more effectively, or to better achieve the design-to-cost goal. These changes have historically been referred to as product improvements, modifications, conversions, reconfiguration, or retrofits. (AR 700-127, 19 Jan 06)

Materiel Command. The materiel command is responsible for national-level (for example, wholesale) logistics support of fielded systems. This includes national maintenance point, national inventory control point, depot, and technical assistance functions. In most instances, the support command is AMC. (AR 700-127, 19 Jan 06)

Materiel Developer. The command, organization, or agency responsible for accomplishing life cycle system management of a materiel system to include the research, development, production, fielding and sustainment that fulfills DA-approved system requirements. (AR 700-127, 19 Jan 06)

Materiel System. An all-inclusive term used to describe the total aggregate of equipment being developed, acquired, and managed by a materiel proponent. The materiel system includes the logistics support hardware and software being developed and acquired to support the mission-performing equipment. (AR 700-127, 19 Jan 06)

Measure. Quantitative or qualitative basis for describing the quality of task performance.

Measures of Performance. Measures designed to quantify the degree of perfection in accomplishing functions or tasks.

Measures of Effectiveness. Measures designed to correspond to accomplishment of mission objectives and achievement of desired effects.

Mechatronics. The synergistic combination of mechanical engineering, electronic engineering, and software engineering. This interdisciplinary engineering field involves the study of automata from an engineering perspective to control advanced hybrid-systems, automotive subsystems and every day equipment. Mechatronics is centered on mechanics, electronics and computing which, combined, make possible the generation of simpler, more economical, reliable and versatile systems. (LIA Future Logistics Innovation Themes Document, 2006)

Media Relations. The ability to plan and conduct activities to provide truthful, timely and accurate information about military activities, consistent with security guidelines, through the media, to national and international audiences. (Derived from JP 1-02 and JP 3-61).

Metaverse. A globally distributed, online, massively multi-user, persistent state world rendered with sufficient detail to qualify as virtual reality and with sufficient interconnection to the real world to significantly impact it. (LIA Future Logistics Innovation Themes Document, 2006)

Metric. A quantitative measure associated with an attribute.

Military Diplomacy (MD). The ability to support those activities and measures U.S. military leaders take to engage military, defense and government officials of another country to communicate USG policies and messages and build defense and coalition relationships. (Derived from March, 2004 National Military Strategic Plan for the War on Terrorism)

Military Assistance of Civil Disturbances (MACDIS). The ability to provide a mission set of civil support involving DoD support, normally based on the direction of the President, to suppress insurrections, rebellions, and domestic violence, and provide federal supplemental assistance to the states to maintain law and order. The ability to provide forces and equipment to support the several states, the District of Columbia, and U.S. territories and possessions to restore and maintain law and order by suppressing insurrections, rebellions, riots and domestic violence. While normally based at the direction of the President with the consent of the Governor, in rare cases this mission may be performed without a Governor's consent to enforce Federal laws. (Strategy for Homeland Defense and Civil Support, Jun 05; Homeland Security JOC, Feb 05)

Military Assistance to Civil Authorities. The ability to provide forces, equipment or training to support the Principal Federal Official (PFO) of the Lead Federal Agency (LFA) on an as-requested, as-available, usually reimbursable basis. Examples include, but are not limited to, mitigating the effects of natural or man-made disasters, wild land firefighting and CBRNE consequence management. (Strategy for Homeland Defense and Civil Support, Jun 05; Homeland Security JOC, Feb 04)

Military Support to Civilian Law Enforcement Agencies (MSCLEA). The ability to provide a mission set of DOD support to civil authorities that include to civilian law enforcement agencies. This includes, but is not limited to: combating terrorism, counter-drug operations, border patrol augmentation, and critical infrastructure protection. The ability to provide forces, equipment or training to support civilian Federal, state or local law enforcement agencies. Examples include, but are not limited to, counter-drug operations, border patrol augmentation, and critical infrastructure protection. (Strategy for Homeland Defense and Civil Support, Jun 05; Homeland Security JOC, Feb 04)

Military Deception (MILDEC). The ability to execute actions to deliberately mislead adversary decision makers as to friendly military capabilities, intentions, and operations, thereby causing the adversary to take specific actions (or inactions) that will contribute to the accomplishment of the friendly mission. (Derived from DRAFT JP 3-58)

Mission. The end state, purpose, and associated tasks assigned to a single commander.

Mixed System. An information system that supports both financial and non-financial functions of the Federal government or components thereof. (U.S. Army PEO EIS and Software Engineering Center, The Enterprise Solutions Competency Center, ERP/SOA Resource Center)

Molecular Self-Assembly. The assembly of molecules without guidance or management from an outside source. Self-assembly can occur spontaneously in nature, for example in cells and other biological systems, as well as in human engineered systems. It usually results in the increase in internal organization of the system. Biological self-assembling systems have been shown to have superior handling, biocompatibility and functionality. These advantages are due directly to self-assembly from biocompatible precursors creating biomaterials engineered at the nano-scale. (LIA Future Logistics Innovation Themes Document, 2006)

Monitor Execution, Assess Effects, and Adapt Operations. The ability for Commanders to maintain SA, assess plan execution effectiveness and rapidly update plans by identifying alternative COAs and redirect forces as circumstances change. Commanders must have visibility over friendly unit decisions and capabilities and the ability to monitor and react to changes in adversary status. Planners must be able to predict desirable and undesirable attack consequences and how effects may propagate throughout an adversary's system. The ability to respond rapidly and effectively to changing circumstances will enable commanders to maintain the initiative. (C2 JIC)

Multi-modal Sensing. The use of multiple sensing modalities (magnetic, optical, electrical, etc.) to detect and analyze motion, light, electric and magnetic fields, etc.

National Support Area. Strategic level location from which equipment and supplies reside for support of JFCs. Generic term which includes Intermediate Staging Bases outside a specific theater.

Near-zero Latency. Latency is the total time delay between the transmission of a communication and its interception at a remote location. Communication over large distances can introduce time delays of one or two seconds and are noticeable by humans. Aside from communication latency, latency in end-to-end components can contribute to overall latency in an end-to-end system. Near-zero latency refers to the reduction in latency to the smallest possible value with the best available technology. (LIA Future Logistics Innovation Themes Document, 2006)

Network-centric. Realization of a networked environment (including infrastructure, systems, processes, and people) that enables a completely different approach to warfighting and business operations. The foundation for net-centricity is the Department's Global Information Grid (GIG). (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Network Management. The ability to provide the network with the desired level of quality, agility, and trustworthiness. NM focuses on the configuration, availability, performance and manageability of network services and the underlying physical assets that provide end-user services, as well as connectivity to enterprise application services. (Derived for Joint Concept of Ops for GIG NetOps)

Non-financial System. An information system that supports non-financial functions of the Federal government or components thereof and any financial data included in the system are insignificant to agency financial management and/or not required for the preparation of financial statements.

Nongovernmental Organization Coordination. The ability to effectively coordinate with key nongovernmental organizations to ensure unity of effort and support of U.S. objectives (e.g., Red Cross/Crescent, Catholic Relief Services). (Modified JP3-08).

Non-recurring Engineering (NRE). The one-time cost of researching, designing, and testing a new product. NRE is unlike production costs, which must be paid continually in order to maintain production.

Objective. A desired end derived from guidance.

OBJ TSC. Serves as the operational and tactical logistics headquarters for the ARFOR, providing command and control of all logistics operations within the JOA. The OBJ TSC is a joint capable design that can support the JFC and is capable of command and control of logistics operations, employing the effects-based approach to military decision making and planning in support of C/JTF operations. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Observation & Collection (All Domains). The ability to use sensors in order to detect and monitor both physical and non-physical objects and events in all domains (i.e., Physical -- maritime, air, space, land; Virtual -- cyber and information; Human -- social, moral and cognitive). Observation and collection include the gathering of pertinent environmental factors that can influence operations throughout the domains. Collection is the means in which observed information is obtained prior to processing. (JCA CRC, 28 Apr 05; modified from JP 2-01; JCA CRC – Mar 06).

Ocean/Hydro/River Survey & Support Operations. The ability to conduct surface and subsurface operations that collect, or enable the collection of, unique environmental conditions in support real time and future operations (i.e., hydrographic, bathymetric, tidal, acoustic, traffic-ability, surface and subsurface conditions).

Offensive Counterair Operations. The ability to conduct offensive operations to destroy, disrupt, or neutralize enemy aircraft, missiles, launch platforms, and their supporting structures and systems both before and after launch, but as close to their source as possible. Offensive counterair operations range throughout enemy territory and are generally conducted at the initiative of friendly forces. These operations include attack operations, fighter sweep, escort, and suppression of enemy air defenses. Also called OCA. (Modified JP 1-02)

On-Line Analytical Processing (OLAP). Broad set of technologies that facilitate drill-down or aggregate analyses, as well as presentation, allocation and consolidation of information along multiple dimensions (e.g., product, location and time). These technologies are well-suited for management by exceptions or objectives, as well as automated or judgmental decision-making. (Extracted from the Encyclopedia of Data Warehousing and Mining)

Operational Availability. A measure of the degree to which a system is either operating or is capable of operating at any time when used in its typical operational and support environment. (AR 700-127, 19 Jan 06)

Operational Planning. The ability to plan using approach that directly ties offensive actions to campaign objectives, drawing on global resources and considering global consequences. Planning must be conducted with the collective knowledge of the decisions and plans of others to produce coherent integration. Planners must be able to focus on exploiting critical adversary vulnerabilities and also must consider friendly critical capabilities and potential collateral damage. Parallel, distributed, collaborative planning capabilities and improved assessment tools are needed to compress process timelines. However, collaboration does not imply decision making by committee or consensus. The ability to assess the suitability of a plan through wargaming and mission rehearsal prior to execution is also needed. (C2 JIC)

Operations Research (OR). Mathematical and constraint programming, and other techniques for mathematically or computationally determining optimal solutions for objective functions in the presence of constraints. (Extracted from the Encyclopedia of Data Warehousing and Mining)

Operations Security (OPSEC). The ability to identify critical information and subsequently analyze friendly actions attendant to military operations and other activities to: a) identify those actions that can be observed by adversary intelligence systems; b) determine indicators hostile intelligence systems might obtain that could be interpreted or pieced together to derive critical information in time to be useful to adversaries; c) select and execute measures that eliminate or reduce to an acceptable level the vulnerabilities of friendly actions to adversary exploitation. (Derived from DRAFT DODD 3600.1)

Operational Reach. The distance and duration across which a unit can successfully employ military capabilities. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Opportunistic Optimization. The ability to optimize based on opportunities. An example of this would be a robot that can optimize its behavior when it senses the opportunity based on data it obtains from sensory elements. (LIA Future Logistics Innovation Themes Document, 2006)

Organize. The ability to package personnel and equipment into optimal units to meet the needs of the Joint Force Commanders. (Derived from Joint Doctrine Encyclopedia)

Outreach. A means by which LTA performs the Discovery process to engage the larger R&D community in order to ensure awareness and understanding of activities that may influence near-, mid-, and far-term R&D initiatives of significance for logistics. (LIA Future Logistics Innovation Themes Document, 2006)

Packaging, Handling, and Storage. The resources, techniques, and methods required for preserving, transporting, loading and unloading, and storing materiel systems, their support equipment, BSM (for example, ammunition, batteries, and POL), and associated supplies of all classes. Includes the procedures, environmental considerations, and equipment preservation requirements for both short- and long-term storage. (AR 700-127, 19 Jan 06)

Pattern Matching. The act of checking for the presence of the constituents of a given pattern. Pattern matching is used to check that things have desired structure and to find relevant structure. (LIA Future Logistics Innovation Themes Document, 2006)

Peace Operations. The capability to conduct a broad range of activities encompassing peacekeeping operations and peace enforcement operations conducted in support of diplomatic efforts to establish and maintain peace. (JP 3-07.3). (JP 1-02)

Performance Based Logistics. An approach that establishes weapon system readiness goals and encourages the creation of incentives to attain those goals aided by clear lines of authority and accountability. PBL places accountability for readiness on program managers who are given the latitude to contract for sustainment from organic providers, the industrial sector, or a partnership between organic and commercial providers. (11th Glossary of Defense Acquisition Acronyms and Terms)

Personnel. Military and civilian persons of the skill level and grade required to operate and support a system, in peacetime and wartime. (AR 700-127, 19 Jan 06)

Personnel Recovery Operations. Operations focused on the task of recovering captured, missing, or isolated personnel from harm's way. PR includes but is not limited to theater search and rescue; combat search and rescue; search and rescue; survival; evasion; resistance; and escape; evasion and escape; and the coordination of negotiated as well as forcible recovery options. PR can occur through military action, action by nongovernmental organizations, other U.S. government-approved action, and/or diplomatic initiatives, or through any of these. (JP 1-02)

Photonic Band Gap. An energy range (and corresponding wavelength range) for which a material neither absorbs light nor allows light propagation. The energy gap in a photonic band-gap material can be created by inducing defects in a material. Photonic band-gap materials hold potential for applications ranging from optical communications to quantum computation. (LIA Future Logistics Innovation Themes Document, 2006)

Photonics. The science and technology of generating and controlling photons, particularly in the visible and near infra-red light spectrum. Scientists in the field of photonics have a strong interest in the use of photons to carry information. The science and applications of photonics are usually based on laser light. (LIA Future Logistics Innovation Themes Document, 2006)

Photovoltaics. The field of electrical engineering and semiconductor physics which is concerned with the development of and research into solar cells. (LIA Future Logistics Innovation Themes Document, 2006)

Plan. Any detailed scheme, program, or method worked out beforehand for the accomplishment of an objective, e.g., a plan of attack. A plan is a form of prediction.

Planning. The ability to create and revise plans rapidly and systematically, as circumstances require; occurs in a networked, collaborative environment, requires the regular involvement of senior DOD leaders, and results in plans containing a range of viable options. (Adaptive Planning Roadmap v1.1)

Planning & Direction. The ability to develop intelligence requirements, coordinate and position the appropriate collection assets, from the national to the tactical level, to ensure robust situational awareness and knowledge of intended domains is gained. (JCA CRC, 28 Apr 05; modified from JP 2-01)

Plasma-based Materials. Materials that are processed via plasma processing techniques. Plasmas have become indispensable for advanced materials processing in many high-tech industries, especially the microelectronics industry. (LIA Future Logistics Innovation Themes Document, 2006)

Point of Need. A physical location designated by the JFC as a receiving point for forces or commodities, for subsequent employment, emplacement, or consumption.

Portfolio Management. The processes, practices and specific activities to perform continuous and consistent evaluation, prioritization, budgeting, and finally selection of investments that provide the greatest value and contribution to the strategic interest of the organization. Through portfolio management, the organization can explicitly assess the tradeoffs among competing investment opportunities in terms of their benefit, costs, and risks. Investment decisions can then be made based on a better understanding of what will be gained or lost through the inclusion or exclusion of certain investments. ("A Summary of First Practices and Lessons Learned in Information Technology Portfolio Management", Page 4, Federal CIO Council Best Practices Committee, March 2002)

Post-production Support (PPS). The management and support activities necessary to ensure continued attainment of readiness and sustainability objectives with economical logistics support after the cessation of the production phase for the acquisition or modernization of a system or equipment. (AR 700-127, 19 Jan 06)

Power Projection Bases. Generic Term referring to locations where forces have been deployed from the Continental United States or other theaters in preparation for employment. The political impact of a Power Projection Base may be to shape advisory behavior and prevent hostilities. If not, forces are then moved into the JOA to support the operation.

Predictive Intelligence. The ability to use intelligence that determines the enemy's intent and anticipates future enemy actions based on its capabilities. (JP 2-01; JCA CRC Mar 06)

Presence. The ability to appropriately position forces to advance and defend U.S. interests by supporting deterrence, projecting power, promoting regional stability and U.S. security commitments, and ensuring continued access.

Processing and Exploitation. The ability to ensure data and information obtained from collection is assimilated through a variety of means to prepare for analysis and production. (JCA CRC, 28 Apr 05; modified from JP 2-01)

Precision Delivery Platform. Air, Surface (Ground and Sea), Subsurface vehicle or apparatus meant to carry and deposit people, equipment or supplies to the point of need without requiring further relocation to meet customer's need. In air: delivery to the aircraft; surface: delivery to the vehicle, ship, boat or ground location for immediate use; subsurface: delivery to a location where submarine commander has designated. Implies very specific times and very small margins of error.

Prediction. The ability to determine future states in order to recognize and exploit opportunities. It encompasses extrapolation from current conditions combined with an understanding of likely actions. From a logistics perspective, it provides the capability to define, assess, and anticipate logistics courses of action, branches, and sequels. Ultimately, the goal of prediction is preemption of demand. (LIA, May 06)

Prediction and Cooperation. The condition that allows the ability to project future outcomes to problems with high degrees of accuracy or possibly predetermine the outcome of proposed courses of action. (LIA Future Logistics Innovation Themes Document, 2006)

Predictive Analytics. Predictive Analytics compasses a variety of techniques from statistics and data mining that process current and historical data in order to make "predictions" about future events. Such predictions rarely take the form of absolute statements, and are more likely to be expressed as values that correspond to the odds of a particular event or behavior taking place in the future.

In business, predictive models are often not embedded in operational processes and activated during live transactions. The models process historical and transactional data to identify the risk or opportunity associated with a specific customer or transaction. These analyses weigh the relationship between hundreds of data elements to isolate each customer's risk or potential, which guides the action on that customer.

Predictive analytics is widely used in making customer decisions. One of the most well-known applications is credit scoring, which is used throughout financial services. Scoring models process a customer's credit history, loan application, customer data, etc., in order to rank-order individuals by their likelihood of making future credit payments on time. Predictive analytics are also used in insurance, telecommunications, retail, travel, healthcare, pharmaceuticals and other fields. (Wikipedia)

Predictive Modeling. The process through which mathematical or numerical technologies are used to understand or reconstruct past behavior, and predict expected behavior in the future. Commonly used tools include statistics, data mining and operations research, as well as numerical or analytical methodologies that rely on domain-knowledge. (Extracted from the Encyclopedia of Data Warehousing and Mining)

Preplanned Product Improvement. Planned future evolutionary improvement of developmental systems for which design considerations are effected during development to enhance future application of projected technology, including improvements planned for ongoing systems that go beyond the current performance envelope to achieve a needed operational capability. (AR 700-127, 19 Jan 06)

Process. A system of operations in the production of something; or, a series of actions, changes, or functions that bring about an end or result. Advances in technology provided information system and communications capabilities that enabled the transformation of the process from manual and local to automated and centralized, with better efficiency and effectiveness. (FM 6-0)

Prognostics. The use of data in the evaluation of a system or component for determining the potential for impending failures. (AR 700-127, 19 Jan 06)

Prognostics and Diagnostics. The process of predicting the future state of a system. Prognostics and Diagnostics systems comprise sensors, a data acquisition system, and microprocessor-based software to perform sensor fusion, analysis, and reporting/interpreting of results with little or no human intervention in real-time or near real-time. (LIA Future Logistics Innovation Themes Document, 2006)

Program Management Documentation (formerly development/program management plan). Documents prepared by the CBTDEV and MATDEV that record program decisions; contain the user's requirement; provide the life-cycle plans for development, testing, production, and support of the materiel system. Used for all acquisitions. An audit trail provided by documents of record that shows all phases of planning and program execution. (AR 700-127, 19 Jan 06)

Protect Against Conventional Weapons. The ability to prevent/mitigate adverse effects to designated personnel, physical assets, and information from conventional weapons. (New definition provided by Joint Protection working group (JCA Offsite Dec 04)).

Protect Against WMD Threat. The ability to integrate and synchronize the dynamic activities of the Department of Defense across the full range of U.S. Government counter-proliferation, nonproliferation, and consequence management efforts to counter WMD, their means of delivery, and related materials. (Derived from National Military Strategy to Combat WMD, Feb 06)

Protect Against Terrorist Threat. The ability to prevent/mitigate adverse effects to designated personnel, physical assets, and information from terrorist acts. (New definition from Force Protection working group (JCA Offsite – Dec 04)).

Protection from Exploitation. The ability to prevent/mitigate adverse effects to designated personnel and physical assets information from enemy actions and to take full advantage of any information that has come to hand for tactical, operational, or strategic purposes. (Modified from JP 1-02).

Provide and Employ Joint Fires. The ability to provide and employ lethal and nonlethal means to defeat enemy forces or to maintain freedom of movement. Joint fires refer to all types of ordnance to include bombs, rockets, missiles, and artillery, as well as other nonlethal means against enemy targets. Employment of Joint Fires is inextricably linked to the ability to conduct decisive maneuver. (Revised from UJTL, CJCSM 3500.04C)

Psychological Operations (PSYOP). The ability to conduct planned operations to convey selected information and indicators to foreign audiences to influence their emotions, motives, objective reasoning, and ultimately the behavior of foreign governments, organizations, groups, and individuals. The purpose of PSYOP is to induce or reinforce foreign attitudes and behavior favorable to the originator's objectives. (Derived from JP 1-02)

Public Affairs Operational Planning. The ability to advise, plan, synchronize and facilitate the timely release of factual public information in support of the commander's strategic and operational objectives. (Derived from JP 3-61)

Public Information. The ability to disseminate truthful, timely and accurate information about military activities, consistent with security guidelines, to local, national and international audiences. (Derived from JP 1-02 and JP 3-61)

Public Websites. The ability to plan, create and sustain delivery of Public Information via a command-sponsored public website. (Derived from JP 1-02 and JP 3-61)

Quantum Computation and Communication. The use of quantum physics to develop secure communications, computers, and processes demonstrating significantly greater capabilities than possible with digital computers. (LIA Future Logistics Innovation Themes Document, 2006)

Quantum Cryptography. An approach to ultra-secure communications that uses quantum mechanics. Traditional cryptography employs various mathematical techniques to restrict eavesdroppers from learning the contents of encrypted messages where as quantum cryptography is based on the physics of information. Using quantum phenomena such as quantum superpositions or quantum entanglement, one can design and implement a communication system which can always detect eavesdropping due to the fact that measurements on the quantum carrier of information (e.g., a photon) disturbs the photons state. (LIA Future Logistics Innovation Themes Document, 2006)

Radio Frequency Identification (RFID). A method of storing and remotely retrieving data using devices called RFID tags or transponders. An RFID tag is a small object that can be attached to or incorporated into a product, animal, or person. RFID tags contain antennas to enable them to receive and respond to radio-frequency queries from an RFID transceiver. Passive tags require no internal power source, whereas active tags require a power source. (LIA Future Logistics Innovation Themes Document, 2006)

Range of Military Operations (ROMO). Operations that encompass the use of military capabilities across the range-of-military-operations, including war and those short of war. These military actions can be applied to complement any combination of the other instruments of national power and occur before, during, and after war. (Derived from Joint Pub 1-02)

Relevant Knowledge. Encompasses the universe of ideas/concepts from which innovative solutions for logistics functions may emerge. It includes the organization of information gathered during the discovery process such that it provides relevant and actionable knowledge for logistics decision-makers. It covers the continuum from near- to far-term, and can logically be organized into themes. (LIA Future Logistics Innovation Themes Document, 2006)

Reconstitution. Those actions taken by a military force during or after operational employment to restore its combat capability to full operational readiness.

Reconstruction. The ability to rebuild the critical systems or infrastructure (i.e., physical, power, communications, economic, justice, governance, societal) necessary to facilitate long-term security and the transition to legitimate local governance. It includes addressing the root cause of the conflict. Reconstruction is likely to be a civil led effort. (Derived from Stability Ops Working Group)

Recovery. Actions taken to extricate damaged or disabled equipment for return to friendly control or repair at another location. (JP 1-02)

Redeployment. The transfer of forces and materiel to support another JFC's operational requirements, or to return personnel, equipment, and materiel to the home and/or demobilization stations for reintegration and/or out processing. (JP 1-02)

Reliability. A fundamental characteristic of a system expressed as the probability that an item will perform its intended functions for a specified time under stated conditions. Reliability ensures that a weapon system is ready to undertake a mission whenever and wherever tasked with a minimum maintenance infrastructure. (AR 700-127, 19 Jan 06)

Reliability-centered Maintenance. A disciplined logic or methodology used to identify preventive maintenance tasks to realize the inherent reliability of equipment at a minimum expenditure of resources. (AR 700-127, 19 Jan 06)

Render Safe Procedures. The application of special explosive ordnance disposal methods and tools to provide for the interruption of functions or separation of essential components of unexploded explosive ordnance to prevent an unacceptable detonation. (AR 700-127, 19 Jan 06)

Repositioning. To place military units, equipment, or supplies at or near the point of planned use or at a designated location to reduce reaction time, and to ensure timely support of a specific force during initial phases of an operation. (JP 1-02)

Responsive Infrastructure. The ability to conduct research and development and provide an industrial infrastructure for developing, building, and maintaining strategic offense forces and defensive systems. This includes the research facilities, manufacturing capacity, and skilled personnel needed to develop, produce, field, sustain, and modernize the elements of the new triad into an integrated strategic force as well as the supporting intelligence and command and control capabilities. (Mod NPR 2001 and NPR Implementer 2003)

Retrograde. Retrograde is the return of forces, system components and carcasses requiring maintenance (or re-set.).

Qubit (also, quantum bit). A unit of quantum information that can hold more than two values. A qubit's most important distinction from a classical bit, however, is not the continuous nature of the state (which can be replicated by any analog quantity), but the fact that multiple qubits can exhibit quantum entanglement, a nonlocal property that allows a set of qubits to express superpositions of different binary strings (01010 and 11111, for example) simultaneously. Such "quantum parallelism" is one of the keys to the potential power of quantum computation. In essence, each independent state of the quantum particle used in the computer can follow its own independent computation path to conclusion while its other states are observed and changed. (LIA Future Logistics Innovation Themes Document, 2006)

Scale-free Social Networks. Social networks are a type of complex system, where the patterns of interaction between individuals and the patterns of connectivity that social networks exhibit are characteristic. In scale-free social networks a few highly connected nodes link the remaining sparsely connected nodes to the system and connectivity is based on a power law. (LIA Future Logistics Innovation Themes Document, 2006)

Scenario (or Business Scenario). An account or synopsis of a projected course of action or events. (DOD Instruction 8260.2, Implementation of Data Collection, Development, and Management for Strategic Analyses, 21 January 2003)

Sea Basing. The ability to rapidly deploy and project combat power from the sea, provide continuous support/sustainment/force protection to joint expeditionary forces, provide expanded operational maneuver options, and facilitate assured access & entry without reliance on land bases within the Joint Operating Area. (Sea basing JIC 24 June 2005)

Security. The ability to establish and maintain protective measures that ensure a state of inviolability from hostile acts or influence. It includes reinforcing the perception of security by the populace. (Derived from definition #2 of the JP 1.02)

Security Cooperation. The ability for DOD to interact with foreign defense establishments to build defense relationships that promote specific U.S. security interests, develop allied and friendly military capabilities for self-defense and coalition operations, including allied transformation, improve information exchange and intelligence sharing to help harmonize views on security challenges, and provide U.S. forces with peacetime and contingency access and en route infrastructure. DOD Security Cooperation will be integrated with other instruments of national power (diplomatic, economic, and informational) to achieve national security, defense and foreign policy objectives. (SECDEF 2003 Security Cooperation Guidance).

Semi-autonomous Agents. Software agents that are capable of making independent decisions and taking actions to satisfy internal goals based upon their perceived environment. (LIA Future Logistics Innovation Themes Document, 2006)

Sense and Respond (Logistics). Sense and Respond Logistics is a transformational network-centric concept that enables Joint effects-based operations and provides precise, agile support. Sense and Respond Logistics relies upon highly adaptive, self-synchronizing, and dynamic physical and functional processes. It predicts, anticipates, and coordinates actions that provide competitive advantage spanning the full range of military operations across the strategic, operational, and tactical levels of war. Sense and Respond Logistics promotes doctrinal and organizational transformation, and supports scalable coherence of command and control, operations, logistics, intelligence, surveillance, and reconnaissance. Implemented as a cross-service, cross-organizational capability, Sense and Respond Logistics provides an end-to-end, point-of-effect to source-of-support network of logistics resources and capabilities. Within Sense and Respond Logistics, every entity, whether military, government, or commercial, is both a potential consumer and a potential provider of logistics. It delivers flexibility, robustness, and scalability for Joint expeditionary warfare through adaptive, responsive, real-time, demand and support networks within U.S., allied, and coalition operations. (OFT Concept Document (Short Version) Operational Sense and Respond Logistics 6 May 2004).

Shared Situational Awareness. The ability of leaders and personnel in the JDDE to understand the supported commanders intent and be aware of the effect and consequences that all distribution decisions will have on supporting the commander and the stakeholders that comprise the enterprise.

Single Army Logistics Enterprise (SALE). An integrated logistics solution that builds, sustains, and generates warfighting capability by enabling a common logistics operating picture from the battlefield (e.g., Global Combat Support System-Army to the wholesale (national) level (for example, Logistics Modernization Program). (AR 700-127, 19 Jan 06)

Single Integrated Financial Management System. A unified set of financial systems and the financial portions of mixed systems encompassing the software, hardware, personnel, processes (manual and automated), procedures, controls and data necessary to carry out financial management functions, manage financial operations of the agency and report on the agency's financial status to central agencies, Congress and the public. Unified means that the systems are planned for and managed together, operated in an integrated fashion, and linked together electronically in an efficient and effective manner to provide agency-wide financial system support necessary to carry out the agency's mission and support the agency's financial management needs. (U.S. Army PEO EIS and Software Engineering Center, The Enterprise Solutions Competency Center, ERP/SOA Resource Center)

Signpost. Recognizable, potential future events indicating that a technology is advancing in a particular direction of interest and at a pace significantly above that extrapolated from current trends. (LIA, 2006)

Space Control. The ability to ensure freedom of action in space for the United States and its allies and, when directed, denies freedom of action in space to an adversary. It may involve activities conducted by land, sea, air space, and/or special operations forces. (JP 3-14)

Space Force Application. The ability to conduct combat operations, in through and from space to influence the course and outcome of conflict. (JP 3-14)

Spatio-temporal Databases. Databases that are concerned with objects that may constantly be changing either their location or shape, or sometimes both. Spatio-temporal databases are highly dynamic databases due to the temporal dimension. (LIA Future Logistics Innovation Themes Document, 2006)

Special Operations. The ability of specially organized, trained and equipped military and paramilitary forces to conduct operations in hostile, denied, or politically sensitive environments to achieve military, diplomatic, informational, and/or economic objectives employing military capabilities for which there is no broad conventional force requirement. These operations may require low visibility, clandestine, or covert capabilities that are applicable across the range of military operations. They can be conducted independently of or in conjunction with operations of conventional forces or other government agencies. They may include operations through, with, or by indigenous or surrogate forces. Also called SO. (Derived from JP 1-02).

Stability Operations. Military support for Stability, Security, Transition and Reconstruction (SSTR). The ability to conduct military and civilian activities across the spectrum from peace to conflict to establish or maintain order in states or regions. Military support to stability, security, transition and reconstruction (SSTR) are Department of Defense activities that support U.S. Government plans for stabilization, security, reconstruction and transition operations, which lead to sustainable peace while advancing U.S. interests. Stability operations are a core U.S. military mission that the Department of Defense shall be prepared to conduct and support. (DODD 3000.05 Military Support for SSTR Operations)

Standard. The minimum proficiency required in the performance of a task. For mission-essential tasks of joint forces, each task standard is defined by the JFC and consists of a measure and criterion.

Standardization and Interoperability. The process of developing concepts, doctrines, procedures, and designs to achieve and maintain the most effective levels of compatibility, interoperability, interchangeability, and commonality in the fields of operations, administration, and materiel. Interoperability: The ability of materiel systems, units, or forces to provide services to, and accept services from, other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together. (AR 700-127, 19 Jan 06)

Stirling Engine. Stirling engines convert any temperature difference directly into movement by the repeated heating and cooling of a sealed amount of working gas. The working gas is sealed within the piston cylinders, so there is no exhaust gas and no valves are required, unlike other types of piston engines. (LIA Future Logistics Innovation Themes Document, 2006)

Store. As an information management activity, store is to retain relevant information in any form, usually for oval and documentation, until it is needed for exercising command and control. C2 systems store information because not all information collected or processed can be displayed at the same time, nor is it relevant at all times. The DA Form 1594, Staff Journal, is a primitive storage means. It retains information or analyses of past outcomes for future use; however, it is difficult to rapidly resort, reorder, and analyze data recorded on this form. (FM 6-0)

Strategic Attack. The ability to conduct an offensive action against a vital target(s), whether military, political, economic, or other, specifically selected to achieve NCA or combatant commander's strategic objectives/effects. (Modified JP 3-0, Chap IV, para 3f)

Strategic Communication. The ability to focus United States Government processes and efforts to understand and engage key audiences to create, strengthen or preserve conditions favorable to advance national interests and objectives through the use of coordinated information, themes, plans, and programs, and actions synchronized with other elements of national power. (Derived from Draft QDR Execution Roadmap for Strategic Communication 2006; unsigned).

Supply Support. Management actions, procedures, and techniques required to determine, acquire, catalog, receive, store, transfer, issue, and dispose of principal and secondary items. Includes provisioning for initial support as well as for replenishment supply support. (AR 700-127, 19 Jan 06)

Supply Support Activity (SSA). Activities assigned a Department of Defense activity address code and that have a supply support mission, i.e., direct support supply units, missile support elements, and maintenance support units. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Supportability. That characteristic of a system and its support system design that provides for sustained system performance at a required readiness level when supported in accordance with specified concepts and procedures. (AR 700-127, 19 Jan 06)

Supportability Analyses (SA). A wide range of related analyses that should be conducted within the system's engineering process. The goals of supportability analyses are to ensure that supportability is included as a system performance requirement and to ensure that the system is concurrently developed or acquired with the optimal support system and infrastructure. Examples of these analyses are repair level analysis, reliability predictions, reliability-centered maintenance (RCM) analysis, failure modes, effects and criticality analysis (FMECA), and LCC analysis. (AR 700-127, 19 Jan 06)

Support Equipment. All ancillary and associated equipment (mobile or fixed) required to operate and support a materiel system, including ASIOE and component items such as trucks, air conditioners, generators, ground-handling and maintenance equipment, tools, metrology, calibration and communications equipment, test equipment, and automatic test equipment with diagnostic software for both on- and off-equipment maintenance. Incorporates the planning and acquisition of support necessary for the operation and sustainment of the support and test equipment itself. Also includes additional support equipment required due to the aggregation of the new system into high organizational-level densities, such as additional line haul fuel trucks or ammunition carriers. (AR 700-127, 19 Jan 06)

Surface Warfare. The ability to conduct maritime operations in order to destroy or neutralize enemy naval surface forces and merchant vessels. (Modified JP 1-02)

Sustainment. The provision of personnel, logistics, and other support required to maintain and prolong operations or combat until successful accomplishment or revision of the mission or of the national objective.

Synchronize Execution Across All Domains. The ability to conduct effective planning as an essential means of achieving synchronized action provided the plan remains appropriate to the situation and is executed properly. However, in keeping with the adage that "no plan survives contact with the enemy," the commander must be able to achieve synchronization when operations are not executed as planned. This can be done through centralized redirection, as in the past, or in a decentralized manner through self-synchronization of subordinate forces. The latter is the preferred method for future C2, but this approach may not always be feasible or appropriate. The commander must have the ability to employ whichever method of synchronization is appropriate to the situation. Self-synchronization requires subordinates to have a clear understanding of the commander's intent, shared SA and operational trust, good communications and the ability to act without detailed direction from above. (C2 JIC)

System Readiness Objectives (SRO). Measures relating to the effectiveness of an operational unit to meet peacetime deployability and wartime mission requirements. Considers the unit set of equipages and the potential logistics support assets and resources available to influence the system operational readiness and sustainability. Peacetime and wartime SRO will differ due to usage rate, operational modes, mission profiles, and operational environments. Examples of SRO include operational availability at peacetime usage rates, operational availability at wartime usage rates, sortie generations per given timeframe (aircraft), and maximum administrative and logistics downtime (intermittent missions). Relates quantitatively to materiel system design parameters and to system support resource requirements. (AR 700-127, 19 Jan 06)

System Support Package (SSP). The set of support elements planned for a system in the operational (deployed) environment, provided before and tested and evaluated during technical T&E and user T&E to determine the adequacy of the planned support capability. (AR 700-127, 19 Jan 06)

Tactical Air Support. The ability to conduct air operations carried out in coordination with surface forces and which directly assist land or maritime operations. (Modified JP 1-02)

Task. An action or activity based upon doctrine, standard procedures, mission analysis or concepts that may be assigned to an individual or organization.

Technical Data. The communications link between people and equipment. Specifications, standards, engineering drawings, task analysis instructions, data item descriptions, reports, equipment publications, tabular data, computer software documentation, and test results used in the development, production, testing, use, maintenance, demilitarization, detoxification, and disposal of military components and systems. Used in designing and executing an ILS program. Computer programs, related software, financial data, and other information relating to contract administration are not technical data. (AR 700-127, 19 Jan 06)

Technology. [1] – Electronic, chemical/material, or digital(software) products and systems considered as a group [2] process for manufacture, invention, or method of such [3] Reference to a specific minimum critical dimension (CD) in the manufacture of silicon based semiconductor devices for applications including microprocessors and memory.

Telepresence. The condition that allows instant remote presence with the ability to see, hear, touch, taste, and smell. It provides a virtual environment for humans to control devices, robots, etc., in a hostile and/or remote real environment with the experience of being fully present at the live real world location remote from one's own physical location. (LIA Future Logistics Innovation Themes Document, 2006)

Teraflop. One trillion floating point operations per second.

Testability. A design characteristic that allows the functional or operational status of a unit and the location of any faults within the unit to be confidently determined in a timely fashion. The status of a unit refers to whether the unit is operable, inoperable, or degraded. Testability applies to all hardware levels of indenture (device, board, equipment, or system). To achieve testability goals, attention must be paid to all design indenture levels and to the integration of test and diagnostic strategies between these levels. The application of testability to the design has impacts in all test activities—manufacturing test in the factory environment, operational test during mission phases to determine overall mission capability, and maintenance testing at all maintenance levels or echelons as driven by the maintenance concept requirements. (AR 700-127, 19 Jan 06)

Test, Measurement, and Diagnostic Equipment (TMDE). A system or device that can be used to evaluate the operational condition of a system or component to identify or isolate any actual or potential malfunction. Diagnostic and prognostic equipment, automatic and semiautomatic equipment, and calibration test and measurement equipment, whether identifiable as a separate end item or contained within the system. (AR 700-127, 19 Jan 06)

Theme. A set of future conditions brought about through imaginable and plausible (deep) future advancements in technology or business processes that provide the means by which logistics functions will be significantly improved and logistics requirements radically reduced. (LIA Future Logistics Innovation Themes Document, 2006)

Theater Sustainment Command (TSC). Provides theater level command and control of logistics for the Army. (Operational Level Logistics Command and Control Concept Capability Plan Version 1.11 November 1, 2005)

Total Ownership Cost. The sum of all financial resources necessary to organize, equip, and sustain military forces sufficient to meet national goals in compliance with all laws, DOD policies, all standards in effect for readiness, safety and quality of life, and all other official measures of performance for DOD and its components. (This includes costs to research, develop, acquire, own, operate, and dispose of defense systems, other equipment and real property; costs to recruit, retain, separate, and support military/civilian personnel; and all other DOD business operations costs.) (AR 700-127, 19 Jan 06)

Training Aid. Generic term referring to any item developed, procured, or fabricated for the purpose of assisting in the conduct of training and process of learning (for example, models, displays, slides, books, and pictures). (AR 700-127, 19 Jan 06)

Training and Training Devices. The processes, procedures, techniques, and equipment used to train personnel to operate and support a system, including individual and crew training, new equipment training, sustainment training at gaining installations, and support for the TDs themselves. (AR 700-127, 19 Jan 06)

Training Device. A three dimensional object and associated computer software developed, fabricated, or procured specifically for improving the learning process. Training devices are justified, developed, and acquired to support designated tasks in developmental or approved individual and collective training programs, soldier manuals, military qualification standards, or Army training and evaluation programs. Training devices are categorized as either system or non-system devices. A system training device is designed for use with one system. A non-system training device is designed for general military training or for use with more than one system. (AR 700-127, 19 Jan 06)

Transportability. The inherent capability of an item to be moved efficiently by towing, self-propulsion, or carrier, using equipment that is planned for the movement of the item via rail, highway, water, and air. (AR 700-127, 19 Jan 06)

Transportation Closure. The actual arrival date of a specified movement requirement at port of debarkation. (JP 1-02)

Understanding. In the context of the cognitive hierarchy, understanding is knowledge that has been synthesized and had judgment applied to it in a specific situation to comprehend the situation's inner relationships. Commanders may know what is happening and why. They and others apply judgment to transform that knowledge into understanding. Judgment is a purely human skill. It is based on experience, expertise, and intuition. While staffs may support commanders in achieving understanding, the most important understanding is that which commanders achieve. When commanders achieve situational understanding, they see patterns emerging from events in the area of interest. They can anticipate the consequences of both their own force's actions and the enemy's. While true understanding should be the basis for their decisions, commanders realize that uncertainty and time preclude achieving perfect situational understanding before deciding and acting. (FM 6-0)

Undersea Warfare (USW). The ability to conduct operations to establish battlespace dominance in the underwater environment, which permits friendly forces to accomplish the full range of potential missions and denies an opposing force the effective use of underwater systems and weapons. It includes offensive and defensive subsurface, antisubmarine, and mine warfare operations. (Modified JP 1-02)

Unit-Configured Load. Pallets or commodity packages created at a source of supply for a specific military unit; unit configured packaging facilitated rapid onward movement of commodities to designated deployed units in the JOA.

User. The MACOM designated to receive the system from the MATDEV for accomplishing an assigned operational mission under a TOE, TDA, or other enabling document. (AR 700-127, 19 Jan 06)

U.S. Government Interagency Integration. The ability to coordinate all instruments of national power to ensure unity of effort. Integrated planning, liaison, logistics, education, and training are critical elements that help synchronize the application and coordination with interagency partners to include state and local governments and agencies. (Modified JP3-08)

Vignette. A concise narrative description that illustrates and summarizes pertinent circumstances and events from a scenario.

Visual Information (VI) Activities. The ability to advise, plan, synchronize, and rapidly acquire and distribute visual products (still and video) to external audiences in support of commanders' strategic and operational objectives. (Derived from JP 1-02 and JP 3-61)

Appendix D. Memory Types

There are various types of memory devices on the market today and development activities that are underway to overcome the inherent limitation associated with any particular implementation. For a data collection system, there will be a mix of memory devices that will be employed in the data collection architecture. Memory devices can be categorized by two types: Volatile and Non-Volatile. As indicated by the category name, Volatile memory devices are devices that do not retain the information once the power has been removed, as compared to Non-Volatile memory devices that retain the information in the device independent of power. Similar to any computer today, data collection system architecture will employ various implementations of the Volatile and Non-Volatile memory devices. A family tree of memory devices are as shown in the figure below.

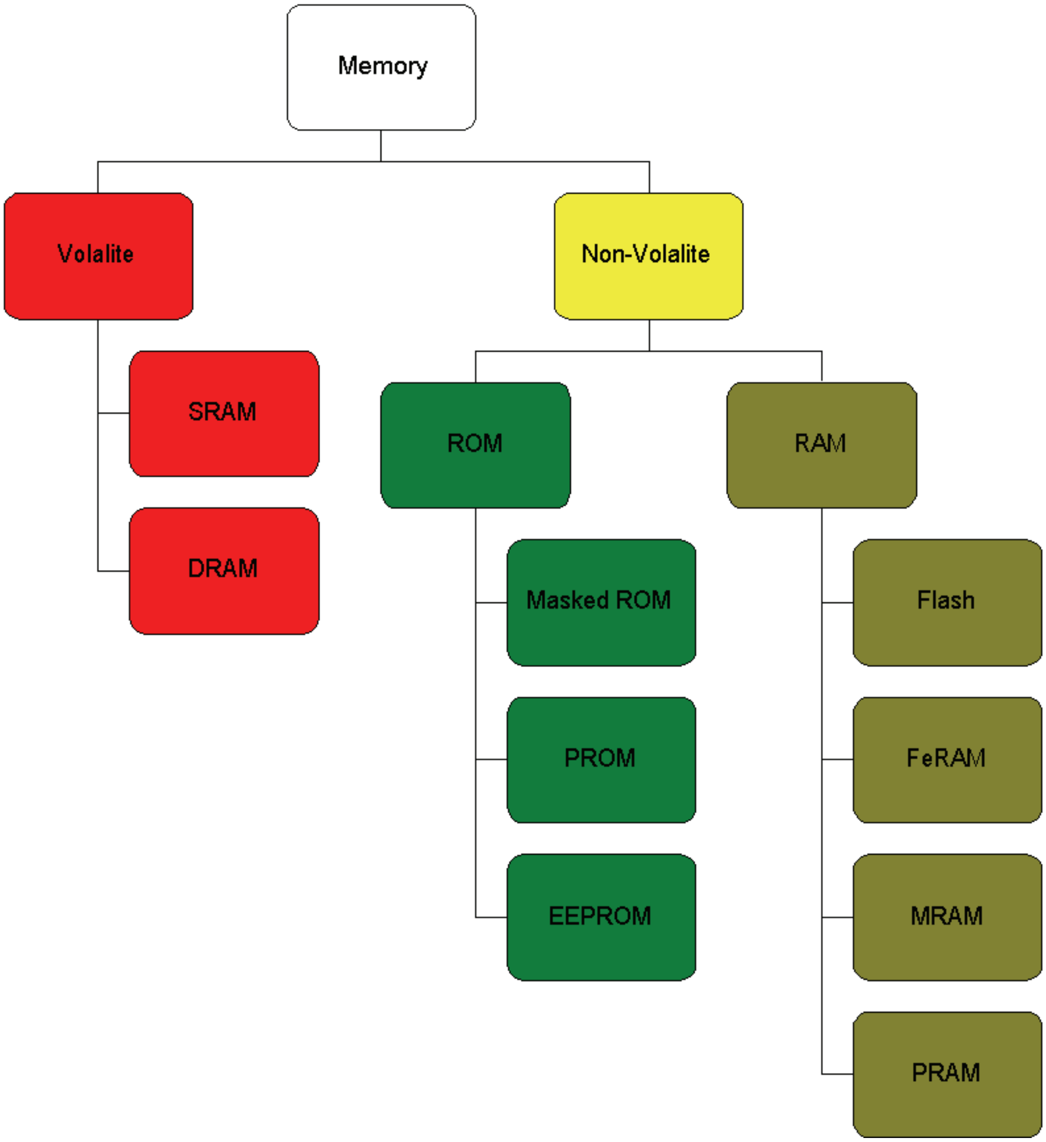


Table of memory acronyms:

SRAM	Static Random Access Memory
DRAM	Dynamic Random Access Memory
PROM	Programmable Read Only Memory
EEPROM	Electrical Eraseable Programmable Read Only Memory
Flash	
FeRAM	Ferroelectric Random Access Memory
MRAM	Magnetoresistive Random Access Memory
PRAM	Phase change Random Access Memory

Characteristics of the memory devices are outlined in the following table:

Type	Volatile?	Writeable?	Erase Size	Max Erase Cycles	Cost (per Byte)
SRAM	Yes	Yes	Byte	Unlimited	Expensive
DRAM	Yes	Yes	Byte	Unlimited	Moderate

Masked ROM	No	No	N/A	N/A	Inexpensive
PROM	No	Once	N/A	N/A	Moderate
EEPROM	No	Yes	Byte	Limited	Expensive
Flash	No	Yes	Sector	Limited	Moderate
FeRAM	No	Yes			
MRAM	No	Yes			
PRAM	No	Yes			

	MRAM	SRAM	DRAM	Flash	FeRam
Read Speed	Fast	Fastest	Medium	Fast	Fast
Write Speed	Fast	Fastest	Medium	Low	Medium
Array Efficiency	Med/High	High	High	Med/Low	Medium
Future Scalability	Good	Good	Limited	Limited	Limited
Cell Density	Med/High	Low	High	Medium	Medium
Non-Volatility	Yes	No	No	Yes	Yes
Endurance	Infinite	Infinite	Infinite	Limited	Limited
Cell Leakage	Low	Low/High	High	Low	Low
Low Voltage	Yes	Yes	Limited	Limited	Limited
Complexity	Medium	Low	Medium	Medium	Medium

INTENTIONALLY LEFT BLANK.

Appendix E. Current Data Collection Interface Standards

There are many types of interfaces that are in existence that have evolved over the decades to transfer data. Data acquisition systems have employed many of these standard interfaces to exchange data to the users. The popular interfaces are Ethernet, PCI, USB, PCI Express, Firewire, Compact Flash, GPIB, RS-232/485, and ISA. Since the accuracy and samples rates of most applications are perfectly within the capabilities of both board- and box-level solutions, other factors must be used to determine which solution is best for a particular application. Here are some of the key factors:

- Distance to the Sensor or Measurement
  - Distance is an important consideration for two reasons: First, cost is expensive for running long wires in a large system. Second, each foot of wire connecting your sensor or output to a remote host computer increases your susceptibility to noise.
- Portability
- Expandability
- Changing or Upgrading
- Price
- Pure Speed
  - See table for various bus/interface specifications and application to 16 bit A/D converter

Bus/Interface	Theoretical Bandwidth	Bandwidth 16-b A/D	Range	Portability
Ethernet (100Base-T)	100 Mb/s	6.25 MS/s	100 meters	Excellent
Gigabit Ethernet (1000Base-T)	1,000 Mb/s	62.5 MS/s	100 meters	Good
Fiber (100Base-FX)	100 Mb/s	6.25 MS/s	2,000 meters	Fair
Firewire 400 (IEEE 1394a)	400 Mb/s	25 MS/s	4.5 meters	Good
Firewire 800 (IEEE 1394b)	800 Mb/s	50 MS/s	4.5+ meters	Good
GPIB (IEEE 488)	12 Mb/s	0.75 MS/s	2 to 4 meters	Fair
PCI/PXI (33-MHz)	1, 056 Mb/s	66 MS/s	local	N/A
PCI/PXI Express	32 Gb/s	2,000 MS/s	local	N/A
PCI-X (133-MHz)	8.5 Gb/s	531 MS/s	local	N/A
RS-232	~100 kb/s	6.25 kS/s	15 meters	Good
RS-485	1 Mb/s	63.5 kS/s	1,200 meters	Fair
USB 2.0	480 Mb/s	30 MS/s	5 meters	Excellent

Appendix F. CLOE and MIMOSA

Common Logistics Operating Environment (CLOE) is a process that is developing the foundation of networked, embedded diagnostic technologies that will support a paradigm shift in logistics from a preventative maintenance to a condition based maintenance practice. As part of this transition, CLOE will help define common data standards, specifications and protocols that will be necessary. Another organization that deals with data structure in the commercial world is Machinery Information Management Open System Alliance (MIMOSA). The standards that MIMOSA is developing and promoting have a significant overlap and impact to the CLOE development. The following are examples of some items that MIMOSA has put forward in its process of standards:

- Issue: Definition of Machine Failure. An alternative too many subjective definitions of machine failures is to establish a single performance-related description of failure for a given type machine as a consensus definition. Recommendation that MIMOSA develop consensus definitions of performance-specific failure for each machine type contained in MIMOSA's set of lookup table entries.
- Issue: Machine Autopsies. MIMOSA incorporate data fields as necessary to identify a machine autopsy examiner into its prognostic protocols.
- Issue: Ancillary Machine History Data.
    - Machine brandname, model number, date of manufacture, serial number, and other identifiers than can be used to segregate machine histories into relational groups.
    - Machine root-cause failure mode effects plus any secondary failure mode that may be evidenced in the machine's condition history.
    - Operating environment details in terms of average load, ambient temperature, power quality, and other environmental considerations such as indoor/outdoor service that may contribute to accelerate machine failures.
    - Repair cycle number and repair service identification (in-house, third party contract, OEM) for machines that have experiences more than one lifetime as the result of repair. These data are essential to evaluating assumptions of repair to "good-as-new" condition. With these data, we can study subpopulations of same-type machines to quantify "goodness" of repairs.

INTENTIONALLY LEFT BLANK.

Appendix G. About the Authors

Romeo de la Cruz del Rosario, Jr. was born in La Plata, MD, in 1971. He received the B.E.E. degree from the Catholic University of America, Washington, D.C., in 1993 and the M.S.E. and Ph.D. degrees in Electrical and Computer Engineering from The Johns Hopkins University, Baltimore, MD. Since 1991 he has been an engineer at the Harry Diamond Laboratory then U.S. Army Research Laboratory working in several areas including high power microwave technology, ultra-wideband radar, and non-lethal technology. Since 1997, he has worked in the Sensors and Electron Devices Directorate, RF Electronics Branch. His research interests include characterization and modeling of heterostructure microwave devices and fabrication and analysis of electron devices and circuits. He is currently the team leader and ATO (Advanced Technology Objective) Manager for Prognostics and Diagnostics for Operational Readiness and Condition Based Maintenance. Dr. del Rosario is a member of Tau Beta Pi.

Kwok F. Tom was born in Washington, DC, in 1952. He received his B.S.E.E and M.S.E.E. from George Washington University in 1974 and 1980, respectively. He started his career as is a government electronics engineer working for the Department of the Army. With over thirty years of experience, he has worked on several programs from the target detection device (TTD) for the PATRIOT PAC2 missile system to proto-type radar systems based on Ultra-Wide Band and Ka Band frequencies. A significant amount of his work was performed on the design, development, production, test and evaluation and system performance analysis associated with the TTD. He was the project leader on the design team for a Ka radar system to be used for high resolution radar measurements. The work on the Ultra-Wide Band radar systems was in the role of group leader associated with the data reduction and image processing. Much of his current work is the team leader for the processing architecture for Prognostics and Diagnostics health monitoring systems.

Gregory A. Mitchell was born in Concord, MA in 1983. He received his B.S. degree in electrical engineering from the University of Maryland, College Park, MD in 2005, and is currently studying for his M.S.E. in RF and Microwave Engineering at The Johns Hopkins University, Baltimore, MD. Since 2002, he has worked at the Army Research Laboratory in the areas of tracking algorithms based on target signatures from magnetic sensor networks and also various active RFID applications. Currently, he is involved with the RF and Electronics Branch Prognostics and Diagnostics program, and is focusing on active RFID budget links and mesh network topologies for RFID sensor networks. Mr. Mitchell is a member of the Eta Kappa Nu electrical and computer engineering honors society.

Brian Glenn Ruth was born in Souderton, PA, in 1960. He received the B.S. degree in Physics from Drexel University in 1983, and has also pursued graduate studies in Electro-Physics at the University of Maryland, College Park, MD. Since 1981 he has been an electronics engineer at the Harry Diamond Laboratory then U.S. Army Research Laboratory working in several areas including high power microwave technology, complex systems modeling and simulation, and agent-based modeling and simulation. Since 1993, he has worked in several different branches within the Survivability/Lethality Analysis Directorate. In the past, his research interests included modeling electromagnetic devices and effects, in which area he has co-developed several models of high-power microwave (HPM) sources and mode-converting antennas in collaboration with academia. More recently, Mr. Ruth has investigated the application of complexity science techniques to vulnerability/lethality analysis, and has also developed the Cellular Automata Based Infiltration (CABIN) model and the Complex Reactive Behavior Combat Agent Model (CoRBCAM) in collaboration with academia. Mr. Ruth is a member of Sigma Pi, the Institute of Electrical and Electronics Engineers (IEEE), and the Association of Old Crows.

Peter J. Grazaitis was born in Dover, NJ in 1952. In 1975, he received his B.S. Degrees in Mathematics and Physics from the University of Scranton, Scranton, PA. In 1980, he received his M.S. degree in Computer Science from The Johns Hopkins University. He started his professional career in 1975 with Allied Chemical Corporation with a research team developing computer controlled crystal growing methods for synthetic crystals for optical and electrical applications. In 1976, he jointed the U.S. Army Human Engineering Laboratory, now the U.S. Army Research Laboratory, and worked on developing computer controlled data collection systems in support of field exercises that the Laboratory conducted. In 1993 he began working on research projects that focused on automated systems for logistical decision support. In 1995, he served as a team leader for on a software technical team supporting the Laboratory's Joint Logistics ACTD program. From 2000 to present, he has been conducting research to examine the use of emerging technologies in business process integration, web services, software agent, and artificial intelligence techniques and their ability to improve Soldier usability of logistical decision support systems. He manages a number of in-house and small business innovative research projects in support of his research efforts.

Tom Ferryman, Ph.D., has over 30 years of experience in a variety of R&D projects, including as Chief Scientist of the Statistical Sciences group at Pacific Northwest National Laboratory and as Chief Systems engineer at Lockheed Aircraft Services Company in charge of the R&D for a $140 million modification to the AC-130 Pave Specter Aircraft, and as Branch Head of the U.S. Navy's Gun Weapon System Analysis group. He has had in-depth involvement in developing analysis tools for a large variety of projects; including NASA Ames' Aviation Safety program including the development of algorithms for analysis of digital flight data, unstructured text data and fusion of multiple aviation data types (digital flight data, digital ATC data, unstructured text data, and survey data). (The NASA work won the 2005 R&D 100 Award for The Morning Report. See www.pnl.gov/statistics)

David E. Scharett has served the Federal Government for some 40 years. He has been with the Department of Energy's Pacific Northwest National Laboratory for the past 19 years researching applications for advanced technologies to meet defense needs. Prior to that Mr. Scharett was heavily involved in Air Force, Army, and Joint Test and Evaluation. A Command Pilot, Test Pilot and Top Gun with over 3000 hours of fighter aircraft and rotor wing experience, Mr. Scharett performed test and evaluation on new munitions, wrote tactics manuals, and developed Joint deployment/employment plans for Southwest Asia. His experience also includes nuclear certification board membership, weapons design, and foreign military exploitation at the compartmentalized level. During his active duty time, Mr. Scharett had extensive test and evaluation experience that included a joint 77 million dollar Army-Air Force initiative that field demonstrated 256 developmental systems many of which were in direct support of wartime CS/CSS operations. The results of these field tests culminated in a 6.5 billion dollar program in 29 MDEPs. Mr. Scharett was a lead planner for the RDJTF (now USCENTCOM) when it was formed to develop OPLANs for Southwest Asia. In that capacity he developed the requirements for all aspects of force deployment and sustainment to include medical services and supplies. He has had assignments in Southeast Asia, Europe, Southwest Asia, and CONUS. His experience includes assignments on the Air Staff – Pentagon, Numbered Air Force Headquarters, Joint forces, Deputy Vice Wing Commander, and Squadron and Flight Command. Mr. Scharett is currently on a Federal interagency assignment to the Army's Logistics Innovation Agency (LIA) as a technology advisor to the Director, LIA. In that capacity he leads a team that researches and evaluates advanced and emerging technologies that could have significant benefit to the Army CS/CSS community. A point of emphasis in this research is to identify novel energy sources that may exist today and those that are being developed or are envisioned in the future. Mr. Scharett has led a team that wrote the logistics portions of the Army Science and Technology Master Plan, a Congressional testimony document. He is responsible for reviewing all proposed Army Small Business Innovative Research (SBIR) topics for logistics application and benefit and then performs the same function for the over 4500 proposals that are submitted annually against those topics. Mr. Scharett has been on numerous source selection committees with contracts ranging from several hundred thousand dollars to seven hundred million. In support of LIA, Mr. Scharett presents "The Art of the Possible" briefing to a wide array of audiences including the Army Logistics Management College's (ALMC) Leadership Course and Change Management Course. He has also presented similar technology briefings to former and current G4s of the Army and AMC Commanders. Mr. Scharett has a Bachelors degree in Civil Engineering from Virginia Polytechnic Institute, a Masters from Golden Gate University and is a graduate of the Air Force War College, the Foreign Internal Defense School (counterterrorism), and was an adjunct professor at the post graduate level for St. Leo University. He is the author of numerous classified documents concerning threat vulnerabilities, tactics manuals, and foreign military exploitation, as well as several logistics articles published in the Army Logistician. He has held compartmentalized clearances, a Critical Nuclear Weapons Design Information (CNWDI) clearance, a DOE Q clearance, and currently holds a DoD Top Secret clearance. Mr. Scharett is a life member of several organizations to include the American Defense Preparedness Association, Red River Valley Fighter Pilots Association, Air Force Association, Military

Officers Association of America, American Legion, and the Society of American Military Engineers.

Charles J. Toomey Jr. currently serves as a Senior Logistics Research Analyst in support of the Logistics Innovation Agency, a field operating activity of the Headquarters, Department of the Army, G-4. He is a retired Army Colonel who recently completed over twenty-six years as a career military logistician. While on active duty, his positions of responsibility ranged from commanding three different supply and maintenance companies as a junior officer, Division Support Operations Officer, two tours of duty at the Army's Human Resources Command as a Quartermaster Corps assignment manager and branch chief, Maintenance Battalion Executive Officer, Special Assistant to the Director of the Defense Logistics Agency, Battalion Commander, Brigade Commander of the Pacific Theater's sole depot level distribution and maintenance facility, culminating his military career as the Defense Logistics Agency's Deputy Executive Director for Distribution and Reutilization Policy. Mr. Toomey's sixteen military relocations took him across the Continental United States on several occasions, including overseas tours in Australia and the Republic of South Korea. He holds a top secret security clearance and a Bachelors of Science degree in Engineering from the United States Military Academy at West Point, New York. He also holds a Masters of Science degree in Logistics Management from the Florida Institute of Technology and a Masters of Science degree in Strategic Studies from the U.S. Army War College. He is also a graduate of the U.S. Army Command and General Staff College. He maintains certificates from the Logistics Executive Development Course and Penn State Executive Development Program in Supply Chain Management. He is an active member of the Veterans of Foreign Wars, the American Legion, Knights of Columbus, the Association of the U.S. Army, and the U.S. Army Quartermaster Association.

No. of Copies	Organization
1 ELEC	ADMNSTR DEFNS TECHL INFO CTR ATTN DTIC OCP 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218
1 CD	DARPA ATTN IXO S WELBY 3701 N FAIRFAX DR ARLINGTON VA 22203-1714
1 CD	OFC OF THE SECY OF DEFNS ATTN ODDRE (R&AT) THE PENTAGON WASHINGTON DC 20301-3080
1 CD	US ARMY TRADOC BATTLE LAB INTEGRATION & TECHL DIRCTRT ATTN ATCD B 10 WHISTLER LANE FT MONROE VA 23651-5850
1 CD	US ARMY INFO SYS ENGRG CMND ATTN AMSEL IE TD F JENIA FT HUACHUCA AZ 85613-5300
1 CD	COMMANDER US ARMY RDECOM ATTN AMSRD AMR W C MCCORKLE 5400 FOWLER RD REDSTONE ARSENAL AL 35898-5000
3 CDS	PACIFIC NORTHWEST NATIONAL LAB ATTN C TOOMEY ATTN D SCHARETT ATTN T FERRYMAN PO BOX 999 RICHLAND WA 99352
1 CD	US ARMY RSRCH LAB ATTN AMSRD ARL CI OK TP TECHL LIB T LANDFRIED BLDG 4600 ABERDEEN PROVING GROUND MD 21005-5066
2 CDS	US ARMY RSRCH LAB ATTN AMSRD ARL HR MB P GRAZAITIS ATTN AMSRD ARL SL BS B RUTH ABERDEEN PROVING GROUND MD 21005-5068
6 CDS	US ARMY RSRCH LAB ATTN AMSRD ARL CI OK T TECHL PUB ATTN AMSRD ARL CI OK TL TECHL LIB ATTN AMSRD ARL SE RE G MITCHELL ATTN AMSRD ARL SE RE K TOM ATTN AMSRD ARL SE RE R DEL ROSARIO ATTN IMNE ALC HR MAIL & RECORDS MGMT ADELPHI MD 20783-1197

Total: 18 (1 ELEC, 17 CDs)

INTENTIONALLY LEFT BLANK.