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Defense Science Board Task Force Report

# ENGINEERING IN THE MANUFACTURING PROCESS

March 1993



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DEFENSE SCIENCE  
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MEMORANDUM FOR DIRECTOR, DEFENSE RESEARCH AND ENGINEERING

SUBJECT: Final Report of the Defense Science Board Task Force on  
Engineering in the Manufacturing Process

I am pleased to forward the attached DSB Summer Study Task Force report entitled "Engineering in the Manufacturing Process," which was co-chaired by Dr. Kent Bowen and Mr. Noel Longuemare. This study represents a logical continuation of DSB manufacturing studies performed in prior years, particularly in the areas of integrated product and process development and dual-use-manufacturing. In this study, however, the primary focus is on Science and Technology (S&T) and the application of IPPD and dual-use concepts even earlier than previous studies have recommended.

The Task Force found that the need to shift from a product focus to a process focus with the primary emphasis on value and solution rather than performance and schedule is of paramount importance. As has been shown in previous DSB studies, superior products result when the manufacturing processes are well understood and very capable. Needed performance features are created, but not at the expense of cost and schedule. DoD and defense industry management must insist on the early integration of product and process development. DoD and industry must depart from a unique part and process mind-set to one that allows for abundant use of commercial parts and processes. To minimize the effect of the industrial base's excess capacity and the current reduction trends, production plants must take maximum advantage of flexible manufacturing practices. Finally, to improve a poor record in transitioning from technology development to production, the S&T community must establish a process mentality at the outset. This new strategy, coupled with early learning through modeling, simulation, and physical experiments, will greatly reduce risk and uncertainty before programs enter acquisition.

I recommend that you review the recommended strategy and management approach contained in the Executive Summary. As a result of its deliberations, the Task Force also developed specific recommendations for experiments, summarized in Chapter 4, to be conducted within S&T Advanced Technology Demonstrations to validate the benefits of the new recommended approaches to S&T.

John S. Foster, Jr.  
Chairman

Attachment



DEFENSE SCIENCE BOARD

OFFICE OF THE SECRETARY OF DEFENSE  
WASHINGTON, D.C. 20301-3140

March 23, 1993

Dr. John S. Foster  
Chairman, Defense Science Board  
OUSD(A), Room 3D865, The Pentagon  
Washington, DC 20301-3140

Dear Dr. Foster:

Attached is the final report of the DSB Task Force Summer Study on *Engineering in the Manufacturing Process*. We believe that the Task Force has addressed fully the objectives of the Terms of Reference to make recommendations on engineering and manufacturing management and technology approaches that can be used to achieve a better product and process balance and result in both unit production and total life cycle cost reduction. Recommended management approaches include integrated product and process development and making the best use of commercial products, practices, and capabilities. The use of modeling and simulation is recommended as a means of achieving early learning and reducing risk.

We believe that implementation of our recommended management approach and the specific recommendations contained in the Executive Summary will provide the means to achieve technologically advanced weapon systems of superior quality but at a cost affordable in today's environment. Providing incentives to the defense industry to institutionalize the best commercial practices also serves to strengthen our nation's competitiveness.

This report is the result of the Task Force efforts by DSB members, consultants from industry and government advisors. It has been a pleasure and a privilege to have led such a talented and dedicated group.

*H. Kent Bowen*

*R. Noel Longuemare*

Dr. H. Kent Bowen  
Co-Chairman

Mr. R. Noel Longuemare  
Co-Chairman

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## EXECUTIVE SUMMARY

This report presents the recommendations of the Defense Science Board (DSB) Summer Study Task Force on *Engineering in the Manufacturing Process*. The terms of reference (TOR)<sup>1</sup> for this Task Force represent a logical continuation of DSB manufacturing studies performed in prior years, particularly in the areas of integrated product and process development (IPPD)<sup>2</sup> and dual-use-manufacturing. In this study, however, the primary focus is on Science and Technology (S&T) and the application of IPPD and dual-use concepts even earlier than previous studies have recommended.

During its study, the Task Force addressed engineering and manufacturing management and technology approaches that can be used to achieve a better product and *process* balance in the S&T phase, which precedes the formal acquisition process, and that result in both unit production and total life cycle cost reduction. It chose S&T "exit criteria" and metrics as the means to demonstrate *process* as well as performance capability during the S&T phase and to reduce downstream acquisition risks. The Task Force also examined a key enabler of IPPD and manufacturing enterprise control—advanced modeling and simulation technology. The work in this area by this Task Force relates to the work of another DSB Summer Study that specifically addressed simulation, the *Readiness, Simulation, and Prototyping* Task Force. The expanded use of best commercial products, practices, and manufacturing capabilities was also considered as an additional way to meet the Department of Defense (DoD) future needs for rapid transition to production and economic low-volume manufacturing.

As a result of its deliberations, the Task Force developed specific recommendations for experiments to be conducted within S&T Advanced Technology Demonstrations (ATDs) to validate the benefits of the new recommended approaches to S&T contained in this report.

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<sup>1</sup> A copy of the Terms of Reference can be found in Appendix A.

<sup>2</sup> Also referred to in previous studies as concurrent or simultaneous engineering.

## BACKGROUND

The change from a bipolar, well-defined threat to a diffuse, uncertain threat has dramatically altered the worldwide national security environment and reduced and changed U.S. defense materiel requirements. This new environment calls for high technology products to be produced with steeply declining procurement budgets. This change affecting U.S. defense industry is occurring at the same time that U.S. commercial industry is responding to a competitive and dynamic world economic situation in which a significant emphasis is being placed on improving product value, process yield, quality, and performance. The survivors in these environments will be firms that are world-class; that is, suppliers who deliver high quality products with the correct performance features at low cost and on time. A major opportunity exists for DoD to create the right conditions to attract such suppliers and take advantage of the rapidly advancing commercial manufacturing processes and product capability. In so doing, it can become a world-class customer.

The term "world-class" implies that the customer-supplier relationship is a long-term one during which profits or benefits, risks, knowledge, and information are shared. World-class suppliers and customers have a deep understanding of design, manufacturing, and IPPD principles. World-class companies are able to deliver products ahead of the competition and at a lower cost because they have acquired a deep understanding of their critical processes, and they design products around these process capabilities. World-class customers provide incentives and minimize non-value-added tasks to elicit responsiveness from suppliers. Suppliers are selected based upon their proven capabilities. Once the customer-supplier relationship is established and the supplier does encounter difficulties with a product or process, the world-class customer helps the supplier solve the problems. However, the supplier's processes are required to be in control and capable, and constant nonperformers are carefully weeded out. World-class customers typically do not overspecify their requirements but strive to minimize the how-to's—they do not compete with their supplier base. Becoming world-class requires profound change in behaviors, procedures, practices, systems, and policies.

The current climate of Defense Conversion and reinvestment is particularly conducive to the needed changes. First, DoD plans to maintain its technological edge by preserving S&T investment levels and emphasizing Advanced Technology Demonstrations (ATDs). This new S&T strategy is the key new ingredient in leveraging the DoD acquisition system in its development of IPPD capabilities with the benefit of significant

product and process improvements developed in these ATDs. Second, the ability to change is also enhanced by Congressional emphasis on dual-use-manufacturing and Defense Conversion. Third and very important, the U.S. industrial base has, in the last 5 to 10 years, undergone a transition to more and more world-class companies and world-class products especially in the competitive commercial area. Finally, more of a convergence exists today between the technology that is used in military systems and that used in commercial products.

Of paramount importance is the need to shift from a product focus to a process focus with the primary emphasis no longer on performance and schedule but, instead, on value and solution. Superior products result when the manufacturing processes are well understood and very capable. Needed performance features are created, but not at the expense of cost and schedule. DoD and defense industry management must insist on the early integration of product and process development and the elimination of functionally separate organizations. Overhead costs must be minimized by using only value-added tasks. Overspecification must be eliminated, and this can be accomplished by assuming commercial-like procurement practices. DoD and industry must depart from a unique part and process mind-set to one that allows for abundant use of commercial parts and processes. To minimize the effect of the industrial base's excess capacity and the current reduction trends, production plants must take maximum advantage of flexible manufacturing practices. Finally, to improve a poor record in transitioning from technology development to production, the S&T community must establish a process mentality at the outset.

### **TASK FORCE APPROACH**

The Task Force formed three subgroups to address the major points of the TOR. Each subgroup contributed a chapter to this report, giving the details of the approach, the experiments, and the recommendations. One subgroup considered requirements in the new S&T environment for early consideration of manufacturing processes and established criteria for making progress in the S&T phase (Chapter 1). Another subgroup examined the uses of advanced modeling and simulation in IPPD (Chapter 2). The third subgroup reviewed opportunities for increased use of best commercial products, practices, and capabilities (Chapter 3). To demonstrate the benefits of the recommended approach and to accelerate the application of the strategy across DoD, the Task Force proposed a number of experiments, to be conducted during the S&T phase. Because of the complexity of DoD acquisitions, clear and compelling evidence of the benefits is needed to support cross-the-

board change. The experiments were chosen to reflect various aspects of technologies, programs, and infrastructure and are summarized in Chapter 4. The recommended strategy and specific recommendations are summarized below.

## **RECOMMENDED STRATEGY**

The Task Force's assessment of the need for management process improvements is based on an understanding of the acquisition practices and constraints that have evolved over the past 40 years.<sup>3</sup> A history of institutionalized policies, management philosophies, training programs, contract rewards, and payment schedules has cast the mold for DoD programs. Constant performance orientation, using the schedule as a rigid form of management, changing the requirements late in the development process, not understanding R&D, giving low or no priority to process development, and making commercial products and capabilities the exception rather than the rule have all contributed to the problems facing DoD and the defense industry today. When process development has not been started early in the S&T phase, programs have fallen victim to high risk, resulting in cost overruns, schedule slips, and unattained performance goals. As a consequence, Defense acquisition has incurred micromanagement by the Congress, a disintegration of trust and harmony between the DoD and the defense industrial base, and a general public perception that the DoD is simply not doing its job. This perception can be dispelled by DoD becoming a world-class customer.

A DoD management process needs to be instituted that focuses from the outset of development on improving the manufacturing process, that uses new tools in modeling and simulation, and that takes advantage of commercial products, processes, and capabilities. There are four elements to this strategy that the Task Force believes are needed:

- Implement IPPD in S&T programs to initiate the cultural change and conduct experiments to demonstrate the benefits of the new approach.
- Build on complementary acquisition phase initiatives.
- Take advantage of the revitalized world-class commercial industrial base.
- Drive a new manufacturing philosophy into DoD from the top.

First, the advanced technology demonstrations (ATDs) planned in DoD's new S&T strategy offer a major opportunity to effect a cultural change, both in S&T and in DoD weapon system development and production. An emphasis on IPPD will guide the

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<sup>3</sup> A historical perspective on how the current situation came to be is contained in Appendix D.

transition from the current performance- and schedule-driven management process to a more balanced solution-driven process. This approach will provide superior technology with high quality, on-time delivery, and affordable costs. This new strategy, coupled with early learning through modeling, simulation, and physical experiments, will greatly reduce risk and uncertainty before programs enter acquisition.

Second, these efforts during S&T should build on complementary initiatives ongoing for the acquisition phase of product development. Examples are Defense Acquisition Board (DAB) emphasis on strict adherence to milestone exit criteria, the use of IPPD in programs such as the F-22 development program, and the attention given to process metrics, such as manufacturing yield for infrared (IR) focal plane arrays. The challenge will be to define implementations of these improved acquisition concepts that are appropriate in the S&T phase.

The third element of the strategy is to take advantage of recent advances in the commercial industry. As defense procurement funds continue to decline, it becomes increasingly important for DoD to make better use of commercial products, the commercial manufacturing base, and the best, world-class, commercial manufacturing policies. This strategy could enhance U.S. commercial competitiveness as well as provide a needed capability for defense products.

Fourth, as noted in the 1991 DSB Summer Study, *Weapon Development and Production Technology*, a new strategy will not be successful unless it is adopted and driven from the top. Cultural change does not occur unless there is a sense of need and urgency, but the current DoD budget environment should be sufficient motivation to reduce the waste and uncertainty. A clear management philosophy must be articulated to emphasize continuous improvement and a more balanced focus between product and process, to encourage a more reasonable business environment between contractors and the government, and to enable greater adoption and use of commercial products and practices. This change will require new policies, management systems, incentives, and extensive training to accelerate the transition, but will enable the DoD to become a world-class customer.

### **Manufacturing Technology Development Responsibilities**

To implement the recommended IPPD approach in balancing product and process development, the USD(A) must take a very active leadership role.

Under the recommended approach, the leaders and program managers of S&T Thrusts 1 through 5 (the "warfighting" thrusts) will be responsible for demonstrating both product performance *and* the product's critical manufacturing processes for the programs within their areas. Thrust 7, *Technology for Affordability*, will be responsible for processes and components common across several thrusts—e.g., rapid design and manufacturing of custom signal processors—and for the required engineering and manufacturing infrastructure. Thrust 6, *Synthetic Environments*, and Thrust 7 will be responsible for the infrastructure linking the electronic battlefield and the IPPD environment. Continuous user feedback by way of battlefield simulations coupled to system functional requirements, along with advanced process modeling and simulation, will provide the necessary mechanism to keep the user in the loop during design and avoid the costly problem of new requirements being imposed during Operational Test and Evaluation (OT&E).

All ATDs should be reviewed for product and process readiness and value before transitioning to Milestone I. While the task of integrating product and process is more familiar after Milestone I, clear expectations must be shown for ATDs well before Milestone I. The metrics should include the manufacturing process capability (e.g.,  $C_p$ ,  $C_{pk}$ ,<sup>4</sup> yield, unit production cost) and whether the product can be produced by commercial lines and used for both DoD and commercial applications. ATD exit criteria should include, along with successful product performance demonstrations, having a scalable manufacturing process in place with agreed-upon maturity-level exit goals.

After Milestone I, program managers will be held responsible for the further development and improvement of all processes unique to their respective programs. The effects of IPPD in the S&T phase will be lost without major investments in IPPD knowledge for the managers of the phases after Milestone I. The depth of process knowledge required and the addition of process metrics at Milestone reviews will be new to the program managers.

IPPD applies to more than relationships between the DoD and defense contractors through defense contracts. It is important that these principles be applied to the interactions between the various facets within the DoD itself—in particular between the organizations of the DDR&E and the Assistant Secretary of Defense for Production &

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<sup>4</sup> Process capability indices,  $C_p$  and  $C_{pk}$ , are defined in Appendix E.

Logistics [ASD (P&L)]---to ensure a seamless continuity throughout the life cycle of our next-generation defense systems.

### **Major Reengineering of Management Process**

To instigate the change within DoD and its suppliers, the defense community must reengineer and refocus the management processes. Underpinning this refocused management must be a DoD manufacturing philosophy that originates at the very top of the DoD leadership. The approach should be based on the adoption of IPPD, to include beginning IPPD in the S&T phase as part of a long-term education and measurement system leading to world-class systems. The institutionalization of manufacturing process maturity metrics will evolve into a DoD and industry standard for evaluating implementation maturity.

To stimulate industry's response—for industry must embrace the idea of beginning IPPD early in the S&T phase—the key is for DoD to make IPPD profitable. Incentives (contractual and otherwise) are needed to motivate industry to make the investment required to quantify metrics on all critical processes and initiate across-the-board improvements in the face of shrinking DoD budgets. Additionally, incentives should motivate industry to facilitate affordable, low-volume production through investments in flexible manufacturing systems. Industry should be permitted and encouraged to use commercial products and processes in DoD systems. Success of the approach will mean that all non-value-added functions are greatly minimized or eliminated.

### **Guiding Principles for a DoD Manufacturing Philosophy**

DoD and the industrial base need a set of guiding principles in a DoD Manufacturing Philosophy. It should be a major statement on emphasizing manufacturing process development in DoD acquisition. This manifesto should stimulate and institutionalize DoD and industry-wide use of IPPD as the management process to reduce risk and uncertainty beginning in the S&T phase and continuing in all succeeding phases of the acquisition process. DoD needs to develop metrics to gauge progress in IPPD implementation and to ensure that the cited objectives are achieved.

The guiding principles for a DoD manufacturing philosophy are as follows:

- Stimulate DoD and industry-wide use of IPPD.
- Develop metrics, goals, and incentives for assessing IPPD and stimulating DoD suppliers.

- Use proven process models.
- Integrate factory information systems.
- "Prove before improve" and "clean up before automate."
- Train managers at all levels in IPPD.
- Constrain product designs to fit the best commercial manufacturing capabilities wherever possible.
- Eliminate non-value-added activities to streamline the process.
- Provide incentives, not bureaucratic regulations.

As an example of an incentive, contract award evaluation criteria should include consideration of the offeror's demonstrated understanding of the capability of the critical manufacturing processes and the specific plans to mature the processes. A second type of incentive would be to provide award fees tied to progress in maturing key processes. Other incentives could be considered, but these two would confirm for industry and government program managers the importance of focusing on IPPD.

## **RECOMMENDATIONS**

### **Deputy Secretary of Defense**

Because top-level commitment is essential to the success of this approach, the Task Force recommends that the Deputy Secretary of Defense (DepSecDef) lead the charge in making DoD a world-class customer. As a first step, he should articulate a DoD Manufacturing Philosophy and ensure that this new policy has a priority. Then, he should see that this new philosophy is communicated and implemented throughout the Department. Cultural change will not occur overnight—continued management support and interest will be needed.

### **Under Secretary of Defense for Acquisition**

The first recommendation for the Under Secretary of Defense for Acquisition [USD(A)] is that he designate a champion to assist in instilling the new manufacturing philosophy in all aspects of defense acquisition. This champion will work with the DDR&E and Service Acquisition Executives (SAEs) to implement changes, educate and train the workforce, and institute metrics and incentives.

Next, the USD(A) should use the flexibility inherent in DoD acquisition policies (DoD Directive 5000.1 and DoD Instruction 5000.2) to require post-Milestone I programs to take advantage of risk-reduction activity performed in the S&T phase and to encourage the inclusion of IPPD in all programs past Milestone I. In many cases this should encourage the elimination of specific steps currently invoked under the 5000 series that would no longer be necessary under the new approach.

In implementing these recommendations, DoD must avoid becoming an "IPPD policeman" or requiring adherence to a strict methodology for implementing IPPD as defined by a set of "how-to" specifications. Rather, it should establish incentives to motivate industry to apply IPPD through a results-oriented approach. For example, DoD could develop for IPPD an assessment process similar to the Software Engineering Institute (SEI) self-assessment process for software.

#### **Director of Defense Research and Engineering**

The Task Force strongly recommends to the DDR&E that IPPD and appropriate exit criteria be implemented in ATDs and all program milestones. This implementation will require a cultural change in the technology community, making education and training of S&T Thrust Leaders and ATD program managers necessary. A major shift in resources will also be needed to develop the process technology and understanding.

Modeling and simulation must be implemented early in the S&T phase to optimize capabilities and accelerate learning. Use of modeling and simulation must continue throughout the product's transition from S&T through development and into production.

Commercial capabilities must be used to the maximum extent possible to satisfy DoD's product needs. To broaden the use of commercial capabilities and to accelerate the change to IPPD, specific experiments should be identified to demonstrate the range of feasibility of dual-use-manufacturing and document the benefits.

Joint planning between the R&D and P&L communities must be established and continued to provide continuity in maximizing and institutionalizing the use of IPPD.

Finally, the Task Force recommends that the DDR&E work with the USD(A) to implement experiments along the lines of those proposed in Chapter 4 of this report.

## **CONCLUSION**

This Task Force believes that the topic of engineering in the manufacturing process is one of the top issues facing DoD today. This topic has been reviewed extensively over the past several years, and it demands top-level, immediate attention.

In hindsight 5 or 10 years from now, DoD and industry will have failed in the new environment if the warfighter's needs are not satisfied with affordable, reliable systems that provide a technological advantage. Success will be achieved if DoD and its suppliers become world-class, if IPPD is adopted on a wide scale, and if the management changes are made to make maximum use of dual-use-manufacturing in products and to significantly reduce overhead, unnecessary constraints, and oversight functions.

# **1. INTEGRATED PRODUCT AND PROCESS DEVELOPMENT**

## **1.1 INTRODUCTION**

### **1.1.1 Terms of Reference**

This chapter responds specifically to the Terms of Reference (TOR) for this Task Force that call for recommendations on the best approaches to reduce unit production and life cycle costs using integrated product and process development (IPPD) tools and environments. Recommendations of technical criteria that can be used to assess progress in maturing manufacturing processes are also included.

### **1.1.2 Prior Related Studies**

This report builds upon and refines the results of prior studies, including the following:

- DSB Report 1991 Summer Study (Advance Copy), *Weapon Development and Production Technology*.
- DSE 1989 Study on *Simultaneous Engineering of Defense Products and Processes* (Draft).
- IDA Report R-338, *The Role of Concurrent Engineering in Weapons System Acquisition.*, 1988.
- DSB 1988 Summer Study on *The Defense Industrial and Technology Base*.

These past studies contributed greatly to an initial understanding of the situation and helped sensitize the community to potential solutions. This study offers a new approach to realizing those solutions.

### **1.1.3 Background**

The citizens of the United States hold both the Department of Defense (DoD) and the defense industry accountable for providing the military with the best equipment that technology can provide for the minimum cost. The recent demonstration of the military's capability in the Gulf War showed that the DoD and defense industry had fulfilled that trust

from the standpoint of the military hardware capability. However, the weapon systems used so effectively in Desert Storm were the legacy of a Cold War acquisition process driven by threat and schedule pressures that no longer exist. It is still crucial to achieve technologically advanced weapons of superior quality at an affordable cost when required, but it must be done with a much smaller portion of the total government budget.

A key element in achieving this goal is implementing IPPD and placing a significant focus on manufacturing processes early in the S&T phase. This approach reduces variability in manufacturing processes that results in high rates of rejection due to product characteristics falling outside the specification limits. The poor yields lead to high scrap and rework and numerous engineering change orders. These reactions stretch schedules and increase program costs—often above target values—and result in program overruns, cancellations, and embarrassment. With a balanced, process-focused approach early in the program, however, the proper design tradeoffs will be conducted and the uncertainty associated with unquantified process capability will be avoided (Figure 1.1). This chapter addresses the key issues and strategy for implementing this approach. Specific experiments are identified and recommended to demonstrate the use and benefits of IPPD. Actions are identified for key DoD officials to accelerate this change to develop more responsive, flexible, and dependable government and industry teams.

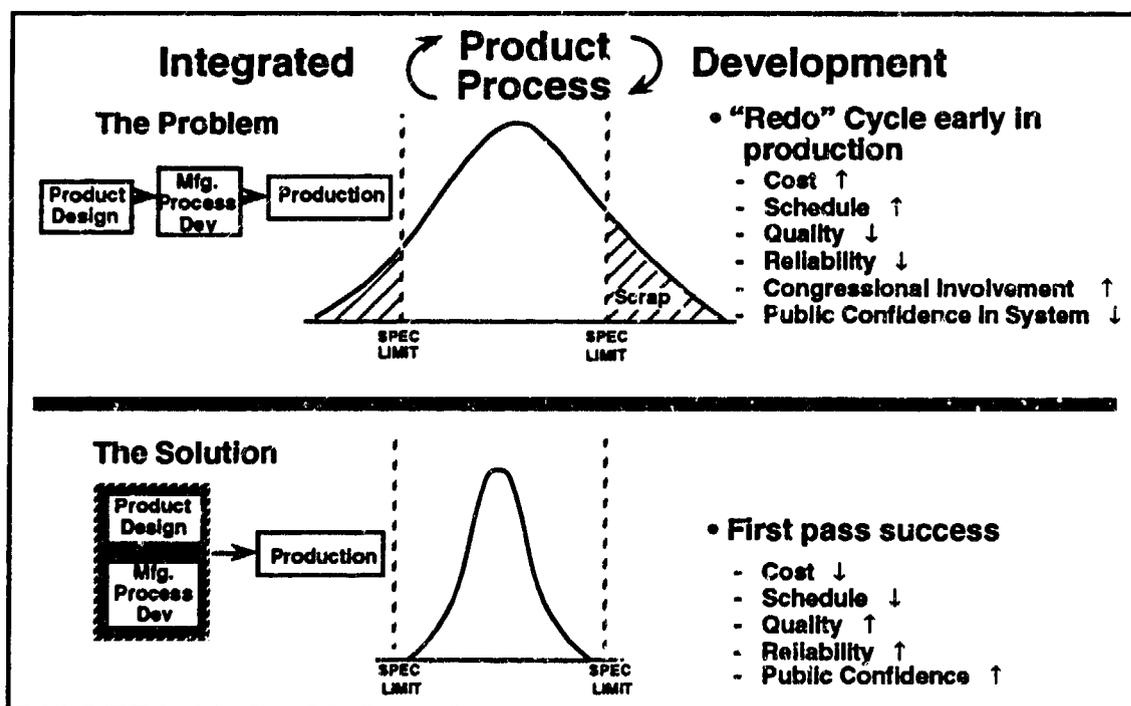


Figure 1.1. Integrated Product and Process Development

## 1.2 CURRENT STATUS

### 1.2.1 Current Product Development Approach

The current product development approach is sequential, focuses on product performance, and is one for which significant schedule and cost overruns have been the rule rather than the exception. A number of products have entered the Engineering and Manufacturing Development (EMD) and early Production phases with little quantitative measure of process capability. Manufacturing process development is usually conducted as a separate activity from the design of the product, usually much later in the development cycle. Products have passed the major milestones primarily by demonstrating the performance features of the system. This situation usually results in a realization at Milestone I (or even further downstream) that the product cannot be manufactured with acceptable yield and quality (Figure 1.2). Inspection and test (non-added-value activities) are then required to sort the good products from the bad—resulting in high scrap and rework—and a major effort must be made to improve yields and quality—an undertaking that often results in numerous design changes for producibility. The program could also be placed on hold while the manufacturing process matures. All these efforts are expensive, time consuming, and disruptive.

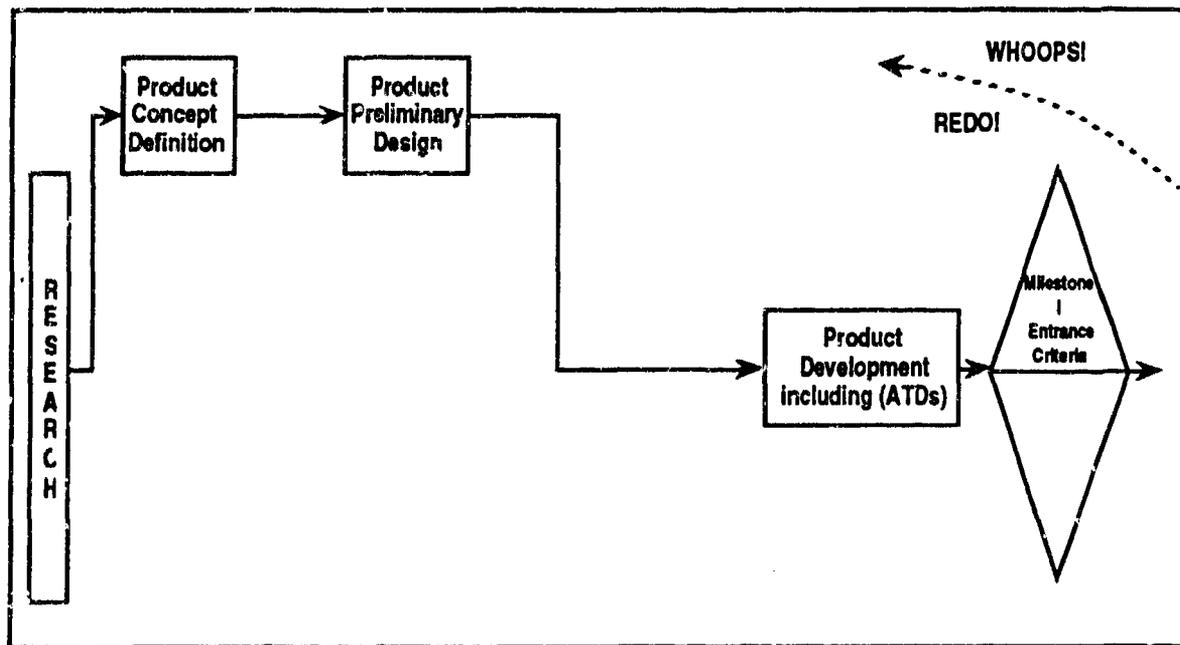


Figure 1.2. Current S&T Product Development Approach

### 1.2.2 Current Focus on Product Metrics

At the start of any development program, the degree of uncertainty in meeting established program objectives is extremely large. Estimates of program cost and design, performance, and schedule goals are optimistically established on a limited knowledge base. The risk is especially severe when new technologies are involved.

Management focus in both government and industry has traditionally been driven by schedule and performance. Milestone reviews have focused primarily on test results with performance and schedule being identified as the critical concerns. Little attention has been given to critical manufacturing processes or producibility issues until the EMD phase of a system's acquisition life cycle. While the degree of uncertainty decreases over time as the knowledge base increases, the degree of risk associated with low rate initial production (LRIP) and first production is still high (Figure 1.3). Corrective actions identified during the EMD and Production phases are very costly to implement and usually result in long schedule delays. Unfortunately, these corrective actions are often needed under the current development process to mature the product and achieve reasonable acceptance test yields. Expensive design margins are maintained to allow for uncontrolled degradation in the production processes. In addition, driving the whole development by the original schedule rather than first solving the key problems causes the schedule to be missed and cost overruns to occur.

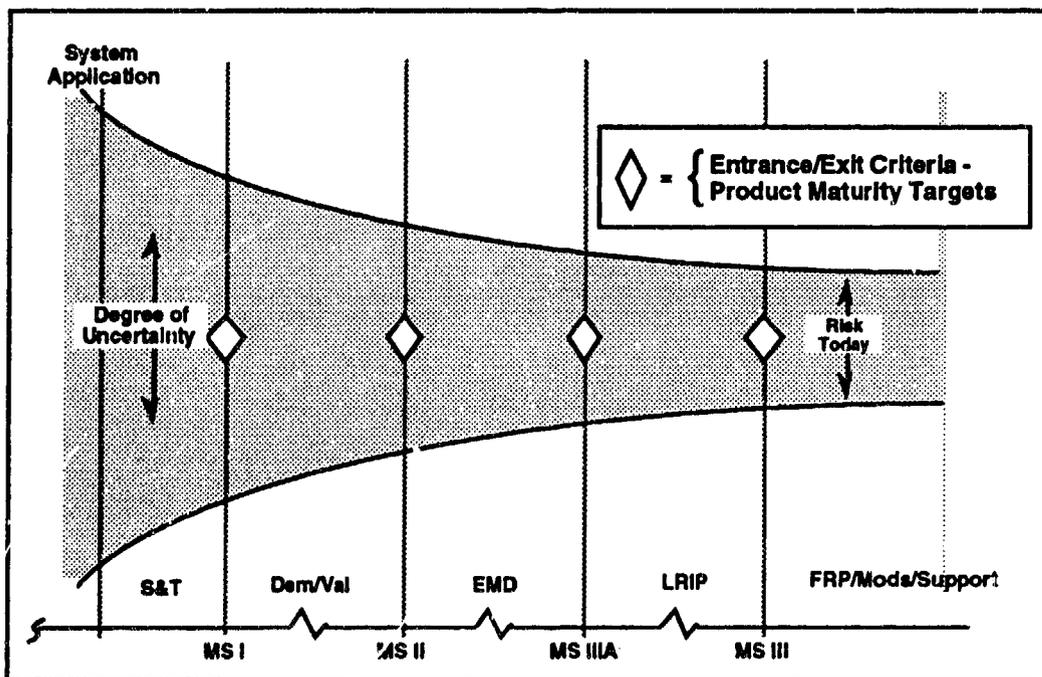


Figure 1.3. High Risk with Current Focus on Product Metrics

### **1.3 VISION**

In the future, programs will enter Production with predictable and affordable costs and schedules without sacrificing the performance features and combat advantage of technologically advanced weapon systems. These systems will be the result of a solution-driven process rather than a schedule-driven one. There will be a proper balance between product and process during the early stages and throughout development. Programs entering EMD will have far lower uncertainty and risk compared with current and prior programs. Relatively low engineering change rates will occur in early Production, since the production processes will be capable of providing the product with very high yields.

Factories will be able to respond quickly to product changes and will be able to produce low-volume products more efficiently. This will result from a more highly integrated manufacturing data infrastructure and more flexible manufacturing work cells. Greater use of commercial parts and processes will help leverage the fewer procurement dollars. A wider use of simulation and modeling will provide greater understanding of the balance between desired performance capabilities and the ability to deliver them. When the need for new capabilities and products arises, they will be provided much more quickly and dependably and will be much more affordable.

### **1.4 ISSUES AND STRATEGY**

#### **1.4.1 Issues**

The current approach to weapons system development is untenable in our present situation. Affordability demands the adoption of an approach that greatly reduces the uncertainty in being able to produce systems within an expected budget and schedule without incurring wasted effort. In the current DoD plans, a major focus is to continue to advance technology and system capabilities in development with few new systems actually entering Production. Those that do enter Production will be at relatively low production rates. Low production rates have historically meant high unit production costs due to the high overhead costs and inefficient use of program-dedicated manufacturing equipment. Affordability again dictates consideration of a new approach.

##### **1.4.1.1 Expensive Risk Reduction During High Spending Phases**

A normal rule of thumb in new programs is that 85 percent of the cost to develop the product is determined during the initial 15 percent of the effort. The greatest leverage in

reducing total program cost and uncertainty (risk) is to solve problems during the earliest stages when the spending rate is lowest (fewer people, machines, and inventory involved). Unfortunately, most DoD programs begin the major focus on manufacturing processes associated with introducing new products in EMD and early Production when the spending rate is rapidly increasing. By that time, the effect of changes is deleterious, particularly on schedule and cost.

It is considerably more desirable to reduce uncertainty and eventual risk during the earlier stages of S&T when the cost of changes is much lower and the positive outcome more certain. Generally, the cost of solving problems and making a change after Milestone I is at least 10 times greater than during S&T. During Production, the impact of a change is normally hundreds of times greater because of the effect on the work in progress and the disruption in ongoing operations (Figure 1.4). To avoid these problems, the emphasis in S&T will have to shift from performance feature demonstrations to an IPPD approach. This shift will require early development of process capabilities and the use of proven processes and metrics when going into Production.

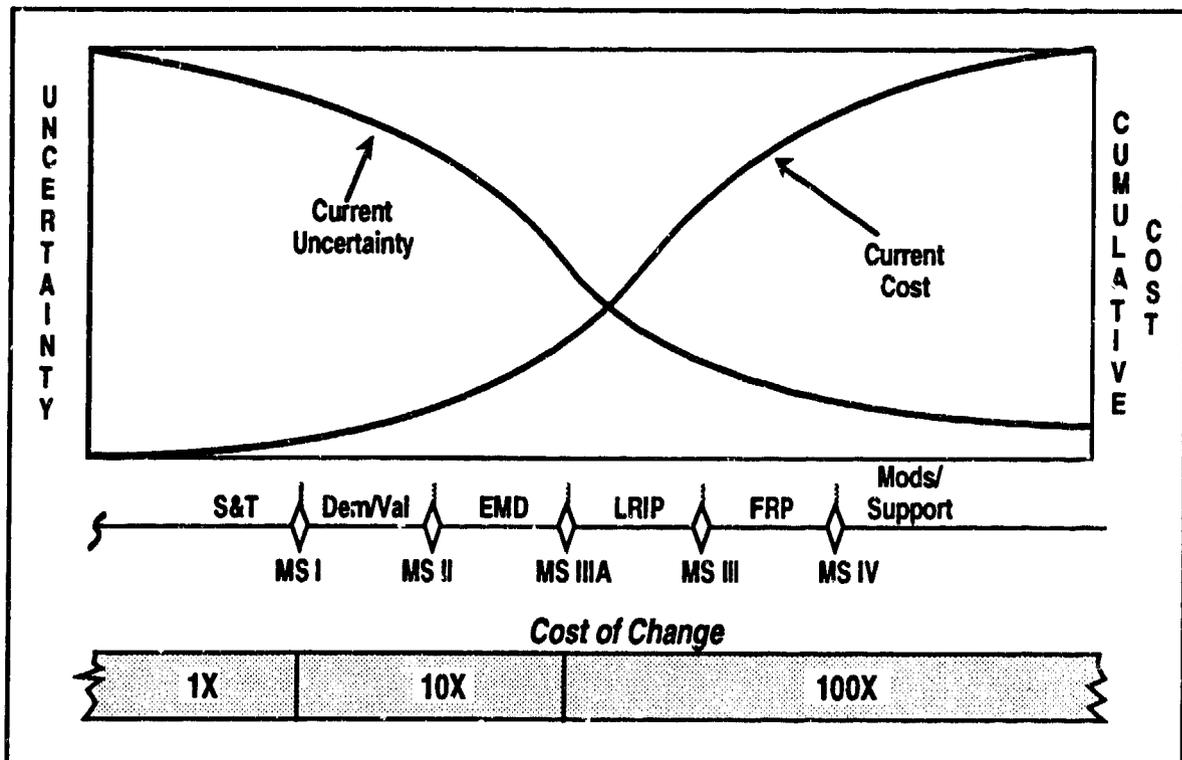


Figure 1.4. High Cost of Late Changes

#### **1.4.1.2 Funding Flow**

The new approach will result in a somewhat longer and more expensive S&T phase, but there will be significant savings in time and money during the more expensive phases of EMD and Production. These savings will result from much less uncertainty associated with critical processes and technologies and a more robust design

Without question, convincing the research community that the resources applied early saves money later is a difficult endeavor. With almost total concentration on product performance, it is difficult for scientists and engineers to concentrate on manufacturing and producibility issues, which is where they must concentrate for this new strategy to work. The resources to do the work of IPPD must be included in the estimate to begin the task or project. Investing up-front in defining the manufacturing processes will result in a minimum total expenditure of resources. In the long term dollars will be saved.

Management of funding for developing manufacturing technology is also very important. Funding for IPPD should be placed where the responsibility for IPPD is—in the hands of the ATD program managers. Funding for development of process technologies that cut across multiple ATDs or weapon systems should be placed with S&T Thrust 7 or Manufacturing S&T (MS&T) program managers.

#### **1.4.1.3 Responsibility of ATD Managers**

ATDs must be focused on achieving a superior capability at a reasonable cost. ATD program managers have to be responsible for demonstrating both product performance and the product's critical manufacturing processes. Critical manufacturing processes will need to be shown as scalable from the laboratory environment to the production environment.

#### **1.4.1.4 Education**

World-class companies have learned the importance of training and education to successfully implement IPPD. Process knowledge and metrics are generally not familiar to program managers and personnel within the acquisition and S&T communities. Blocks of instruction should be included in the programs at the Defense Systems Management College, Industrial College of the Armed Forces, and the Services' Professional Military Education Schools. In addition, special briefings with informational brochures, pamphlets, or handbooks should be presented to all personnel in the S&T and acquisition communities.

### 1.4.2 Strategy

The basic strategy is to integrate development of the product with the development of the product manufacturing process, beginning in the S&T phase and continuing throughout the product life cycle.

IPPD is the management process that optimizes the system through iterative product and process design tradeoffs. It allows the customer to get the most performance and quality in the shortest time at the lowest risk and, thus, with the lowest cost. IPPD integrates consideration of all activities from product concept through production and field support using a multifunctional team. The starting point is an initial definition of product requirements, an initial product solution (concept), and a target unit cost that is deemed to be affordable (i.e., able to successfully compete for funding in a constrained budget based on potential military benefit).

The IPPD technique iterates and balances product performance and process capability by using the target unit cost as a figure of merit for decision making regarding the product's performance, design characterization, and manufacturing processes. It requires achievement of a pre-specified and increasing level of product and process maturity during each succeeding phase of the development process to achieve the target unit cost for the product. The result is a producible product that meets refined performance, schedule, and cost goals.

Measures of the capability of a manufacturing process commonly used in industry are the process capability indices,  $C_p$  and  $C_{pk}$ .<sup>1</sup> These indices are indicators of the ability of a stable manufacturing process to provide quality products within specification limits. Processes with values less than 1.0 can be interpreted as resulting in significant fallout or waste (the "Problem" in Figure 1.1.).

By using an IPPD approach beginning with the S&T phase and continuing throughout the acquisition life cycle, DoD can accelerate total program risk reduction. The Task Force recommends that S&T ATDs be required to establish both critical product *and process* goals as exit criteria and that this practice be continued at all acquisition decision points. It proposes that suitable process capability and performance metrics be the measure of process maturity used in establishing the maturity targets, beginning with Milestone I, tailored uniquely for each program. These metrics, e.g.,  $C_p$  and  $C_{pk}$ , if deemed

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<sup>1</sup> Calculation of the process capability indices,  $C_p$  and  $C_{pk}$ , is described in Appendix E.

appropriate for a specific program, should be defined for each critical process and should grow at each decision point in accordance with a plan for achieving process maturity, established prior to Milestone I.

S&T schedules and budgets should reflect the additional time and funding that will be required to develop the critical manufacturing processes. Milestone I will slip to the right as shown in Figure 1.5; however, the total acquisition time—that is, the time from Milestone I to Production—will decrease significantly, as will life cycle cost, risk, and uncertainty.

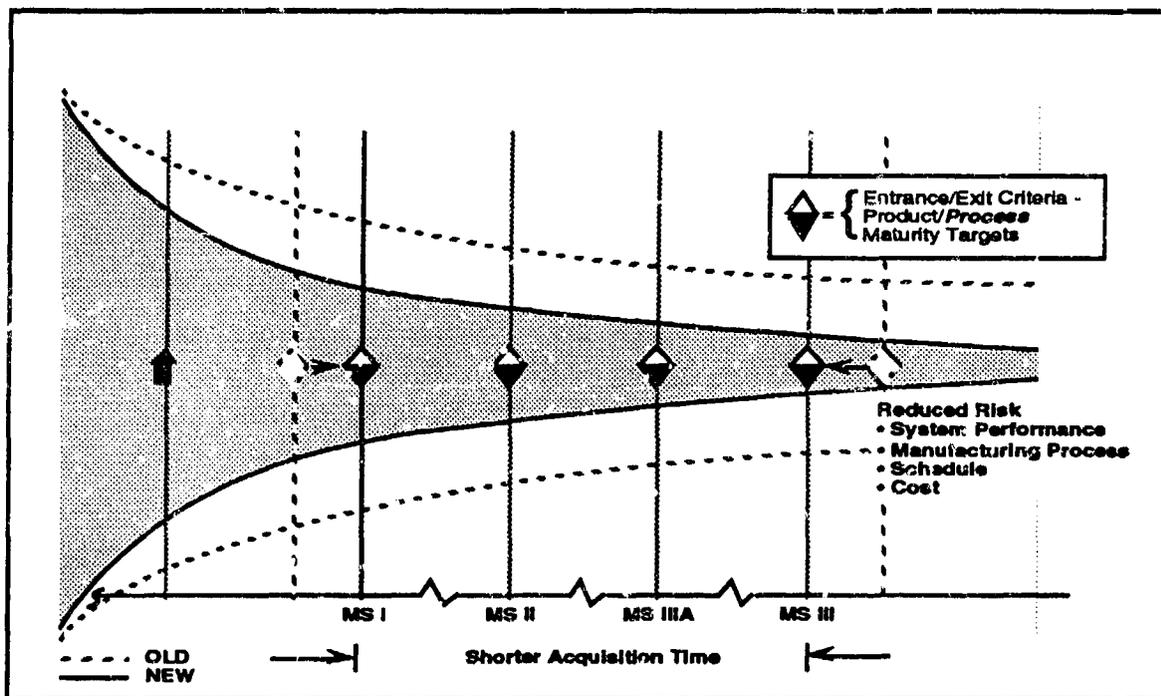


Figure 1.5. Accelerated Risk Reduction Resulting From Early Focus on Product and Process Metrics

### 1.4.3 Quality, Cost, and Schedule Payoffs

A balanced approach of product and process in the S&T phase results in a much more mature design entering Acquisition. Many of the producibility tradeoffs will have been completed, and a process development activity will have been conducted on critical processes with a goal of achieving an acceptable process capability prior to production. As a result, there is a much lower change rate in EMD and early Production with much less disruption of costs and schedules (Figure 1.6).

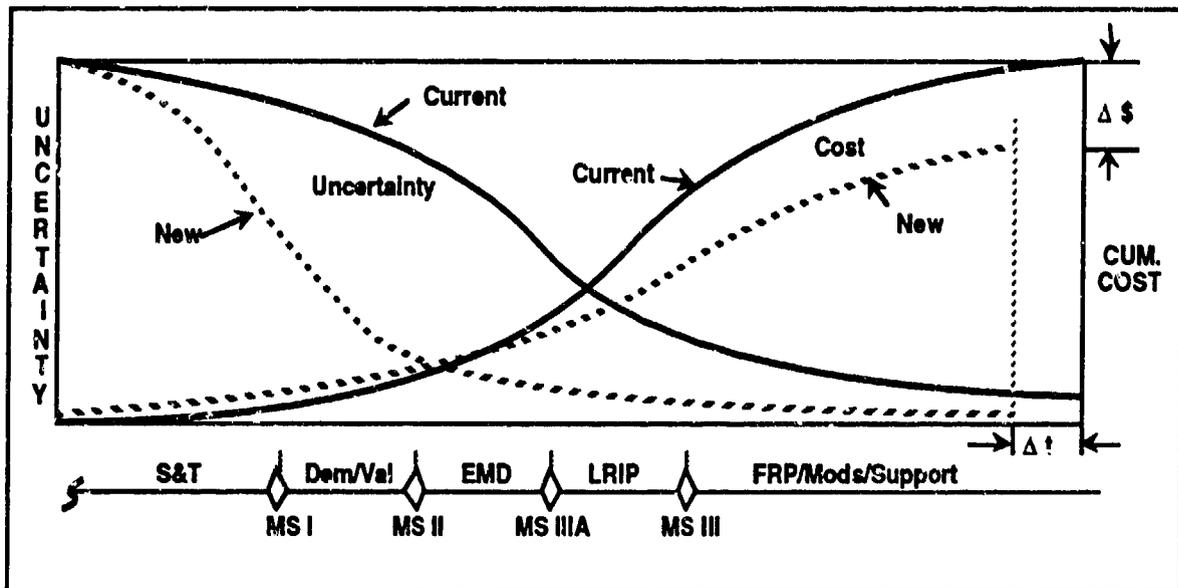


Figure 1.6. Improvements in Quality, Cost, and Schedule Resulting From IPPD

The IPPD approach is well known and widely used in commercial industry. In fact, the approach (sometimes discussed as simultaneous or concurrent engineering) is mandatory for survival in the semiconductor industry and has been identified as the major factor in the success of the Japanese auto industry.<sup>2</sup> A report by the Institute for Defense Analyses (IDA) in December 1988 summarized the experience of 13 contractors, both DoD and commercial, using IPPD.<sup>3</sup> Activities ranged from component level to complete products. The investigation showed overwhelming support and benefits (Table 1.1).

Table 1.1. Findings on Concurrent Engineering

Business Unit	Benefits
Boeing Ballistic Systems Division	30 percent cost savings; 67 percent inspection ratio reduction
McDonnell Douglas TAV-8B	68 percent fewer drawing changes; 58 percent scrap reduction
Hewlett Packard Instruments	35 percent less development time; 60 percent lower field failure rate
John Deere & Company	30 percent development cost savings; 60 percent development time reduction

<sup>2</sup> James P. Womack, Daniel T. Jones, and Daniel Roos, *The Machine that Changed the World*. [Based on the Massachusetts Institute of Technology 5-million Dollar 5-year Study on the Future of the Automobile], Rawson Associates, New York, 1990.

<sup>3</sup> Robert I. Winner, James P. Pennell, Harold E. Bertrand, and Marko M.G. Slusarczuk, *The Role of Concurrent Engineering in Weapons System Acquisition*, IDA Report R-338, December 1988.

Other more recent examples include a 30 percent improvement in time-to-market for the new Chrysler Viper, greater than 90 percent reduction in time to deliver the GBU-28, 30 percent development cost reduction for Delco radios, a fourfold increase in reliability of a Hewlett Packard Gas Chromatograph and a 50 percent reduction in development time and cost for the Westinghouse modular radar (MODAR). A 30 percent reduction in overall program cost is not uncommon. The reduced cost is associated with fewer changes in early Production, much less rework (associated with poor design margin and late design changes), and higher yields. A high quality product, with more dependable deliveries, at low costs is the result.

## **1.5 IMPLEMENTATION**

Implementing IPPD beginning in the S&T phase will require a revolution in the way S&T managers think about product development. As initial product concepts are conceived, effort must also be applied to define the process that would be used to manufacture the product. Modeling and simulation should be used to maximum advantage in acquiring early learning and reducing risk. The product and process concepts should be iterated to achieve acceptable confidence before proceeding to the next phase in which preliminary design and product implementation processes are defined. This definition will provide the basis for establishing a product cost target and assessing risk before the S&T "product" enters the ATD phase. Each ATD (as well as other 6.2 and 6.3A programs) will then have specific exit criteria for product performance and for process maturity. The process metrics will include yield, capability, quality, and dual-use-manufacturing potential. The exit criteria will also require a plan for process maturity development to achieve specified process metrics during EMD (Figure 1.7).

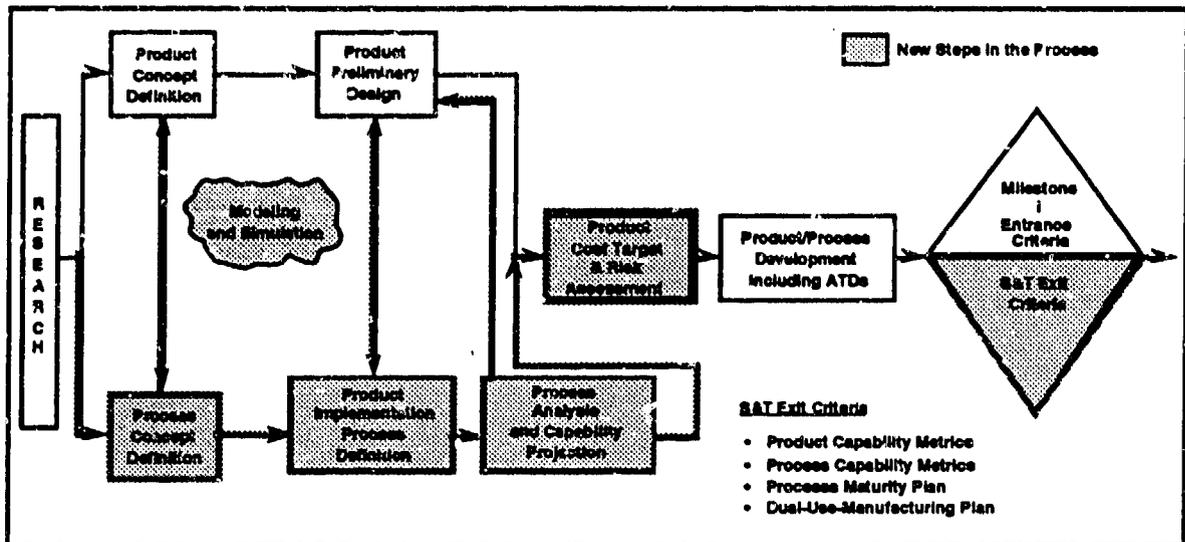


Figure 1.7. Recommended Approach—IPPD in the S&T Phase

## 1.6 CONCLUSIONS AND RECOMMENDATIONS

The subgroup reached four major conclusions about the DoD's future use of IPPD to develop and produce superior, low-cost products through its suppliers:

- New and increased emphasis is needed on the development of key manufacturing processes, starting early in S&T, and on continuing to mature these key processes during acquisition.
- With the increased understanding of processes, the use of IPPD in the S&T phase will increase the quality of the product characteristics at reduced costs and risks.
- Exit criteria from the S&T phase should, as appropriate, use the same metrics employed by the best commercial companies, in which process maturity indices, including critical process capability indices, are as important as product performance features.
- Development and inculcation of IPPD principles in the S&T phase should set the pattern for the downstream phases. The implementation of integrated problem solution methods, process capability exit criteria, and process understanding must be continued as part of the acquisition process following Milestone I.

These conclusions led the subgroup to recommend that a DoD manufacturing manifesto or set of guiding principles be articulated by top management in the DoD. This manufacturing philosophy should emphasize manufacturing process development. It should stimulate and institutionalize DoD and industry-wide use of IPPD as the

management process for reducing risk and uncertainty beginning in the S&T phase and continuing in all succeeding phases of the acquisition process. DoD needs to develop metrics to gauge progress in IPPD implementation and to ensure that the cited objectives are achieved. In so doing, DoD must avoid becoming an "IPPD policeman" or requiring adherence to a strict methodology for implementing IPPD as defined by a set of "how-to" specifications. Rather, it should establish incentives to motivate industry to apply IPPD through a results-oriented approach. Incentives (contractual and otherwise) are needed to motivate industry to make the investment required to quantify metrics on all critical processes and initiate across-the-board improvements in the face of shrinking DoD budgets. Additionally, incentives should motivate industry to facilitate affordable, low-volume production through investments in flexible manufacturing systems. Incentives could include consideration of the offeror's demonstrated understanding of the capability of the critical manufacturing processes and the specific plans to mature the processes for contract award evaluation criteria or providing award fees tied to progress in maturing key processes.

The subgroup recommends that IPPD and appropriate exit criteria be implemented in ATDs and at all program milestones. This implementation will require a cultural change in the S&T community, making education and training of S&T Thrust Leaders and ATD program managers necessary. A major shift in resources will also be needed to develop the process technology and understanding. Joint planning between the R&D and P&L communities must be established and continued to provide continuity in maximizing and institutionalizing the use of IPPD.

## 2. MODELING AND SIMULATION

### 2.1 INTRODUCTION

#### 2.1.1 Terms of Reference

This chapter has been developed in response to the Terms of Reference (TOR) that call for requirements for advanced simulation, visualization, design of experiments, and dynamic control technologies at levels ranging from detailed product and process design to overall manufacturing enterprise control. It has been developed in coordination with the DSB Task Force on *Simulation, Readiness and Prototyping* in addressing the interface between detailed engineering simulations and higher level simulations in the synthetic battlefield.

#### 2.1.2 Prior Related Studies

This report builds upon and refines results of other studies, including the following:

- Army Science Board 1991 Summer Study Final Report, *Army Simulation Strategy*.
- CALS Technical Report 002, *Application of Concurrent Engineering to Mechanical Systems Design*, June 1989.
- IDA Document D-1161, *A Review of Study Panel Recommendations for Defense Modeling and Simulation*, J. D. Fletcher, June 1992.

#### 2.1.3 Functional Areas

Three functional areas are involved in improving weapon system cost, risk, and performance through continuous inclusion of manufacturing parameters in design decisions: (1) battlefield experience, (2) engineering design of the product and its manufacturing processes (Integrated Product and Process Development—IPPD), and (3) the industrial base. The elements of these functional areas are arranged in adjoining hierarchical listings in Figure 2.1. This chapter analyzes the present status of modeling and simulation—including their interrelationships—in each functional area, and proposes changes that are necessary to accomplish iterative optimization of the product and its

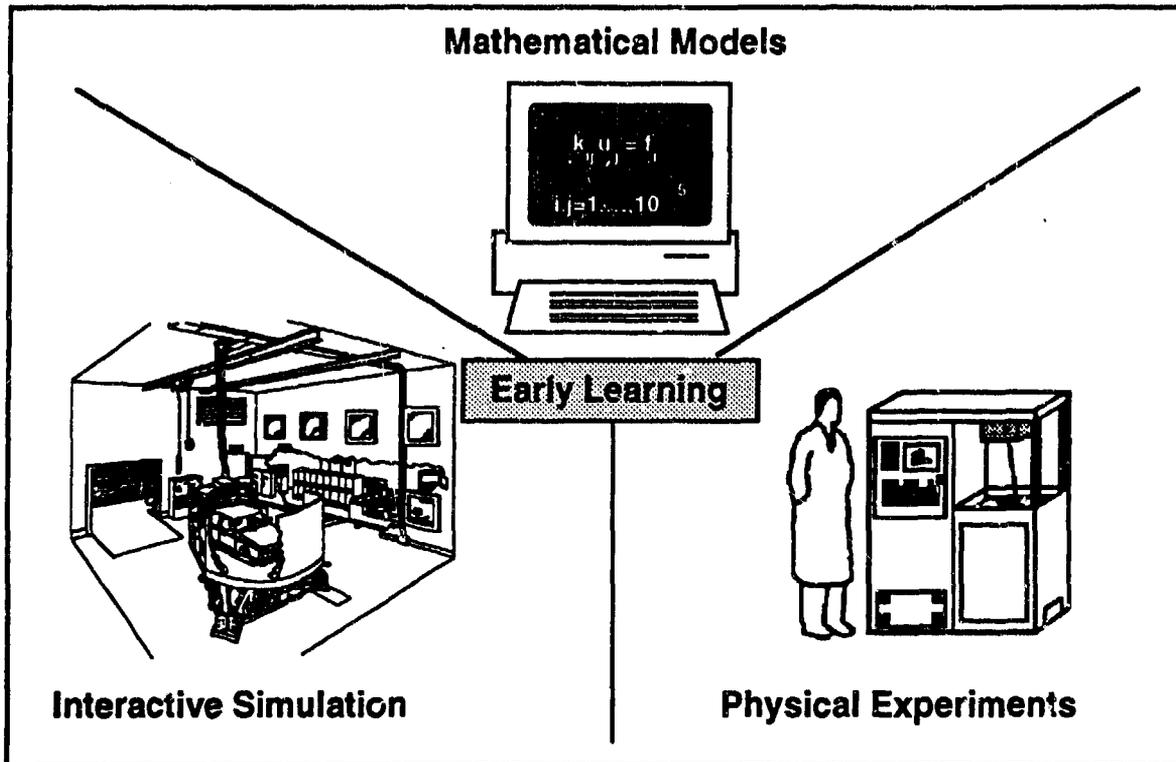
associated manufacturing processes. The proposed strategy is based on bringing these changes into full deployment by the year 2000, through a series of evolutionary developments. Recommendations for modeling and simulation improvements and for experiments employing Advanced Technology Demonstrations (ATDs) are developed, and the benefits of the proposed vision and strategy are described.

<b>Battlefield</b>	<b>IPPD</b>	<b>Industrial Base</b>
Battlefield Performance		Sector
Operational Requirements Definition	System Functional Performance	Enterprise Performance
	Design Alternatives	Company (Factory)
	Manufacturing Process Design (Design of Experiments)	Shop Floor
		Unit Processes

**Figure 2.1. Modeling and Simulation Symmetry Among Functional Areas**

#### **2.1.4 Scope of Modeling and Simulation in IPPD**

Simulation may be defined as “the imitative representation of the function of one system or process by means of the functioning of another.” This subgroup focused on uses of simulation and modeling in support of the IPPD functions shown in Figure 2.1, which suggest that there are distinctly different technical approaches between modeling and simulation in the context of IPPD as compared to the battlefield simulation examined by the DSB Task Force on *Simulation, Readiness, and Prototyping*. The scope and approaches to modeling and simulation in the IPPD process are shown in Figure 2.2 and Table 2.1, respectively, and are described in succeeding subsections.



**Figure 2.2. The Scope of Modeling and Simulation in IPPD**

**Table 2.1. Approaches to Modeling and Simulation in IPPD**

<ul style="list-style-type: none"> <li>• <b>Mathematical Models</b> <ul style="list-style-type: none"> <li>— Based on first principles or empirical data</li> <li>— Must be validated/verified to establish confidence</li> </ul> </li> <li>• <b>Interactive Simulation</b> <ul style="list-style-type: none"> <li>— Accounts for difficult to predict interactions</li> <li>— Includes real-time warfighter- and hardware-in-the-loop interactive engineering simulation</li> <li>— Must be validated/verified to establish confidence</li> </ul> </li> <li>• <b>Physical Experiments</b> <ul style="list-style-type: none"> <li>— Provide empirical models based on experimental data</li> <li>— Reduce the cost of simulation, in appropriate circumstances</li> <li>— Validate models</li> </ul> </li> </ul>
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#### **2.1.4.1 Mathematical Models**

Mathematical models based on first principles of physics that describe the behavior of machines, engineering materials, electronic devices, graphical images, etc., comprise the most commonly conceived form of models. When they are feasible, mathematical models provide valuable relationships between design and manufacturing characteristics of weapon systems and their performance. Even when mathematical models can be constructed, they contain parameters whose values must be defined or verified through experimentation. The accuracy of these parameters and the underlying idealizations associated with mathematical models must be validated to establish confidence in the models before they are used to support engineering decision making. Particularly in the case of manufacturing processes, the associated physics, chemistry, and related disciplinary behavior are often either impossible or extraordinarily difficult to model mathematically from first principles.

#### **2.1.4.2 Interactive Simulation**

Aspects of weapon system performance such as automatic ammunition loading, adaptive vehicle suspension, and a warfighter's ability to extract information from a display screen are difficult or impossible to model mathematically. Yet, they must be accounted for in real-time warfighter- and hardware-in-the-loop interactive engineering simulation. A combination of physical components, the actual warfighter, and mathematical models of components must function in an integrated real-time engineering simulation (shown schematically at the lower left of Figure 2.2) to provide confidence in tradeoffs that involve such difficult-to-model components and weapon system performance. As in the case of mathematical modeling, interactive simulations must be validated to provide confidence that engineering decisions based on their use are rational and correct.

#### **2.1.4.3 Physical Experiments**

Numerous important effects that cannot yet be modeled mathematically may be modeled by physical experiments that need not be conducted in real time. This is particularly true for manufacturing processes that have not yet reached a state of mathematical modeling maturity to support IPPD. Physical experiments or pilot process plants may serve to simulate large-scale manufacturing processes and plants to be used in manufacturing weapon systems. Once constructed, they can provide timely experimental information needed to support design and manufacturing tradeoffs that influence cost, performance, and battlefield effectiveness of weapon systems. For well-understood manufacturing processes and weapon performance characteristics, empirical models based

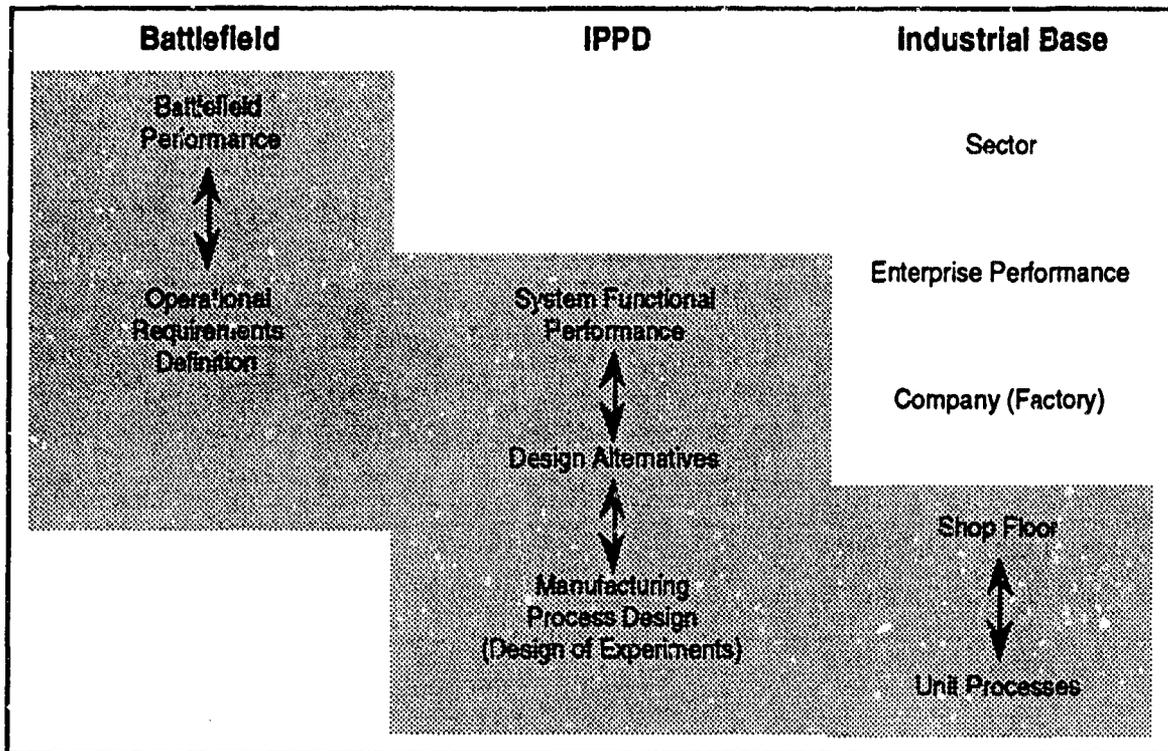
on experimental data are adequate for simulation in support of IPPD. Examples of such situations include the relationships between standard machining process feeds and speeds, weld material deposit and rod traverse speed, and vehicle suspension oscillation frequency as a function of mass and damping characteristics. Such empirical models should be used when they provide the desired information to reduce the cost of simulation and enhance the timeliness of its use in IPPD. When empirical models are adequate, there is no need for or benefit in creating mathematical models that yield no new information for the intended application.

## **2.2 CURRENT STATUS OF MODELING AND SIMULATION IN IPPD**

In addition to well-established physical experimentation and empirical approaches to modeling and simulation, technological developments are needed to bridge the gap between battlefield simulation, simulation in support of IPPD, and manufacturing process simulation shown in the shaded region of Figure 2.3. The status of specific simulation tools is summarized in Table 2.2 and outlined in the subsections that follow.

The vertical arrows in Figure 2.3 indicate the types of iteration activities that can be envisioned between major model elements within a functional simulation environment. In essence, this is "feed-up/feed-down" information exchange. The solid arrows indicate areas where the practice of modeling and simulation is present today.

Since appropriate modules in each functional area (battlefield, IPPD, and industrial base) have not been developed with a standard architecture, data transfer format, and network/module protocol, no horizontal electronic communication currently exists between the IPPD environment and the synthetic battlefield or industrial base. Such communication links would allow for "feed-back/feed-forward" capabilities for design decision making across the full spectrum of battlefield effectiveness, IPPD, and industrial base considerations. These interfaces are required to ensure a robust design. Since this important communication capability does not exist in electronic form, product and manufacturing process designers cannot effectively test their design alternatives on the synthetic battlefield.



**Figure 2.3. Current Status of Iterative Modeling and Simulation**

**Table 2.2. Current Status of Modeling and Simulation Capability**

Modeling and Simulation Capability	Status
Distributed interactive battlefield simulation relating weapon system characteristics to warfighting effectiveness	Emerging as powerful tool for incorporating human behavior into the modeling process
Warfighter-in-the-loop engineering simulation defining design and system performance tradeoffs	On the horizon as powerful tool for comprehensive system performance assessment and design
Hardware-in-the-loop physical simulation accounting for difficult-to-model behavior and failure modes	Facilities and tools emerging, but isolated
Weapon performance modeling and simulation relating design characteristics to weapon system performance characteristics	Individual discipline tools well developed, but isolated
Manufacturing process modeling and simulation relating design characteristics to requirements of the manufacturing system	Inadequate empirical and theoretical data on many unit processes.
Architecture and standards for integration of simulation tools	In early development stages

### **2.2.1 Distributed Interactive Battlefield Simulation**

The distributed interactive Simulation Network (SIMNET) that has recently been developed by the Defense Advanced Research Projects Agency (DARPA) and is now being operated by the Army is a powerful new battlefield simulation tool to relate weapon system characteristics to warfighting effectiveness. It supports the spectrum of functions shown at the upper left of Figure 2.3. A mix of weapon systems simulators, such as tanks, armored personnel carriers, helicopters, and fighter aircraft, provides the individual warfighter audio and video interaction with an integrated battlefield environment. This capability can now be used for both training and evaluation of the warfighting benefit of conceptual weapon systems in a combined arms battlefield environment. The use of warfighter-in-the-loop battlefield simulation eliminates any assumptions that are inherent in the modeling of human behavior and thereby increases confidence in results of the simulation. System performance is an input to the simulation, and SIMNET provides insight into how the warfighter will actually employ the system on a synthetic battlefield. In combination with SIMNET, emerging engineering simulation tools hold the potential to revolutionize the process of weapon system requirements definition, weapon system conceptual design, and evaluation of the impact of manufacturing capabilities on warfighting effectiveness in a realistic battlefield environment.

### **2.2.2 Warfighter-in-the-Loop Engineering Simulation**

Recent advances in real-time weapon system simulation provide the potential for warfighter-in-the-loop engineering simulation of weapon system performance, at an engineering level of detail that is suitable for tailoring the design of the weapon system to the capability of the warfighter. Acceleration of initial developments in this area will create a new engineering simulation capability for use in IPPD that emulates proving ground prototype testing, using a real-time engineering simulation in lieu of the physical prototype. This revolutionary new capability, called "virtual prototyping," offers the potential to drastically reduce the time and cost of weapon system concept and prototype design. An extraordinarily powerful warfighter-in-the-loop engineering simulation tool is thus on the horizon, to bridge the gap between the newly created distributed interactive battlefield simulation capability and non-real-time Computer Aided-Engineering (CAE) simulation capabilities that are reasonably well developed in the engineering community. The use of engineering models in the simulation of a weapon system eliminates the need for many of the performance assumptions normally associated with the modeling process. Properly

implemented, warfighter-in-the-loop engineering simulation allows the designer to input design parameters to the simulation and infer weapon system performance in the hands of an actual warfighter. When combined with warfighter-in-the-loop battlefield simulations such as SIMNET, in which weapon system performance is an input, comprehensive system performance assessments can be made.

### **2.2.3 Hardware-in-the-Loop Physical Simulation**

Analogous to warfighter-in-the-loop engineering simulation, weapon subsystems that are difficult or impossible to model mathematically can now be incorporated in real-time hardware-in-the-loop engineering simulations, in some cases with the warfighter in the loop, to determine performance characteristics of weapon systems and subsystems in a field environment. Hardware-in-the-loop simulators for tank-automotive subsystems, aircraft subsystems, and missile subsystems are emerging, but they function in isolated subsystem development environments. They have not yet been integrated into an IPPD simulation environment to support both distributed interactive battlefield simulation and warfighter-in-the-loop engineering simulation. The use of hardware-in-the-loop simulation eliminates all assumptions related to subsystem performance and gives the truest indication of how the subsystem actually performs in a field environment.

### **2.2.4 Weapon Performance Modeling and Simulation**

Well-developed engineering analysis tools in numerous disciplines are available to relate design characteristics to weapon system performance in a non-real-time simulation environment. CAE tools used for this purpose include solid modeling, structural finite element modeling and analysis, mechanical system dynamic modeling and analysis, armor penetration and vulnerability analysis, signature analysis, and a broad spectrum of discipline-specific analysis tools that run on a range of workstations, mini-supercomputers, and supercomputers. For the most part, these CAE tools are well developed, but they reside in isolated, discipline-specific application environments. They have not yet been integrated into an IPPD infrastructure that can provide timely support to engineering decision making and data creation for the higher levels of modeling and simulation capability described in previous subsections.

### **2.2.5 Industrial Base Simulation**

The manufacturing system involves the prime contractor and the supplier chain. Production consists of piece-part, subassembly, and full weapon system assembly. Any major weapon system production base consists of hundreds of companies from several sectors, organized through the chain from producing piece-parts to final assembly of the system. The Modeling and Simulation subgroup saw no need to model the industrial base above the shop floor, shown at the right of Figure 2.3, in support of product and process design (although other enterprise management functions might be served by such simulations). In order to model this system at or below the shop floor, for the purpose of iterative examination of affordability tradeoffs with performance by means of synthetic battlefield simulation, critical unit processes must be determined and modeled as part of a weapon system model. Such models can then be designed to be robust against the requirements to meet durability, reliability, and affordability standards. As this capability is developed, an electronic communication channel between process design and unit processes at the lower right of Figure 2.3 will be needed.

The approach taken to model critical unit processes has been to determine their characteristics by means of physical experiments and data gathered over time from factory experience. The electronics industry has used design interactive simulations for some time to determine thermal characteristics, solderability, lead-hole relationships, and simulated process capability for the product designed. Computer systems employing empirical data bases are now emerging that can both simulate and control manufacturing operations. No attempt has been made to model levels higher than the shop floor in the industrial base.

### **2.2.6 Architecture and Standards for Infrastructure Integration**

As noted above, numerous CAE modeling and simulation tools and a broad range of hardware- and warfighter-in-the-loop engineering simulators exist or are on the horizon to support timely and cost-effective IPPD. They tend to be isolated, however, and communication among the numerous tools that support weapon system and manufacturing process development is difficult. This results in unnecessarily slow and costly use of these tools in the design of weapon systems and associated manufacturing processes. To meet affordability objectives in S&T ATDs and in the acquisition process, a uniform architecture and standards for integration of this plethora of tools is required to create an effective IPPD environment. While some progress is being made, integration of modeling and simulation tools to create the needed infrastructure is in the very early stage of development.

## 2.3 VISION

The vision for modeling and simulation in the DoD manufacturing process, as stated in Table 2.3, includes capabilities that can be achieved during the decade to support versatile and cost effective engineering and manufacturing processes. Elements of the vision will be realized through an evolutionary process that involves continuous test and validation of engineering modeling and simulation technologies in the S&T ATD process and throughout the acquisition process.

**Table 2.3. Vision for Modeling and Simulation in the Manufacturing Process by Year 2000**

Capability	Envisioned Application
Modeling and simulation	Used throughout the IPPD process including battlefield performance, operational requirements definition, system functionality assessment, product design, manufacturing process design, factory capability and cost tradeoffs, and logistics support assessment.
Warfighter-in-the-loop engineering simulation	Used to accelerate learning in engineering development, fabrication, and testing, and to reduce the cost of physical prototyping required to validate both the simulation and the design.
Synthetic environment	Seamless electronic information feedback and feed-forward capabilities for decision making across all aspects of the life cycle.

Modeling and simulation will progress to different stages of maturity for different sectors of the industrial base during the next 3 to 7. The goal will be to reduce the time, cost, and risk associated with weapon system development and production by:

- Electronically linking the synthetic battlefield and the IPPD environment
- Improving design for system performance
- Iterating design alternatives with manufacturing process decisions
- Improving manufacturing process capability
- Linking the IPPD environment and factory operations.

Today, the semiconductor and chemical industries and many areas of single product or single process design have validated models and simulations of all their manufacturing

processes. Validation of models and simulations used in product and process design will be carried out in specific, sector-oriented ATDs. The ability to feed back and feed forward those capabilities will allow decision making to improve all aspects of the product life cycle. As a result of the actions recommended in this chapter, modeling and simulation capabilities in the year 2000 will become as summarized below and described in more detail in the subsequent subsections.

- Warfighter- and hardware-in-the-loop simulation used in product design.
- Modeling and simulation of capabilities for critical manufacturing processes as standard industry practice.
- Architectures and infrastructures implemented within companies and among companies within sectors to support interoperability of models and tools in IPPD.
- Electronic interchange between the synthetic battlefield and IPPD achieved.
- Methodology and value of selected interchanges between IPPD and shop floor established.
- Data available for critical unit processes.

### **2.3.1 Modeling and Simulation Throughout Product Development**

Varying levels of modeling and simulation tools, some of which exist and others of which will be developed as an integral part of the S&T process, will substantially impact the DoD engineering process. Weapon system concepts will be developed, tested, and evaluated using simulation, with minimum essential physical prototype fabrication, test, and evaluation for validation and benchmarking of capabilities and simulation tools. Distributed interactive battlefield simulation will be carried out using the existing SIMNET and its derivatives to involve the warfighter in assessing the value of new weapons and technologies in a combined force battlefield environment. This revolutionary new distributed interactive simulation capability will be complemented by real-time warfighter-in-the-loop engineering simulators and non-real-time engineering simulation tools to bridge the gap between the current engineering design environment and the new, synthetic, combined-arms battlefield. Engineering modeling and simulation capabilities developed and implemented during the decade will revolutionize the process of IPPD, including both the design of the weapon system and its associated manufacturing processes. Improved fundamental understanding of manufacturing processes that is gained in process modeling research will both enhance the ability to optimize manufacturing processes for specific

applications and support tradeoff analysis of factory capability versus product cost, prior to entry into EMD of candidate weapon systems. Finally, the engineering modeling and simulation tools developed during the decade will permit maintainability, reliability, and related supportability specialists to participate in the weapon system design process at the very beginning, hence permitting supportability to be designed into the product.

### **2.3.2 Determination of Cost Drivers in Manufacturing Simulation**

During product and process design, manufacturing engineers will prepare macro and micro process plans for designs that are to be evaluated on the battlefield. The macro process plan is the routing from station to station on the shop floor, while the micro process plan is the detailed instruction set (e.g., tooling, fixtures, thermal cycle, and joining material) for each station. For the most part, these plans will be based on known unit processes that have been proven in manufacturing and for which variability curves are available for analysis. When new processes are required, however, an extensive experimental determination of a practical unit process and its variability is required. The variability curves will be matched to tolerances to determine the process capability. The resulting design will then be tested using engineering simulation techniques to determine durability and reliability. The macro and micro process plans will be used to determine unit costs for a range of production rates. This process will be iterated until an acceptable tradeoff between battlefield performance, cost, durability, and reliability is determined.

### **2.3.3 Warfighter- and Hardware-in-the-Loop Engineering Simulation**

Developments by DARPA and the Army in warfighter-in-the-loop engineering simulation for support of acquisition will be intensified to emulate the costly and time-consuming conventional process of prototype design, fabrication, and testing. Warfighter-in-the-loop engineering simulators will support engineering performance simulation at a design level of detail and will account for human factors and fundamental human response quantification and measurement. This will create the level of realism required for design of weapon systems to function effectively in the hands of a broad cross section of warfighters. Taken with carefully planned hardware-based experiments for simulation validation and parameter determination, a fundamental understanding of critical engineering tradeoffs will be achieved.

#### **2.3.4 Modeling and Simulation Tool Validation**

Significant developments in modeling and simulation tools will be carried out in joint ATDs among the S&T Program's Thrust 7, *Technology for Affordability*, and Thrusts 1-5, the weapon system thrusts. The cost of validation will be significant, but this step is required to ensure that a true representation of the manufacturing process exists. Validation should be part of an ATD's exit criteria. Test and validation using real weapon system applications will provide confidence that product and manufacturing process simulations can be used in lieu of repetitive prototype design, fabrication, and test.

#### **2.3.5 Environment for Information Feedback and Feed-Forward**

DoD efforts that have been initiated to integrate advanced engineering tools for support of IPPD of weapon systems will be accelerated under Thrust 7 to create tools and technologies for affordability. Communication standards and formats will be developed to permit effective electronic integration of the broad range of modeling and simulation tools that must function harmoniously to achieve the vision outlined above.

### **2.4 ISSUES AND STRATEGY**

Comparing the future vision presented in Section 2.3 with the current status presented in Section 2.2 highlights the following gaps in the modeling and simulation process:

- Lack of electronic integration of synthetic battlefield with engineering design environment.
- No architecture or infrastructure to support reuse and interoperability of models and tools in IPPD.
- Inadequate empirical and theoretical data on most unit manufacturing processes.

The subgroup found a lack of electronic integration of the synthetic battlefield with the engineering design environment. Little data is available to indicate the use of battlefield simulation in the design process, except by way of manual communication of requirements. There appears to be no technological limitations to performing this activity, but time and resources are required to develop the linkage and data bases to support IPPD. To date, there is no architecture or infrastructure to support reuse and interoperability of modules and tools for IPPD. Also, empirical and theoretical data on most unit manufacturing

processes are found to be inadequate. These gaps need to be bridged, or filled, so that modeling and simulation can be used effectively throughout the development process.

#### **2.4.1 Criteria for Simulation in IPPD**

Consistent with the goal of creating and using simulations only when they meet critical needs and yield concrete benefits, four criteria for creating manufacturing system simulations have been established as follows:

- (1) The simulation must have the capability to control the real factory (e.g., semiconductors, crystal filters).
- (2) The simulation must provide timely information feedback to the IPPD environment (e.g., establish cost, performance, and quantity tradeoffs, define process flow impediments).
- (3) The simulation must provide cost tradeoffs for weapon system affordability assessment.
- (4) The value of the simulation must exceed the cost of its creation and use.

At least one of the first three criteria, and in all cases the fourth, should be met prior to investment in a proposed simulation.

##### **2.4.1.1 Capability to Control the Real Factory**

Investment in modeling and simulation may be justified if the resulting simulation has the capability to be used in controlling the real factory. Simulations of manufacturing processes that initially support manufacturing process design may have enough value in controlling the real factory, creating desired quality and manufacturing yield, to justify their development and validation. Automated factory control, with emphasis on rapid initiation of limited rate and full-scale production, can then be achieved through use of simulation-based computer control of the manufacturing process.

##### **2.4.1.2 Timely Information Feedback to IPPD**

Models and simulations developed for manufacturing process design can often provide critical information on product performance and cost that can be achieved with available manufacturing processes, in support of the IPPD process. With validated manufacturing system simulation tools, product and manufacturing process design iterations can be carried out to quantify tradeoffs associated with cost, production rate, and product quality that are dictated by the manufacturing process.

#### **2.4.1.3 Cost Tradeoffs for Weapon System Affordability Assessment**

The IPPD process can be developed to determine the affordability of weapon systems, based on the simulated use of new technology. Simulation can reduce the costly cycle of design, prototype, test, redesign, retest. The product and manufacturing processes developed will then meet the predicted yields and cost, prior to manufacturing.

#### **2.4.1.4 Value Must Exceed the Cost of Its Creation and Use**

Even if one or all of the above criteria are met, it is imperative that the value of a proposed simulation exceed the cost of its creation, validation, and use. Otherwise, the simulation is being created for its own sake. The value of a simulation must be judged in terms of the reduction in time and cost achieved, as compared with achieving the desired result by means other than modeling and simulation.

### **2.4.2 Major Issues To Be Resolved**

The subgroup identified six significant issues regarding the use of modeling and simulation in the engineering and manufacturing process:

- (1) Can modeling and simulation be used to shorten the time and substantially reduce the cost of conventional prototype fabrication and test methodology?
- (2) What is currently capable of being modeled and simulated?
- (3) What should be modeled and simulated?
- (4) Does an infrastructure exist to support modeling and simulation?
- (5) Should modeling and simulation be used as a DoD source selection tool?
- (6) Can modeling and simulation guide selective investments in the industrial base?

The subgroup's response to these questions is in the following subsections.

#### **2.4.2.1 Time and Cost Reduction of Conventional Prototype Fabrication and Test**

Judicious use of modeling and simulation methods, concentrating on critical performance and manufacturing process issues and taking advantage of available models of noncritical weapon performance and manufacturing capabilities, can significantly reduce the time and cost of the weapon system design cycle. Use of validated models in simulation of a weapon system and the associated manufacturing processes can avoid one or more cycles of the conventional prototype fabrication and test process, hence significantly shortening

the time and substantially reducing the cost of weapon system and manufacturing process design.

#### **2.4.2.2 Existing Capabilities**

Many aspects of weapon system performance are now capable of being simulated with confidence, whereas some performance-related design tradeoffs require real-time interactive warfighter- and hardware-in-the-loop engineering simulation methods that are under development. Well-developed engineering analysis tools are currently available in many sectors and are available for the non-real-time simulation environment. Tools such as solid modeling, computational fluid mechanics, finite element structural analysis, thermal analysis, and mechanical system dynamic simulation are used today for product design and occasionally for design of manufacturing processes. Additional tools need to be developed for all new process ATDs. Currently, only selected manufacturing processes can be modeled mathematically using first principles. Thus, most simulations of manufacturing processes must be carried out using physical experiments or empirical models that are based on experimental data.

#### **2.4.2.3 Judicious Use**

Critical weapon system performance and manufacturing process characteristics should receive high priority for modeling and simulation in support of IPPD. Care should be taken to avoid the evangelistic use of modeling and simulation when it is not needed. The least cost and time-consuming modeling and simulation approach should be adopted to meet specific high priority needs in product and process design.

#### **2.4.2.4 Infrastructure Support**

The major challenge in effective use of engineering modeling and simulation, particularly as regards achieving a rapid response simulation capability, is enhancing the poor infrastructure that is currently in place to support modeling and simulation. Individual discipline-oriented simulation tools exist, but most are embedded in specialized organizations. Data communication standards and tools to exploit the broad range of simulation tools required in weapon system and manufacturing process design do not exist.

#### **2.4.2.5 Guide to Selective Investments in the Industrial Base**

Models of the manufacturing industrial base are needed at a level of sophistication that reflects the impact of investments on product cost, production quantity, product

quality, and industrial base responsiveness. Such a capability may or may not be feasible in the foreseeable future, depending on the industrial sector involved.

#### **2.4.2.6 Source Selection Tool**

Some sectors of the industrial base are capable of using modeling and simulation as a discriminator for source selection. This capability needs to be expanded (where feasible) to many sectors of the industrial base.

#### **2.4.3 Manufacturing System Simulation in the ATD Process**

Manufacturing costs are dependent on the determination and validation of unit process physics. In the event of a new material application or the need for a new process with an old material (e.g., x-ray lithography), manufacturing costs are unknown until the process is understood, verified, and tested for repeatability throughout its total process sequence. Thus, the affordability of engineering simulation feedback to battlefield simulation will require extensive analysis and experimentation. It is therefore recommended that ATDs involving only a few new processes combined with known processes be selected to demonstrate modeling and simulation technology.

Historically, technology demonstrators have not devoted serious attention to the ability to cost-effectively produce products based on the technology being developed. Although some benefit in this area may be derived from first principles mathematical modeling and simulation technology, the newness of the manufacturing processes involved will generally require extensive physical validation.

Simulation is being used to determine manufacturing queues, flow time, cycle time, and manufacturing bottlenecks. This activity needs to be continued and integrated into the development of ATDs.

In the past, the DoD S&T community has not been willing to spend the resources required to validate production capability, and the DoD Production and Logistics (P&L) community has been preoccupied with industrial base issues involving production of weapon systems. Therefore, the important area of production risk abatement for key technology insertions has fallen into an organization chasm.

#### **2.4.4 Industrial Base Issues**

Manufacturing process technology is dependent on organizations since it involves training of specialists and combined managerial and technological skills. In fact, it is these

specialist skills that are essential for military applications and that must be highlighted in any study of the defense industrial base. The loss of organizational process capability through bankruptcies, buyouts, retirements, and other "wild card" events can make reconstitution expensive and exceed the 5-year warning period.

## **2.5 IMPLEMENTATION**

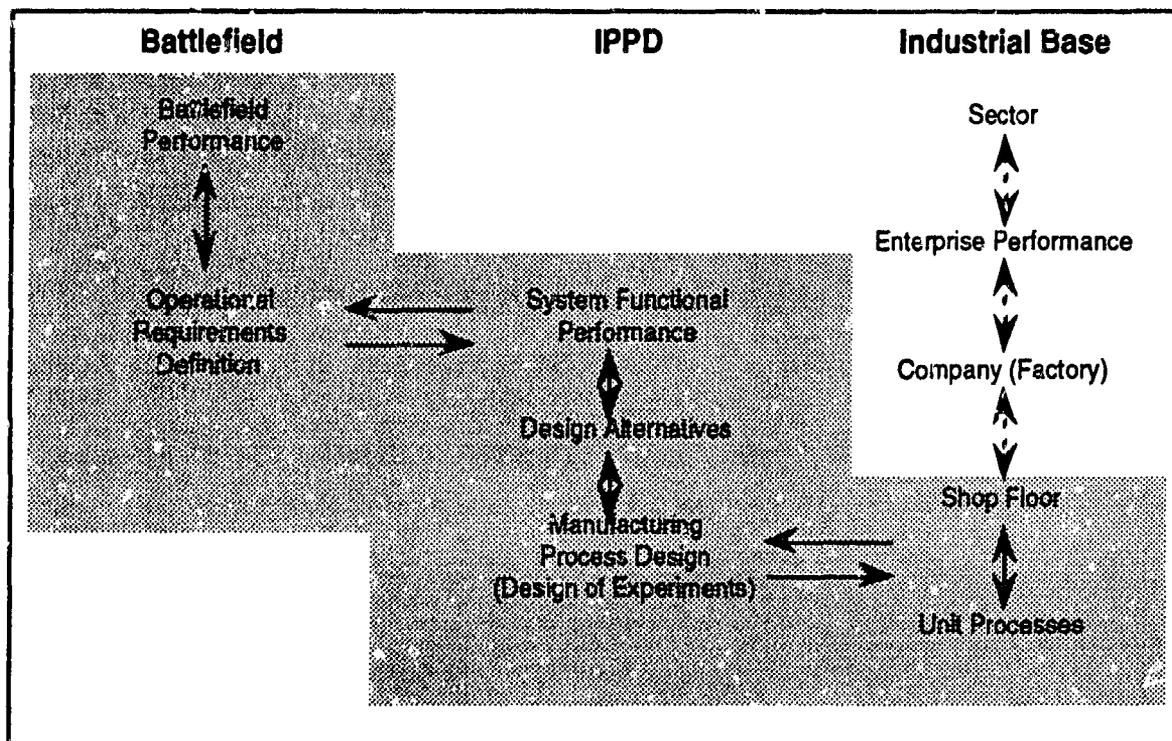
Modeling and simulation will become an integral activity in support of the new S&T and acquisition strategy: Modest basic developments will be achieved in modeling and simulation in general; significant effort will be devoted to integrating the IPPD environment with the battlefield and industrial base functional areas; and carefully chosen experiments will be conducted to test, demonstrate, and refine an integrated engineering environment. Improvements needed to achieve the desired capability for iterative product and manufacturing process optimization using modeling and simulation are shown schematically in Figure 2.4. An infrastructure to support real-time interactive modeling and simulation in each of the three functional areas of the highlighted region of Figure 2.4 will permit iterative interaction among modeling and simulation tools to support the following:

- (1) Battlefield operational simulation to determine requirements and evaluate the warfighting capabilities of candidate designs.
- (2) Integrated product and process design that accounts for tradeoffs among design alternatives as they influence system performance and manufacturing process capabilities.
- (3) Tuning of unit processes in the shop floor environment to support low- and high-volume production of weapon subsystems and systems.

Equally important, horizontal electronic communications are required between the IPPD environment and the battlefield and industrial base sectors, as shown in parallel horizontal arrows between these sectors in the highlighted region of Figure 2.4. These interactions need not be in real time, as indicated by the parallel arrows, but should be implemented using an electronic medium. Initial efforts to define the needed communications between the IPPD and battlefield environments have begun and can be systematically implemented and tested through ATD experiments. The interchange between IPPD and the shop floor, however, is rarely found today. The semiconductor industry is one in which the interchange does exist, and the benefits are clear. In other sectors, care must be taken in defining the level of electronic interaction needed and the benefits to be derived.

DoD has developed an excellent battlefield-to-requirements simulation system, but it must be interfaced with industry's system that includes design and manufacturing models and simulations. Numerous examples exist in which the design process received incomplete operational requirements, but deficiencies remained undetected until Operational Test and Evaluation (OT&E). Creation of the communication links recommended will allow for earlier user involvement and better definition of operational requirements at the start of development.

If all appropriate modules in each of the functional areas of the highlighted segment of Figure 2.4 were developed, and if a standard architecture, transfer format, and network protocols existed, then the appropriate level of information exchange between the respective functional simulation environments would be as indicated by the horizontal parallel arrows. This is the communication capability that will provide feedback and feed-forward capabilities for decision making across the functional environment boundaries between IPPD, the battlefield, and the shop floor. The vertical arrows above the shop floor in the industrial base functional area are shown dashed because, at this time, the investment return is much less clear.



**Figure 2.4. Improvements Needed for Iterative Optimization Using Modeling and Simulation**

The subgroup recommends three actions, described in the following subsections, to accelerate the transition to the enhanced modeling and simulation environment shown in Figure 2.4.

### **2.5.1 Conduct Experiments**

The first action is to conduct experiments that iterate among the synthetic battlefield, the IPPD environment, and the simulated factory. ATD experiments that cross boundaries between Thrusts 1-5 and Thrust 6 (Synthetic Environments) and Thrust 7 should be selected to develop and demonstrate capabilities and limitations offered by modeling and simulation in IPPD. Examples of such experiments are given in Chapter 4 with details in Appendix I. The objective in these experiments is to iterate, in a cost effective and timely manner, among (1) the synthetic battlefield for warfighting effectiveness, (2) the IPPD environment for product and manufacturing process design, and (3) the simulated factory for production of weapon systems in the industrial base. Tradeoffs involved in these three major functions are required to optimize product and process designs within the capability of the industrial base to meet warfighting needs in a cost-effective and timely manner. Concrete experiments that augment simulation efforts planned in existing ATDs are recommended to challenge all aspects of this revolutionary new approach to product optimization and process design. This is the least costly and most effective approach to test the bounds of modeling and simulation technology and to form a foundation for practical modeling and simulation tools that can be expanded over time to meet a broad range of DoD needs.

Prior to exit from an ATD, manufacturing capability and affordability should be demonstrated through use of modeling and simulation as well as selected validation and physical prototyping efforts. Modeling and simulation should be carried out at a level of sophistication, detail, and cost that is appropriate for the value received. Projections of warfighting capability, cost, and production schedule achievable through adoption of advanced concepts and technologies represent the primary value of ATDs. Exit criteria should be defined to ensure that validated simulations of critical weapon system performance and critical manufacturing process characteristics are available for downstream decision making regarding entry into EMD at some point in the near or long term.

### **2.5.2 Develop and Demonstrate Architectures and Protocols**

The second action is to develop and demonstrate architectures, data transfer formats, and network and module protocols. The major impediment to effective use of modeling and simulation methods and technologies for the foreseeable future is the lack of interoperability of modeling and simulation tools. A high priority within Thrust 7 should be given to development of standard architectures, data transfer formats, and network/module protocols that will permit effective sharing of distributed data and models to be migrated to the various companies in the industrial base to realize the potential offered by modeling and simulation in support of weapon system and manufacturing process design.

### **2.5.3 Increase Research**

The final action is to increase research on basic manufacturing process physics, sensors, and control logic. The current state-of-the-art in manufacturing process simulation is limited by the ability to model and simulate the fundamental physics of manufacturing processes, sensor functions, and control mechanisms. Research focused on developing models and simulations of critical manufacturing processes associated with future weapon systems is needed. Data from such research can provide product and process design tradeoffs to achieve better and more realistic simulations in the foreseeable future.

## **2.6 CONCLUSIONS AND RECOMMENDATIONS**

A key element in achieving IPPD objectives is early learning and systematic product and manufacturing process optimization through iterative use of modeling and simulation. Revolutionary new modeling and simulation capabilities are on the horizon to support product and manufacturing process design tradeoffs that influence battlefield warfighting effectiveness and the industrial base. Realization of these modeling and simulation capabilities will permit defense product and manufacturing process optimization through multiple simulation-based design iterations that are not economically feasible in finite time using the conventional approach of prototype-based design, build, test, break, and fix.

The new DoD S&T strategy provides an opportunity to systematically develop and demonstrate the modeling and simulation approach to IPPD. Strategic investment in selected ongoing and new ATDs is key to achieving this potential at modest cost. In Appendix I, three system- and subsystem-oriented ATDs are identified that can be augmented to exercise the full spectrum of modeling and simulation methods and tools in

IPPD. They involve applications that are typical of those encountered by all three Services and a broad range of product and process technologies found in Thrusts 1-5. The recommended infrastructure ATD will support these application-oriented ATDs and demonstrate a modeling and simulation environment that couples the synthetic battlefield of Thrust 6 with the industrial base to create a revolutionary new IPPD capability for DoD. The capability developed will provide the foundation for systematic use of IPPD throughout weapon system development and production.

Successful completion of the recommended experiments (Chapter 4) will validate the significant cost and time savings that can be achieved using modeling and simulation in IPPD. This new capability will permit the DoD to continue acquiring world-class weapon systems, but in a shorter time and at reduced cost. DoD will thus meet its goal to become a world-class customer, and defense industry participants that develop and adopt the modeling and simulation approach to IPPD will function as world-class suppliers.

The subgroup delineated six specific recommendations to implement the actions described in Section 2.5 and reach the goal of becoming world-class in modeling and simulation for IPPD. They are as follows:

- (1) Demonstrate warfighter-in-the-loop simulation for product design in Thrust 1-5 ATDs.
- (2) Require the use of a combination of modeling, simulation and physical prototyping in appropriate ATDs to demonstrate manufacturing capability and life cycle cost prior to Milestone I.
- (3) Develop and demonstrate standard architectures and infrastructures for interoperability of models and tools as part of a Thrust 7 Infrastructure Demonstration supporting selected Thrust 1-5 ATDs.
- (4) Require Thrusts 6 and 7 to develop and adopt data transfer formats and network and module protocols that permit electronic sharing of data between the synthetic battlefield and IPPD, to be used for Thrusts 1-5.
- (5) Require Manufacturing Science and Technology Program to develop and demonstrate electronic interchange between IPPD and the shop floor environment.
- (6) Increase research on manufacturing process physics, sensors, and control logic and develop libraries.

### **3. COMMERCIAL PRODUCTS, PRACTICES, AND CAPABILITIES (DUAL-USE-MANUFACTURING)**

#### **3.1 INTRODUCTION**

##### **3.1.1 Terms of Reference**

This chapter responds specifically to the following tasks outlined in the Terms of Reference (TOR) for the Task Force:

- Evaluate DoD and commercial technology plan alignment.
- Assess technology drivers (commercial and DoD) in key industrial sectors.
- Suggest technology investments and engineering practices to promote dual use.

##### **3.1.2 Prior Related Studies**

The subgroup spent a substantial amount of time reviewing previous studies on this subject so that it could then build on past work. It found several excellent studies that, when taken as a body, strongly encouraged the DoD to employ dual-use-manufacturing more extensively. The most significant of these were the following:

- DSB Report 1986 Summer Study (January 1987), *Use of Commercial Components in Military Equipment*.
- DSB Report (June 1989), *Use of Commercial Components in Military Equipment*.
- DSB Report 1988 Summer Study (October 1988), *The Defense Industrial and Technology Base*.
- DSB Report 1991 Summer Study (Draft), *Weapon Development and Production Technology*.

Later in this chapter the term dual-use-manufacturing will be defined more specifically, but initially it is used to simply refer to military use of existing commercial products and practices. Thus, dual-use-manufacturing refers to a single product or practice that can be used both in the commercial world and the military world.

The subgroup determined that, while virtually all the recommendations in the prior studies had merit, very few of them had been implemented vigorously. There are some indications that dual-use-manufacturing has increased, but these indications are, in the subgroup's view, largely anecdotal and do not appear to form a substantial trend toward greater DoD implementation of dual-use-manufacturing. Subgroup members felt that significant improvements still need to be made and that today's environment is different than the environment of previous studies.<sup>1</sup>

### 3.2 CURRENT STATUS

The first issue in the current environment is the operational setting in which the DoD must function in the future. The decline of communism has been surprisingly quick and definitive. Unstable leaders who must be closely monitored still remain scattered around the world; however, they are not grouped together under one large political banner with massive military resources at their command as was the case until recently. This dramatic switch changes not only the DoD's military task but also, to a significant degree, the perception by the public, and much of government, about the need for extensive use of our nation's resources on military capability. The resolve of the public to decrease military spending is not only prompted by the obvious opportunity to do so but compounded by important domestic agendas that have become much more urgent recently. In short, the prevalent thinking is that there are many urgent needs for domestic resources and, since threat of war has virtually disappeared, the military budget can be slashed dramatically. The subgroup did not address the correctness of this rationale but feels strongly that it will prevail in the future.

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<sup>1</sup> Where the need for improvement has been recognized in the DoD, many actions have been initiated or taken to simplify the acquisition process. For example, some of the paperwork associated with the acquisition process made the use of commercially available products difficult. Specifications were used that were unique to military procurement, and their excessive use drove up the cost. Today, over 75 percent of the 500 acquisition directives have been deleted, the Defense Federal Acquisition Regulations (DFARS) have been cut in half, nearly 6,000 standards have been canceled, and the DoD is using more than 2,000 industry standards or simple commercial descriptions in place of specifications once unique to defense products. Major efforts are now under way in DoD to permit the use of commercial products and support the use of dual-use technologies during acquisition. Despite these new top-level policies, however, change at the implementation level has been slow, and more remains to be done.

Fortunately, there is another element of the environment that should make the DoD's job of coping with the shift in public priorities easier to accomplish. This help can come from the rather large body of knowledge and lessons learned by industry over the last several years regarding new product generation and operating efficiencies. These lessons have been learned not only by commercial industry but also by defense industry, and they can be brought to bear almost unmodified by the DoD if it is willing to undertake changes as dramatic as those in industry.

U.S. industry is in an agonizing battle for survival. It is operating in an incredibly competitive environment in which jobs are being cut 25 to 100 percent across companies. Survivors are going through major cultural change that includes a focus on customer satisfaction, total quality, value-added analyses, improved management, employee empowerment, cross-functional teams, and training and education.

This modification in the way industry has chosen to conduct its business, and the way it looks at its problems has occurred mostly in the last 5 to 10 years. Many industries have been pushed virtually to the brink of extinction by worldwide high competition. The automobile, steel, commercial shipbuilding, and home electronics industries have all suffered a dramatic loss of market share because of their inability to become as efficient and effective as their competition. Many industries learned from these examples, became much more effective, and are now competitive. It is the lessons learned by these resurgent companies that can provide the foundation for a new approach that DoD can take in conducting its business. These progressive industrial firms, and a number of academic institutions and the government, have done considerable research on how to transform a slipping company into a revitalized, successful, company.

The situation that the DoD is in today has many similarities to the challenge commercial industry faces. Commercial industry customers want more value for their money and, in many cases, want to spend less to get better products. In the case of the DoD, the public realizes that the U.S. military is the best performing and most capable force in the world. They demand a continuation of that high level but just do not want to pay as much for it. It is imperative that DoD benefit from commercial industry experience in facing this challenge.

DoD must recognize that it must work with both defense and commercial industries to maximize the value received from the dollars spent. Examples of successful collaboration are shown in Table 3.1. Discussions of commercialization in the electronics and shipbuilding industries are contained in Appendices G and H, respectively.

**Table 3.1. Examples of Successful Dual-Use Programs**

- Carousel IV Inertial Navigation System (INS) (Air Force).
- Commercial utility cargo vehicle (Army).
- Heavy expanded mobility tactical truck (Army)
  - Commercially available components.
- Maritime prepositioning ships (Navy).
- DC-10 → KC-10 (Air Force).
- EA6B mission planning system (Navy).
- GPS from Trimble (Army).
- Modular radar program (Modar).

In summary, the subgroup reached two fundamental conclusions about the new environment: (1) the challenge of dramatically improving the performance/cost ratio is clearly facing the DoD and will be for the future, and (2) the tools and techniques necessary to face this challenge are available. The remainder of this subgroup's study dealt with defining those tools and techniques and suggesting ways in which their efficacy can be demonstrated. The Terms of Reference for this Summer Study, unlike those of previous studies, encouraged the Task Force to suggest specific experiments to demonstrate the recommended tools and techniques. Several experiments are discussed in Chapter 4 and Appendix I.

The remaining sections of this chapter will deal with the various ways dual-use-manufacturing can be productive for DoD. The subgroup did not study and recommend ways in which new tools and techniques can be effectively instilled in the hearts and minds of DoD personnel and does not wish to minimize the difficulty that the DoD faces in installing these new paradigms. Success stories in industry often do not address the changing of peoples' minds and habits. This change will be long and arduous but will be worth the effort.

### **3.3 VISION**

In the Introduction, dual-use-manufacturing was defined in its simplest form as being the joint use of identical products and processes by both the DoD and commercial

industry. That definition can be expanded to allow a more detailed discussion of the vision of how dual-use-manufacturing can be of value to DoD. Dual-use-manufacturing involves more than just products—it also refers to the joint use of flexible factories, the adoption by DoD of successful operating practices from industry, and the convergence of military technologies into commercial technologies. These four types of dual-use-manufacturing are depicted in Figure 3.1 and described in the following subsections.

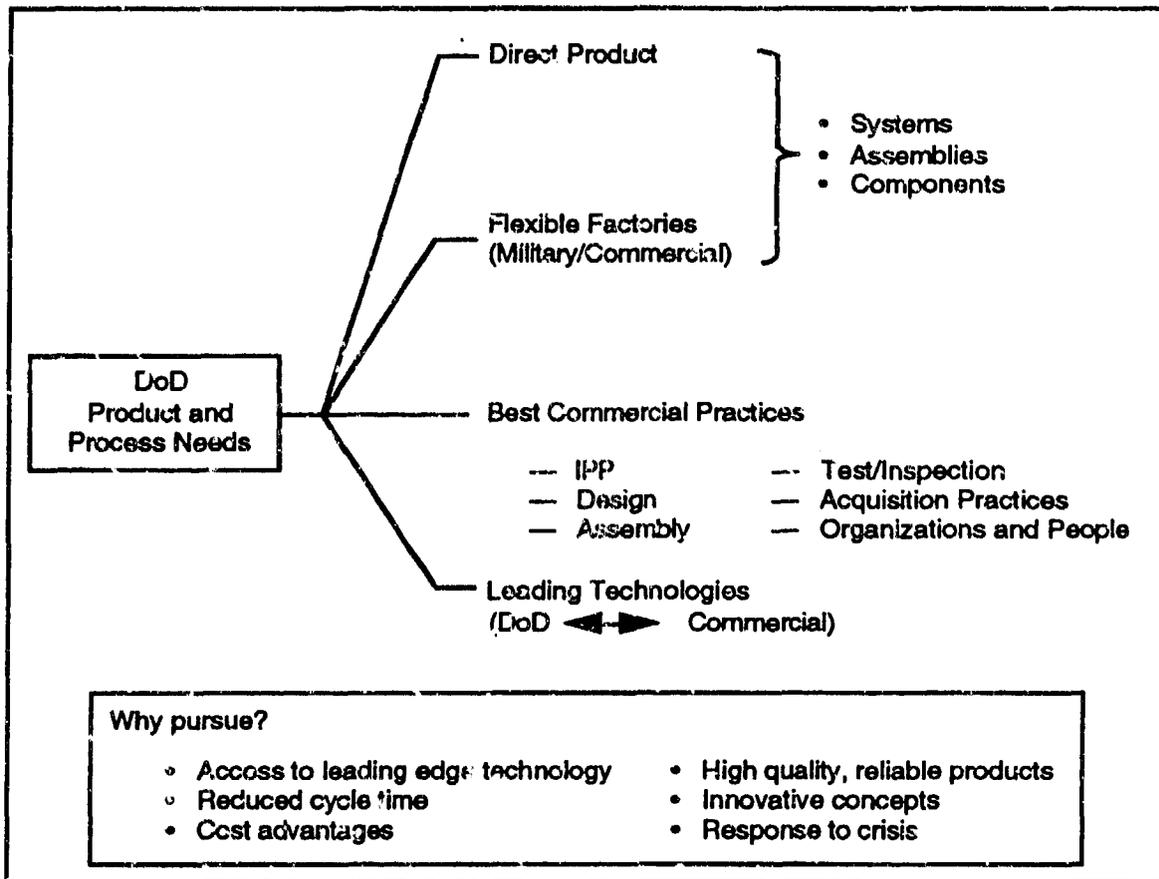


Figure 3.1. Four Paths to Dual-Use-Manufacturing

### 3.3.1 Direct Product Use

The first type of dual-use-manufacturing deals with direct product use, i.e., a product that can be used by the military in exactly the same form as it is in commercial industrial practice. This product could be anything from a transistor or a printed circuit board to a subassembly or a complete electronic product. With direct product use, the military procurement officer can buy the commercial version using the commercial stock number and product definition. Certainly there are many procurements that do have unique

military characteristics in terms of performance, environmental hardening, or expected life. However, the subgroup is certain that a careful analysis would show that many commercial components would perform quite satisfactorily in a military environment. It requires more effort on the part of the DoD personnel to ascertain that the commercial version will work satisfactorily, but when cost differences of ten to one are at stake, these analyses are well worth the effort.

In the past there probably was greater justification for unique military requirements than at the present, particularly along the lines of quality. Understandably, the military expects that 100 percent of a batch of delivered products will meet specifications. Even one defective component is unsatisfactory, particularly to the Service person receiving that defective component. Prior to the mid-1980s, commercial industry clearly thought that if 90 to 95 percent of the shipped products were conforming, it was sufficient. Today, most successful commercial companies strive for product quality of 100 percent. Thus, commercial industry's approach to quality has become dramatically closer to the military approach, and DoD's attitude toward commercial products should reflect this.

One last note in this category of dual-use-manufacturing: It is not sufficient for the military procurement to simply buy commercial products. Emphasis should be on seeking out high-volume commercial products. Cost savings will be maximized only if the most popular commercial products are bought.

### **3.3.2 Flexible Factories**

The second approach to dual-use-manufacturing is the use of flexible, commercial factories by DoD. This use encourages the DoD to participate with sub and prime contractors and suppliers who have initiated a flexible environment for their manufacturing. In this environment, the supplier has chosen several similar but different products to produce on the same production line. The motivation for the supplier to do this, of course, is the flexibility gained by being able to respond to various customers with a changing product mix that matches the customer's changing requirements. Usually, flexible factories also have the characteristic of very short through-put times. The attendant customer benefit is very short lead times from order to receipt of goods.

Many companies have embarked on these programs and have successfully taken competitive advantage of the improved operating characteristics achieved. Here, as with the first dual-use-manufacturing category, more effort will be required by DoD personnel than would be required if flexible manufacturing were not sought out. Five or six different

products cannot simply be put onto the same line—someone must make sure that the DoD product will fit the parameters established by the supplier for flexible manufacturing. The products must have similar processes, use standard parts, employ identical information systems, and require consistent manufacturing administrative practices. The requirements of the supplier to meet this flexible profile are not necessarily rigorous but need to be addressed early in the manufacturing cycle.

The benefits derived from joining a flexible factory fall into two general categories, both of which are substantial and usually well worth the added effort. The first benefit is that DoD will have embedded its product into the supplier's best manufacturing activities. Flexible manufacturing is currently viewed as an extremely valuable competitive tool, and most manufacturers are putting their best people and best practices on these lines. Thus, DoD will be able to directly benefit from the best the supplier has to offer.

The second benefit derives from the very reason the technique is popular with commercial industry—that is, providing flexibility to meet customer's changing requirements in a very short time. In the case of DoD, the benefit is probably greater than it is for most customers. The DoD's needs are more likely to vary dramatically than are the needs of other customers because changing world circumstances are usually completely unforeseen. As an example, say DoD has embedded its products into a flexible manufacturing line and requires only 10 percent of the line's output during politically quiescent periods. Then suddenly, a politically unstable situation erupts and DoD needs 90 percent of the supplier's output. It is relatively easy to increase DoD's share from 10 to 90 percent if it is on a flexible line. Industry's old, inflexible approach would usually require many months for it to acquire inventory for the added production. Today, industry is successfully trying to operate with less and less inventory, and, thus, products built on unique and separate lines will have even less flexibility than in the past.

One last important point is that in a flexible environment, the total capacity of the line is relatively inflexible. What is flexible is the mix of products made on the line, thus allowing for a dramatic change in any one of the customer's requirements for his products made on that flexible line. Obviously, the supplier hopes that other customers' needs will decrease in the same period.

### **3.3.3 Best Commercial Practices**

The third approach to dual-use-manufacturing is in the somewhat broad and vague category of best commercial practices. Industry has learned many new ways of

approaching activities and processes that work dramatically better than the old ways. It is imperative that DoD take advantage of these lessons learned. Two general categories of practices are recommended. The first is practices that the DoD needs to incorporate in its own way of doing business. The second is practices that DoD should demand of its suppliers. This distinction is somewhat of an oversimplification because DoD does engage in manufacturing activities and, thus, a number of the practices it demands of its suppliers will also be applicable to the manufacturing aspects of DoD. However, since the predominant opportunity for improvement lies in DoD's adopting recently learned industrial procurement practices, the distinction is made here.

The following lists first cover the practices that the subgroup recommends DoD adopt internally. These practices will appear to be primarily procurement practices but must be instilled conceptually throughout the entire DoD organization. The following practices are generally accepted by industry to be those of a world-class customer:

**Performance improvements driven from the top throughout the organization.** The person in charge must believe in and actively pursue all the elements of the organization's enhanced performance. This includes establishing goals, monitoring progress, and appropriately rewarding successful achievers. Some improvement initiatives have started at the lower levels in many organizations. However, top management must at least create an environment where these changes are viewed as "professionally acceptable" (not all business environments welcome change). It is better if the top executive establishes process improvement as the "order of the day" and follows up on his or her pronouncements.

**Willingness to share responsibilities with suppliers for the long haul.** Both supplier and customer must recognize that they are dependent upon each other, as well as themselves, for their own success. Each should adopt a feeling of responsibility for the other's performance and take appropriate steps to further these goals. If an otherwise good supplier is driven by inappropriate cost and performance expectations to exit the business, the customer has lost, not gained. Customers should be willing to inform key suppliers of their expectations of technical performance, cost, quality, and delivery parameters and even levels of business expected. Both supplier and customer must realize that they both need an appropriate reward and risk ratio to continue the relationship and that each has a responsibility to the other for obtaining a satisfactory ratio. In short, DoD must expect suppliers to make a profit as well as share the risk.

**Involvement of suppliers in cross-functional teams.** Planning done internally in the DoD by teams made up of engineers, operating people, and procurement people should include key suppliers in the early phases. This is particularly true when completely new systems are being considered. Suppliers frequently can make productive suggestions that, if given early enough, can modify product configurations to reduce cost and

enhance performance and reliability. Further, when suppliers understand the general direction the customer is attempting to go, they can adjust their resources, both human and equipment, to better meet the needs of their customers on an appropriate time scale.

**Immediate feedback on performance.** World-class customers provide their suppliers with performance feedback in a mode designed to enhance performance, not simply to police unsatisfactory activities. Customers should share performance information in a timely fashion and include, where possible, suggestions for improved performance—not simply a good or bad grade.

**Provision of incentives to suppliers for continuous performance improvement.** Suppliers need to know that the customer appreciates improved performance and is willing to share the rewards of that performance with the supplier. Rewards can vary from monetary incentives to simply a higher esteem in the eyes of the customer that could result in a higher level of future business.

**Willingness to trade performance and cost.** Dialogue between the customer and supplier needs to occur for full understanding of the product's cost and feature structure. Suppliers are usually in the best position to identify the cost of various features while the customer is in the best position to quantify the value to DoD of each of these features. The supplier must be willing to help the customer understand what each feature costs so the customer can decide if each feature's value exceeds its cost. If not, customer and supplier should eliminate the feature or pursue other products that include only features worth their cost. This dialogue should be an integral part of any customer and supplier relationship and should occur early in the procurement cycle.

**Understanding of supplier's process matrix and willingness to participate in improvement.** A world-class customer needs to understand the processes whereby the supplier is producing the provided products. In instances where the processes provide minimum value or inadequate quality, the customer must participate in identification and subsequent modification of the offending processes at the supplier's facility.

**Buying to performance specifications (minimize how-to constraints).** The customer's job is only to describe the problem that he wants solved by the supplier's product. Stated another way, the customer should restrict himself to describing what he wants the product to do. While the customer can participate in suggesting how the supplier might go about providing the features required, the customer should recognize that the supplier is in the best position to determine how to meet the performance requirements and should not provide detailed process sheets and part drawings to the supplier. Providing this level of detail frequently eliminates the opportunity for the supplier to creatively address the customer's needs.

**Minimizing low-value-added tasks.** The customer should analyze all requirements, particularly such non-product requirements as cost accounting information, forms, and other record keeping, to determine whether they are

really of use to the customer. The customer should participate with the supplier in determining the cost and whether the requirements are worthwhile. This assessment needs to be undertaken periodically since even once-useful practices frequently stay on the books long after anyone can remember why they are being pursued.

The above list includes the major elements of what is generally accepted by industry today as world-class procurement philosophy, which the subgroup recommends that the DoD incorporate.

The second category of new practices in industry that can benefit the DoD comprises the numerous new internal practices that companies have used to improve their performance. These practices probably will not directly affect DoD, but to the extent that DoD can insist that its suppliers use these practices, the effectiveness of the military resources can be enhanced dramatically.

The following list is a good example of the types of characteristics that the DoD can look for and demand among its important suppliers. Consistent with the previous list, the subgroup feels it is extremely important for DoD to establish close relationships with its suppliers by going far beyond simply awarding contracts, receiving material, and paying bills. The DoD must encourage and require suppliers to conform to the best existing business practices and techniques. The payoff will be better products, stronger suppliers, and better supplier performance. Probably most important, the DoD can establish a group of suppliers who do business with DoD not only for the profit but also for the learning and strengthening experience. The list of important practices by successful companies includes the following:

**Making extensive, or even exclusive, use of IPPD as described in Chapter 1 of this report.** Briefly, IPPD means that the product is engineered simultaneously with the processes necessary to produce it. In the past, designers would invent a product and then turn it over to the process personnel for development of the processes. In today's world, the product designers work in close harmony with the process people using existing processes where they can and being careful to design within the limits of those processes. When new processes are required, the product designers decide with the process engineers the characteristics of that new process far enough ahead of time so that the process may be developed and proved before it is incorporated into the design of the product. Evidence of this technique will help DoD ensure that the procurements of products new to the market place can be accomplished within cost budgets and at the highest possible level of quality.

**Showing evidence that operating habits reflect a deep dedication to the continuous improvement of every process within a company.** In the old paradigm, processes were worked on

until they were reliable enough to provide reasonable yields. Today, each process must be improved continuously and the cost must be decreased on an ongoing basis. Yields are not satisfactory until they reach 100 percent. As one knows, costs are never zero and yields are almost never 100 percent, but the suppliers must believe that almost perfect is not good enough, and their goal should be perfect processes.

By "processes" is meant not only the physical process necessary to produce the product but also the variety of processes necessary to manage and administer the company. This includes accounting processes, procurement processes, information processes, marketing processes, and all the human endeavors that contribute to providing a product to DoD. These management processes are certainly more difficult to measure and evaluate than physical manufacturing processes but usually make up a greater total dollar expense than do the physical processes. There are a number of ways to measure these administrative processes, including Total Quality Management (TQM). Much has been written about this new management tool, both academically and by practicing companies. The subgroup suggests that this be investigated by representatives of the DoD for inclusion, not only in DoD operating practices, but within the practices of its suppliers.

**Extensive use of close partnerships throughout the structure of the organization.** One type of partnership was described briefly in the first practice listed above, that of integrating the design engineer with the process engineers. That integration should be expanded to form a complete cross-functional team that includes not only the engineers but also marketing people, manufacturing people, and finance people. This ensures that the development of a product has all the disciplines represented at every stage of formulation, planning, and execution.

Other partnerships, such as that between the DoD supplier and its suppliers are nearly as valuable. Do the suppliers use these partnerships to formulate their operating practices and their overall product and technology directions? Having a partnership in name only is of little use. DoD needs to look for evidence that partnerships do in fact produce the desired effects.

One type of partnership frequently overlooked but of a great potential benefit is a partnership between different departments within a company. Partnerships are most effective in this regard between departments, one of which serves the other. If these departments understand that they have a customer and supplier relationship, as they truly do, and attempt to satisfy each other's needs on that basis, great improvements can be made in the efficacy of internal departments.

**Thoughtful use of modern information systems.** Most world-class suppliers use Electronic Data Interchange (EDI) when passing information between customers and supplier. Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) is also frequently found in the more progressive firms. This is not to imply that firms should become slaves to their computers, but rather that they should make careful analyses of the various tasks facing them and, where those processes are

under control and well understood, use connectivity among computers to speed up and streamline their activities. However, turning a poorly defined and inadequately designed process over to a computer will simply generate mistakes faster. Thus, in analyzing its key suppliers, DoD not only must look for the use of computers throughout the firms but also must come to some conclusion as to how appropriate the computer is for each application.

The above thoughts are not only applicable to information automation (computers) but also to physical automation found usually in manufacturing. Automation is frequently used effectively to increase efficiency and quality, but DoD must convince itself that the processes automated were appropriate before assigning high grades to any supplier.

**Effective, efficient organization.** One of the most difficult to assess, but potentially significant, characteristics of a world-class supplier is its organization. In the past, many firms have fallen to the temptation to organize themselves in a very traditional hierarchical fashion with layers of managers. This approach is costly and incompatible with efficient or fast-reacting operating postures. About the only thing that can be said for it is that it is reasonably efficient as a watchdog organization. If you don't trust your employees, a hierarchical organization allows more people to watch others and thus keep bad things from happening. It also, for that matter, keeps good things from happening. Progressive firms have frequently replaced a hierarchical organization with flatter, shallower organizations that are designed around an important business characteristic or competitive advantage that the firm wishes to achieve.

Another fairly frequently used technique is to base the organization on the information flow that must occur for the firm to be successful. A popular organizational design centers on small operating units. These units are given a unique single charter, such as for a single product line, and the responsibility for all aspects of that product (i.e., manufacturing, engineering, marketing, and finance). This is not to say that smaller operating units are always affordable or the best way of doing business, but they certainly offer significant advantages of flexibility and focus.

Thus, when analyzing a supplier, the DoD needs to consider whether the supplier's organization makes sense for the task at hand. For instance, in using small organization units, manufacturing companies frequently give the responsibility for all the production steps (fabrication through assembly, test, and shipment) for one product to a small group of people. Thus, these employees understand very well that their responsibility is toward that single product. This type of organization doesn't always work, however, if a very expensive process is needed in the manufacture of products across several production units. Each production line, for instance, cannot have its own integrated circuit fabrication activity. It would simply be too expensive to replicate several times throughout a plant. Thus, more expensive processes are frequently centralized with the attendant disadvantage of losing people's focus on the end product. In the interest of economy, however, centralization is sometimes the only sensible approach.

These organizational considerations apply not only to the physical processes in manufacturing but also to the organization of such important departments as Research and Development. A significant question is: Should the lab be organized around products or technical expertise? For example, should there be a power supply department that invents power supplies for all products in the lab, or should there simply be a team of engineers (including a power supply engineer) working on Product A, another on Product B, and so on. This latter organization has the technical inefficiencies of having the power supply people scattered throughout the entire organization. Inefficiencies can occur (1) because power supply engineers can't exchange ideas and problem solutions nearly as freely and (2) the products with the poorest power supply engineers will have the poorest power supplies. These problems would be substantially mitigated if all power supply engineers were located together. However, experience has shown that a great deal of enthusiasm and product loyalty can more than make up for the dilution of some levels of technical expertise.

The reason for mentioning this quandary between product concentration and functional concentration is not to suggest which is correct but simply to indicate that there are times and places for each. A supplier that chooses one predominantly over the other is not guided by a complete understanding of their mission but rather by tradition and will likely be poorly served.

**Effective and efficient decision making processes.** Even with an effective organization in place, if the people best equipped to make decisions are not empowered to do so, the best organization will not function properly. People need to be held accountable for their responsibilities but at the same time be allowed the freedom to discharge those responsibilities effectively. Well-intended cross-functional teams, for example, will become mired in ineffectiveness if all their decisions must be passed up through their respective management to top management. People need the freedom to make decisions that govern the discharge of their responsibilities.

**Use of statistical models.** Traditionally, companies have made decisions based on intuition or, at best, "back of the envelope" calculations. While both techniques are appropriate and should be used in any major decision, a third important tool that has been overlooked until recently by many companies is the statistical modeling of processes.

For example, some firms have recently chosen to consolidate similar facilities only after using both intuition and numerical models. In times past, intuition said that consolidated facilities were sometimes more efficient, but the dilution of product focus, as noted previously, offset the potential savings. While this wisdom may be correct in general, it can be quickly quantified with mathematical models. In many cases, these models do a valuable job of estimating or dimensioning the potential savings, even if they are only accurate within 10 percent. In some cases, the potential savings were significantly greater than anyone could have imagined. These results opened top executives' minds to further studying a situation they would have dismissed out of hand in previous years. In other cases, models have allowed companies to distribute inventory more effectively

along their entire supply chains in the interest of higher customer service levels.

The subgroup is not proposing models instead of rational decision making, but evidence of the appropriate use of models by a supplier is a good indication that the supplier is continually seeking to improve its operations. It also shows that the supplier is using modern tools to aid its progress. Here again, it is important to make sure that the firm is not simply giving lip service to modeling but uses the intelligence gained through modeling as an aid in making decisions.

**Valuing the accumulated knowledge and skill of the employees.** Progressive firms encourage and facilitate continuous training and education of all their people. They view their employees' skills as their most valuable resource. Further, they understand that skills need to be continually modernized and expanded for the firm's future to be bright. Educational learning is viewed as an investment opportunity, not as a burdensome expense or fringe benefit that must be tolerated.

The subgroup believes that this list contains the major characteristics among the leading firms worldwide. The subgroup recommends that the DoD understand its suppliers' operations, at least to the extent of the above characteristics. The subgroup thinks it is important that this understanding of suppliers' operations be shared by DoD procurement people, DoD engineering people, and DoD operating people. The entire DoD team must be responsible for the overall supplier evaluation and corrective action suggestions.

Before leaving this subject, it is necessary to address a potential rejection of this vision on the grounds that DoD should only care about the products procured and should not be concerned about how companies go about providing them. There is some validity to this position, particularly in the very short term. However, the subgroup contends that long-term relationships between supplier and customer are the only way successful firms will do business in the future, and this should be true for the DoD as well.

As with any human relationship, understanding the characteristics and the needs of others can go a long way towards establishing a successful relationship in which both parties contribute to each other's success.

### 3.3.4 Leading Technologies

The last of the four dual-use-manufacturing approaches proposes a substantial alignment of DoD technologies with the dominant technologies of the commercial world.<sup>2</sup> This is certainly a longer term process than the first three dual-use-manufacturing proposals but it ultimately will be as important as the others. Dual-use-manufacturing of technologies will not only be productive in its own right but will undoubtedly affect very favorably the accomplishment of the other three dual-use-manufacturing categories in future years.

There are two distinct reasons for this proposal. The first is that by using virtually the same technology as the commercial world, DoD can effectively piggyback on the enormous resources spent by industrial firms to further these technologies. Thus, for a fraction of the development cost, or possibly at no cost, the DoD can enjoy the benefits of many technological advances. It certainly does take some effort on DoD's part to manage the alignment early enough in the development of the technology so that it can be effective, but the benefits are potentially enormous.

It is the subgroup's view that a conscientious effort on DoD's part to align with commercial technologies will go over well in industry and will allow DoD to have a definite effect on the direction that these technologies are going. This may not be obvious on the surface. If DoD is pushing for a completely different technology than commercial industry is pursuing, only a very small industrial group will be interested in being DoD's supplier—those companies content to serve only DoD. The subgroup believes that as DoD's budget decreases, it is likely that the number of firms willing to have one customer, i.e., DoD, will diminish. On the other hand, if DoD has aligned a given technology with the dominant commercial industry technology, it can present itself as a very important customer to virtually all leading industrial firms pursuing that technology. DoD will then get the attention it deserves both in terms of price and delivery accommodations and in shaping technological directions. The subgroup thinks it is far more productive for DoD to be an important customer for all industrial firms than a major customer for a few firms.

The second important aspect of dual-use-manufacturing technology is that the more it can be used to diminish research investments, the more money will be available to invest in these technologies that are clearly unique to DoD needs. Certainly, the technology of warheads is not one that can be shared with commercial industry, but it is a necessary one

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<sup>2</sup> Technologies used in best commercial practices for IPPD are discussed in Appendix F.

to be funded. These funds are much more likely to be available if technology duality has been sought wherever possible.

Not only will DoD benefit from dramatically reduced research and development costs, but the adoption of the key commercial industry technologies will assure DoD of an inexpensive, high quality flow of production units once these technologies are put into use.

Although there are precedents for the subgroup's advice in the first three dual-use-manufacturing suggestions, there is little in the world that represents technology sharing. Many companies are just beginning to recognize the potential benefits that they and the rest of their industry can derive from partnerships with a shared technology focus. The most successful example comes in the form of technology trades. Firms simply agree to trade wanted technologies. The technologies are not necessarily related but seem to be of equal value to the participants.

Another sharing mechanism is technology that is jointly developed. In this procedure, each firm develops a step in the process, and the partners participate in integrating them into a final technology. However, the different objectives of individual firms usually cause their process steps to be poorly compatible with the steps invented by other firms.

A third example is the joint funding by several companies of an independent organization to do research. This is currently being tried in several experiments, but the jury is still out. There does seem to be some hope for success, however.

This lack of existing industrial experience in shared technology does not diminish the subgroup's enthusiasm for pursuing this technique. The DoD might play an important role in the development of successful formats for technology sharing. Being a catalyst in this important, next-generation, phenomena would certainly make a contribution to the country's industrial strength.

### **3.3.5 Summary**

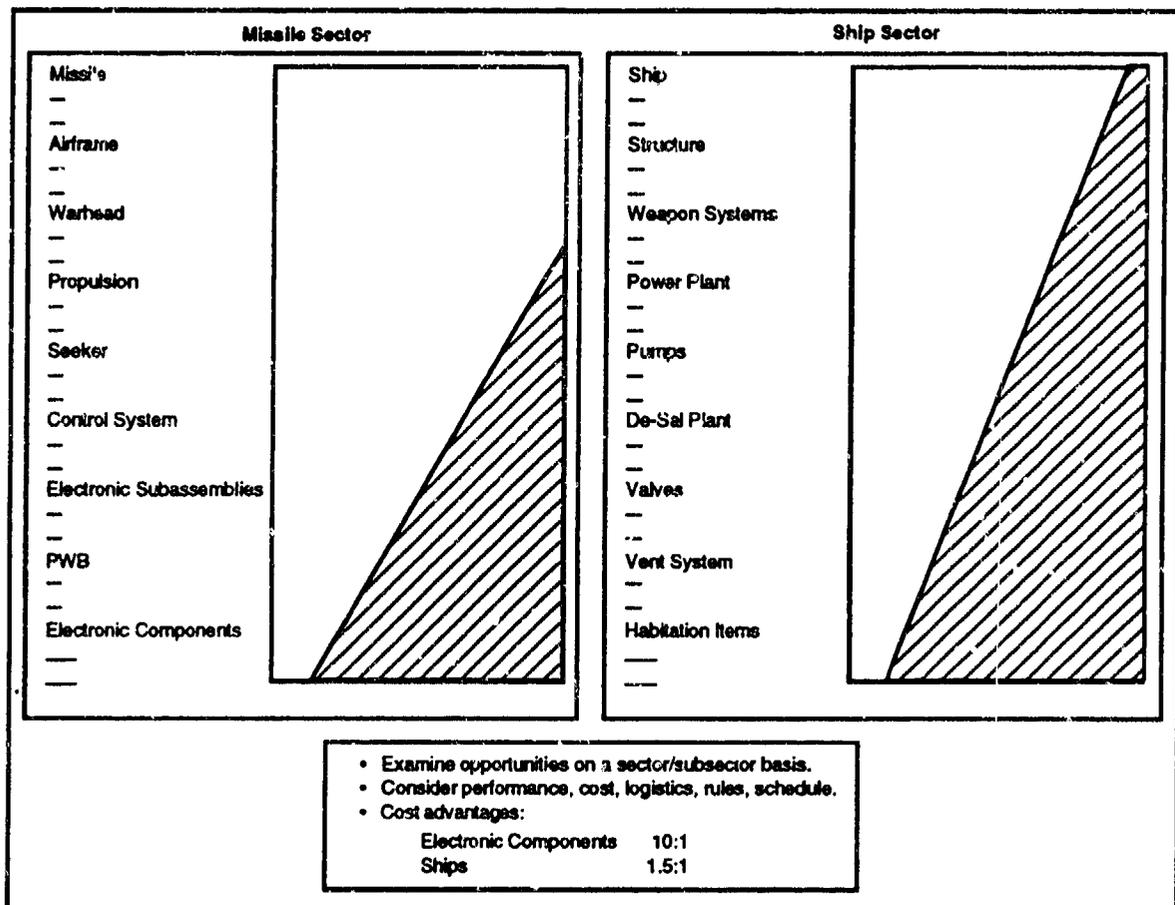
The subgroup strongly recommends that each of these dual-use-manufacturing approaches be pursued vigorously by the DoD. It would be helpful if the potential benefits that would accrue through such a vigorous implementation could be quantified. Unfortunately, only rough estimates can be made.

Hopefully, the experiments suggested in Chapter 4 and Appendix I will provide data on the benefits and go a long way toward convincing DoD of the potential efficacy of dual-use-manufacturing. Some insights can be gained from industry to help understand the magnitude of the potential benefits. It should be understood that all the techniques mentioned above are reasonably new to industry and that, while virtually all of them have been tried, all have not been implemented within any one company known to the subgroup members as of the writing of this report. However, some companies have experimented by segregating certain programs and applying most of the principles discussed above. In instances that subgroup members are familiar with, the results have been no less than astounding. Performance enhancements in terms of cost, product performance, product reliability, and speed of delivery have been improved by factors of two or three. This is repeated for emphasis: The subgroup is not suggesting simply 10, 20, or even 50 percent improvements, but 200 to 400 percent improvements have been accomplished. The subgroup feels strongly that these principles are valuable not only within themselves but also in combination; together, they have a substantial synergistic effect. It is as if the effectiveness of the programs taken together is a multiplication of, not an addition of, each of the enhancements. Thus, two programs whose improvements would each yield a 50 percent performance increase when taken together would yield not two times improvement but two and one-fourth times improvement. The subgroup's industry experience confirms this.

### **3.4 ISSUES AND STRATEGY**

When initially examining DoD activities for potential dual-use-manufacturing examples, one might think that opportunities are limited. A spontaneous reaction might be, "Yes, we can procure administrative supplies such as personal computers and typewriters through a dual-use-manufacturing mode but certainly the procurement of sophisticated armaments such as missiles and ships are so military-unique that dual-use-manufacturing is inappropriate." The subgroup concluded that all sectors must be examined with an open mind to determine dual-use-manufacturing opportunities because more opportunities are available than appear on the surface, as in the case of missiles and ships (Figure 3.2). Certainly when considering the entire missile or the entire ship (with the exception of cargo ships) one would agree that a uniquely military requirement must be met. However, when dividing both missiles and ships into their components, one finds more and more applicability of dual-use-manufacturing as the end product is broken into smaller parts. As one progresses down both types of products in Figure 3.2, more and more subassemblies

and components are found that could easily be categorized as a generic device and, thus, applicable to dual-use-manufacturing. For example, propulsion systems and control systems, while contributing to the military end-use of the missile, find very comparable components in commercial life. While the unique military requirements may preclude dual-use-manufacturing direct purchase, other dual-use-manufacturing opportunities should apply. Taking the example further, there would seem to be clear advantages to dual-use-manufacturing of technology in all the subelements of the missiles—including propulsion and below—and, in the case of ships, at least in power plants and below.



**Figure 3.2. Sector Dual-Use-Manufacturing Opportunities (Notional)**

The subgroup suggests that appropriate experts in all DoD sectors be put to the task of analyzing the requirements of their procurements and identifying those items that would benefit from dual-use-manufacturing. The subgroup is convinced that the success of this endeavor will be directly proportional to the open-mindedness of the investigator and not

limited by any lack of real opportunities. In short, appropriate experts in each of the sectors or military categories must be motivated to find dual-use-manufacturing opportunity—not to find excuses why dual-use-manufacturing will not work. It will be necessary to identify and make required changes to statutes, regulations, specifications, and directives to enable and facilitate dual-use-manufacturing.<sup>3</sup>

### 3.5 IMPLEMENTATION

The opportunities for dual-use-manufacturing have great potential, but the change required to take advantage of this potential is massive. To start the effort, DoD will have to undertake an initiative to engender a much higher level of commitment to dual-use-manufacturing within its ranks. This initiative should encompass the following:

- Selecting a dual-use-manufacturing champion as a high profile, hard charging, highly-qualified individual who reports to the Under Secretary of Defense for Acquisition [USD(A)] and works full time in this job.
- Giving this person the responsibility to make real changes in the culture, regulations, directives of the DoD and the freedom to motivate changes in statutes governing DoD.
- Giving this person the resources and support necessary to be successful.
- Continuously monitoring progress being made toward the goals and the use of appropriate management tools to ensure success.

At a minimum, the dual-use-manufacturing champion should:

- Establish a DoD and industry team to identify both dual-use-manufacturing opportunities and constraints by sector and subsector.
- Establish definitions, metrics, and goals (by sector) for dual-use-manufacturing (e.g., ratio of commercial to total expenditures).
- Aggressively pursue modifications to statutes, regulations, specifications, and directives which impede dual-use-manufacturing.
- Conduct experiments to provide additional hard data on benefits and limitations of dual-use-manufacturing.

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<sup>3</sup> See recommendations in *Interpreting Commercial and Military Technologies for National Strength*, Report of the Center for Strategic and International Studies (CSIS) Steering Committee on Security and Technology, Washington, D.C., March, 1991; and Statements of George K. Krikorian, PE, American Defense Preparedness Association (ADPA), before the House Armed Services Committee (HASC), Subcommittee on Investigation, July 22, 1992.

### 3.6 CONCLUSIONS AND RECOMMENDATIONS

The subgroup is completely convinced that the DoD must take dramatic steps to improve its cost/performance ratio. Performance of the military has always been extremely high—the best in the world—as demonstrated by the recent Gulf War. While the public continues to demand excellent performance, that performance is now expected at a much lower cost. Meeting this expectation is urgent and should be a top priority.

Many, if not all, of the tools necessary for this reformation are at hand. Commercial industries have learned much over the last 5 to 10 years in their struggle for survival. They learned to use many tools and techniques to help improve their cost/performance ratio, and their lessons learned are highly applicable to DoD's situation.

Accomplishing the needed transformation is a difficult task. Commercial industry, while learning the lessons mentioned, also found that they are difficult to implement—particularly in companies with a successful past. Many employees and top managers of these companies simply could not believe that their past formulas would no longer serve them well. In all too many companies, signs of decay had to be reflected in the financial statements before management could be persuaded to take dramatic action to change the way they approached their business. No one would want the DoD to have to see inferior outcomes to be motivated to change. It should not take losing a military war to recognize that past formulas for success cannot be relied on for future success.

New formulas must be found. Hopefully, the reader is convinced that changes are appropriate. If so, the critical question becomes How are they accomplished? Industry has tried several techniques, the most successful being those that include a deep commitment by the managers at the top of the company. This has been discussed several times in the body of this report, but it is mentioned again because of its key nature. The people at the top must eat, breathe, act, and talk in an environment of continuously improving the performance matrix of the DoD.

The subgroup recognizes that the leaders of the DoD currently have challenging jobs and very full schedules. Thus, it seems unrealistic to expect any of them to take on this additional "change agent" job as a full-time or nearly-full-time activity. The subgroup does feel, however, that the task of vitalizing the DoD towards change is a full-time occupation, particularly in the first several years. Once the entire Department is infused with enthusiasm and dedication to continuing to make changes, the full-time assignment is unnecessary. In fact, the best sign that the program has succeeded will occur when a full-

time "champion of change" is no longer needed because everyone in the organization accepts their own responsibility for continuous improvement. In short, when change for improvement becomes a way of life at the DoD, the Champion will not only be superficial but probably detrimental to the operation of the Department. Until that time comes, however, the subgroup thinks the Champion is an appropriate organizational mechanism and strongly suggests that someone be selected for that function. In the following paragraphs, the subgroup shares its views on where the organizational level to which that person should report, the personal characteristics the Champion must have, and the types of duties he or she should perform.

First of all, the reporting relationship should be one that gives the Champion the best chance of success. Accordingly, the Champion should report directly to the Under Secretary of Defense for Acquisition, USD(A). Only with this relationship will the Champion command respect and support that is needed to accomplish the job. This arrangement would also make it easier for the DoD to monitor the Champion's progress toward changing the behavioral paradigms of the DoD. Moreover, it would make it easier for the USD(A) to lend support, assign resources, and make decisions that indicate to everyone in the organization that he is determined to make the program work. The Champion's job should be full time, not tacked onto other responsibilities. Although it is possible for one person to have two important assignments, from a practical standpoint one part of the job emerge as the most important and the other would suffer. Even if the one that predominated were the "change" job, the secondary assignment would suffer and would clearly put the Champion at a career disadvantage. Further, the challenge of the management job is sufficiently demanding, and the attention of the Champion should not be diverted in the least way from this important and very difficult undertaking.

The personal characteristics of the Champion are somewhat difficult to define. A variety of different personalities could make the job work, and there is no specific silhouette to which the Champion must conform. However, some characteristics will undoubtedly be needed in the job.

The first characteristic, of course, is a good background both educationally and experientially. While the Champion does not absolutely need to come from the DoD, he or she must possess an understanding of the workings of the Department and of the job the Department must accomplish. The Champion's educational background should probably be somewhat similar to the current leadership of the DoD. The Champion should be a

bright, energetic, hard-charging person who isn't easily discouraged and who can persevere with a very high energy level, even in the face of temporary setbacks.

The Champion must have a proper balance of being a demanding manager and yet not appear to be too pushy. Since most of the changes needed will not be under his or her immediate control, the Champion needs to have a track record of making things happen.

It is likely that DoD management will not want to have this person stay in the Champion role for a major part of his or her career—probably a 2- or 3-year assignment would be best. It is impossible to determine how long the DepSecDef will want to have a Champion in place; it may be 5 years and it may be 10 years. Thus, it should be expected that several Champions will have this job before the task is complete.

After choosing the Champion, the USD(A) must do two things to set the stage properly for change to actually happen. First, the proper resources and support must be provided in terms of staff and access to key resources in the Department. Second and most important, the USD(A) must communicate both directly and by his actions that he is sponsoring this program and is very anxious for it to be a success. This message needs to be delivered not only to other members of the current USD(A) staff but also throughout the DoD ranks. The subgroup suspects that among the congressional ranks, there are a number of leaders who will welcome the opportunity to participate in this program and help the USD(A) and the Champion make it successful.

The subject of the duties of the Champion is quite difficult to address and will undoubtedly change as the assignment progresses. The act of changing the way a large successful organization views its responsibilities and how to discharge them is different for virtually every organization. As the magnitude of the job becomes clearer, the Champion will undoubtedly modify his or her priorities as things are tried and results evaluated. The subgroup is convinced that a properly chosen Champion, who has the characteristics listed above and is dedicated and enthusiastic about changing the way the DoD does business, will find many ways to effect his or her objectives.

There are, however, three important tasks that can begin immediately and that should be the first steps of any action plan. The first is to establish a matrix of goals for all four of the dual-use-manufacturing phases listed above. As an example, the Direct Product Use category might have as a goal the percentage of commercial procurement versus total procurement. The level of commercial interest will vary by procurement sector and subsector. Thus, the total DoD goal should be a composite of all the subsector goals that

are determined by careful discussions and negotiations between the Champion and the appropriate managers of the procurement sectors.

The other three dual-use-manufacturing categories are certainly harder to quantify. The Flexible Factory and the Technology Dual Use categories lend themselves to some rather simple measures such as establishing relationships with X number of suppliers for a flexible factory environment or with Y number of technologists for technology sharing. Care must be taken to avoid focusing excessively on the exact numbers X and Y represent and to concentrate instead on the substance of the relationships and the likelihood of meaningful programs ensuing.

The remaining dual-use-manufacturing mode, that of adopting current industry practices, is indeed highly subjective. Industry has had some success with TQM where nonnumerical objectives have been used. Some examples of these objectives are increased design capabilities, new administrative processes, or enhanced performance in subjective areas such as marketing. Many people in industry are suspicious of this technique since it does not deal with numerical goals. The subgroup feels that it has merit and should be pursued.

The second obvious task the Champion should undertake is to initiate and manage the experiments described in Chapter 4 and Appendix I. These experiments are intended to provide data and concrete evidence that the principles espoused by the subgroup will provide substantially enhanced performance. These experiments will not provide the only data available to the Champion; he or she should pursue commercial industrial firms and academic institutions to locate other evidence that can be used in convincing other DoD managers of the importance of this program.

A third initial step for the Champion would be to establish an advisory council. This step is much more subjective than the first definitive steps discussed above, but in one form or another, the subgroup thinks it would be a productive beginning. The advisory council would perform two obvious functions, both of which would provide guides to the composition of the council.

The first is pretty straightforward and is the usual reason for advisory councils, i.e., to provide expertise on the various subjects affected by the Champion's objectives. The Council makeup could include people who understand how change is brought about, perhaps someone from the academic world or from a company who has successfully undertaken change. Another set of expertise that must be represented is the departments

who will be most affected by the changed paradigms, specifically the procurement departments. Thus, representatives should be chosen for the advisory council from the major procurement sectors. A third category of important people on the advisory council will be from the DoD service sectors since they will enjoy the rewards, or bear the burdens, of the new way of conducting business.

In addition to providing expertise, the advisory council will have another important function. Experience has shown that when representatives of the departments affected by a change are allowed to participate in the planning for the change, they become owners of the plan and are very effective ambassadors to their departments as advocates of the plan. In short, they will accept much of the responsibility for winning support for the change plan within their respected departments.

This chapter has outlined the thinking of this subgroup. The subgroup is confident that the description of the challenge facing DoD is an accurate one and is equally confident that many tools are available to DoD to help meet these challenges. The difficult part is not the generation of strategic statements as to what changes should take place in the way DoD operates. The most difficult and often painful part of the task is to remake the attitudes of people into the new paradigms. The accomplishment of this transformation is imperative if the United States is to remain as strong as it has been for the last 200-odd years. The transformation will take a substantial length of time, but the length of the journey cannot be cause for delaying its beginning. The time to start is now.

## **4. EXPERIMENTS**

The Task Force recommends that a number of experiments be conducted as an aid in implementing the needed process, management, and cultural changes. Execution of these experiments would provide an opportunity for the DoD community and defense industry to carefully examine the benefits of the Task Force recommendations to implement IPP in the S&T phase, apply modeling and simulation across a broader scope, and take advantage of commercial products and practices. A summary of the experiments is given in this chapter. Specific detail can be found in Appendix I.

The recommended experiments would allow the new approach to be refined before it is applied widely across all DoD programs. Most of the recommended experiments address specific weapon system ATDs from S&T Thrusts 1-5. While it is important to apply IPP to all ATDs, a few should be chosen for special emphasis to serve as role models for success.

In addition to experiments that are specifically designed to assist ATDs, the Task Force proposes experiments that will examine improvements in infrastructure across the enterprise and in dual-use-manufacturing technologies. These additional types of experiments will provide a better understanding of potential savings associated with use of the commercial products and processes. These experiments will also aid in identifying areas of opportunity for application of commercial products.

The Task Force recommends that three classes of experiments be conducted:

- I — Application of IPP in the Science and Technology (S&T) phase
- II — Demonstration of dual-use-manufacturing capabilities
- III — Demonstration of the supporting technology base and infrastructure

Class I experiments are intended to introduce IPP techniques into S&T weapon system thrust ATDs and into programs that are transitioning to further systems development. The recommended experiments are the application of IPP, with appropriate modeling and simulation, to the design of the thick sections and other composite parts of the Composite Armored Vehicle (CAV), the use of modeling and simulation in IPP for the Light Contingency Vehicle (LCV), the reduction of risks in the Advanced Field Artillery

System (AFAS), and the definition and demonstration of affordable technology insertions for a derivative engine for the multi-role fighter (MRF), and manufacturing technology programs for Integrated High Performance Turbine Engine Technology (IHPTET).

Class II experiments are for dual-use-manufacturing and are chosen to demonstrate and validate the advantages of applying industry's new manufacturing techniques to products for the DoD. Three experiments are recommended. In the first experiment, two Gallium Arsenide (GaAs) semi-conductors, one military and one commercial, are constructed on the same production line. This experiment will demonstrate the viability and advantages of flexible and shared factories. The second experiment is to design and manufacture an existing military electronic subassembly using commercial practices and facilities. This experiment is intended to demonstrate the favorable effect that the entire string of commercial product generation practices can have on the cost, reliability, and performance of military products. The third dual-use-manufacturing experiment will show how creative products can result from an integrated design and manufacturing partnership (IPPD). It involves the design and construction of major ship modules, such as a desalinization plant, on shore in a production environment rather than on water after launch. Dramatic improvements in cost and time to install or upgrade are the expected result of this experiment.

Class III experiments are focused on the supporting technology base and infrastructure. Three experiments are proposed for this area: (1) the fabrication of aircraft structural components using IPP in composite materials; (2) modeling and simulation connectivity between the synthetic battlefield, the IPPD environment, and the shop floor; and (3) demonstration of the flexible manufacturing environment for low-volume and low-cost manufacturing.

The following sections provide a description of the proposed experiments for each of the three classes. Funding profiles are estimates based on information available to the Task Force. Details for each of the experiments require coordination and planning input from the appropriate Program or Thrust Area Manager.

## **4.1 APPLICATION OF IPP IN THE S&T PHASE**

### **4.1.1 Composite Structure for the Composite Armored Vehicle**

Several programs are proposed for composite structures. However, in all of its investigations, the Task Force could not find a model or simulation for the manufacturing processes for composite materials. Most composite work appears to be based on empirical techniques. A model that was based on fundamental principles could not be found. In the opinion of the Task Force, an effort should be initiated to develop a model or simulation for the manufacturing processes associated with composite structures. An appropriate vehicle for the modeling and simulation efforts would be the Army's Composite Armored Vehicle (CAV) ATD.

The CAV ATD involves fundamental manufacturing technology constraints, as well as significant tradeoffs between performance and operational tactics. The CAV, being developed by the Army in Thrust 5, represents an operational concept associated with a scout function that is carried out by a lightweight combat vehicle with substantial armor protection provided by composite materials and substantial firepower. Fundamental design, performance, stealth, vulnerability, manufacturing, and cost tradeoffs must be addressed in this ATD. Augmentation of the current CAV ATD to develop models and simulations of thick composites for armor and support structures will permit performance, cost, and production quantity tradeoffs to be made, based on thick composite manufacturing capabilities. This extension of the CAV as a joint ATD between Thrusts 5 and 7 provides an outstanding opportunity to test and guide development of effective tools and technologies associated with affordability in a project with fundamental manufacturing considerations and tradeoffs.

The advantages of composite armor as an integral of a combat vehicle has been demonstrated in various prototypes. Designing vehicles using composites keeps sharp corners to a minimum and thus reduces radar cross-sections. It also cuts down significantly on welding of heat-treated metal alloys and armor for the overall vehicle. Since the number of parts and joining operations is reduced, fewer templates and tools are necessary. This results in less required floor space, lower energy costs, and fewer man-hours per finished vehicle. However, taking the step from prototype fabrication to a manufacturing capability of at least 60 vehicles per month, demands, at the least, a conservative, planned approach centered on a capability using wide, thick, composite broadgoods.

An experiment is needed to develop the critical manufacturing process associated with the composite material that will meet the Army's critical weight and threat requirements. Manufacturing of the type of composite structures that will meet the requirements of the CAV involves laying down many layers of woven, ballistic fabric prepregated onto a complex tool. The current technique for accomplishing this task is labor intensive; however, incorporating various levels of automation into the manufacturing process would reduce future production costs. Some types of automated equipment that handle wide broadgoods have been developed over the past 15 years, but none have proven to be reliable. Some of the problem areas that have been identified are methods of cutting material, proper tape alignment and tension, inertia problems due to the mass of the tape dispensing head when covering various contours, and quality of the tape itself.

What is required is the development of a flexible manufacturing fabrication cell that is designed for producing both thin and thick composite structures. The separate components available for this integrated fabrication cell have been shown to be reliable and are currently in use in the aerospace and automotive industries. These components require modification and integration, however, to handle wide composite broadgoods of the type to meet the CAV requirements (i.e., broadgoods required to build the thick, large, composite structures needed for major components of the next-generation family of armored vehicles).

An additional experiment would propose to modify reliable composite fabrication equipment by integrating automated broadgood cutting equipment with semi-automated overhead dispensing equipment, tailored for wide broadgoods to be laid down onto equally wide tools. In this way, material can be cut to order on an as-required basis directly off wide rolls that can be carried to an overhead dispenser automatically. Positioning, laydown, and debulking of each ply at a specified pressure could be accomplished either manually or by a sequence of machine operations. These critical processes then could be measured to determine process maturity growth.

#### **4.1.2 Light Contingency Vehicle**

The Light Contingency Vehicle (LCV) ATD involves a revolutionary new weapon system concept that will require fundamental tradeoffs between performance, manufacturing, cost, and operational tactics. The LCV, which represents a departure from conventional heavy forces, is one of three vehicle ATDs being pursued in Thrust 5. Its objective is to demonstrate how emerging technologies can be integrated to show that a credible force can be rapidly projected into future contingency operations. The LCV is a

joint DARPA-Army-Marine Corps ATD with a large user base that seeks to develop an 8- to 10-ton survivable vehicle with numerous automated and semi-automated modes of operation for use in surveillance and weapon delivery. Current ATD plans call for significant modeling and simulation efforts in consideration of numerous technical and operational alternatives, each involving fundamental performance, manufacturing cost, and operational tradeoffs. Appropriately augmented with modeling and simulation of critical manufacturing processes, this ATD will exercise the full capability of modeling and simulation for IPPD. This experiment will provide an excellent test for creating critical manufacturing process models that can be used to meet Thrust 5 objectives, enhance Thrust 7 objectives of technology for affordability, and exploit the synthetic battlefield environment of Thrust 6. Planners of this ATD have incorporated some elements of the efforts needed in their project plan. Augmentation of this ATD, to create a joint ATD among Thrusts 5 and 7 that uses the synthetic battlefield environment created by Thrust 6, will be a productive and cost effective experiment.

#### **4.1.3 Advanced Field Artillery System**

The Advanced Field Artillery System (AFAS) ATD comprises two subsystems: (1) an automated ammunition subsystem and (2) the armament subsystem. The automated ammunition subsystem consists of the ammunition supply mechanism, projectile magazine, and ammunition control hardware. The armament subsystem consists of the turret drive and controller hardware, 52-caliber 155-mm Liquid Propellant Gun, and turret structure. The major thrusts in AFAS program include the advanced fire control, extended range and accuracy suite, automated ammunition handling, advanced propellant, and extended range and high-rate-of-fire armament.

The current focus of advanced technologies is on the following AFAS hardware:

- Regeneration Liquid Propellant Gun (RLPG) System
- Automated Ammo Handling System (AAHS)
- Fire Control/Battlefield Management (FCBM)
- Multi Option Fuze—Artillery (MOFA).

The Task Force suggests three areas of the AFAS ATD for potential IPP experiments: metal forming and coating, liquid propellant, and the platform electronics. All of the areas involve critical manufacturing processes or have integration problems that require baselining and the determination of cost impacts.

Because the faster projectile generates intense heat and has a higher propellant charge and increased rate of fire, the gun tube and chamber will require plating. Cadmium plating has been used in the past for this application. However, environmental problems associated with Cadmium will require new, alternative cost-effective approaches to be developed.

The Liquid Propellant (LP) is a new technique for artillery, and new facilities will be required for its production. Hydroxyl Ammonium Nitrate (HAN), Tri-ethanol Ammonium Nitrate (TEAN), and water are mixed together to produce the combustible liquid propellant. The critical process parameters for the manufacturing of LP need refinement to eliminate problems associated with operational requirements. The chemical processes associated with the manufacturing of LP present an excellent opportunity for defining  $C_{pk}$  and using it as a maturity growth indicator.

The platform electronics include a projectile tracking system and a muzzle velocity management and prediction system. Both systems are in the early definition phase and will use advanced electronics to meet their intended use (e.g., millimeter wave technology and neural networks). The Task Force felt that an IPP approach to problem solving and defining critical processes would be of significant benefit to the overall program.

#### **4.1.4 Multi-Role Fighter Engine**

A new ATD is suggested to define and demonstrate affordable technology insertions into a derivative engine for an Air Force Multi-Role Fighter (MRF). The objective is to demonstrate that the time, cost, and risk for a derivative engine can be significantly reduced by the appropriate use of modeling and simulation technology. The synthetic battlefield would be used to define the benefits of stealth characteristics, speed, range, maneuverability, etc. Engine system requirements, such as radar cross section, installed thrust, specific fuel consumption, and weight, will be generated. Design models will then be used to determine the nature and degree of the required technology insertions to the present baseline production F-16 engine (e.g., ceramic thermal barrier coatings, advanced super alloy turbine blade, and multi-hole laser drilled combustor liner). Process models, factory models, and cost models for the technology insertions will then be developed. A risk analysis of the latter models will determine the degree of validation required. By using an advanced derivative of a current production engine, the detailed design, manufacturing process, and factory models that need to be developed will be limited to those related to the technology insertions. Through use of existing data for the

remainder of the engine, the entire feedback and feed-forward capabilities involving IPPD will be demonstrated.

#### **4.1.5 Integrated High Performance Turbine Engine Technology**

The goal of the Integrated High Performance Turbine Engine Technology (IHPTET) program is to double gas turbine propulsion system capability by around the turn of the century for a wide range of aircraft and missile applications, including all DoD needs. The program is in three time-phased steps, so that technology will be available for near-term system needs. Accomplishments will lead to durable high performance (i.e., high output and weight, low fuel consumption) engines, capable of built-in stealth. The program will have a great effect on both military aircraft superiority and commercial aircraft competitiveness. The approach to achieving these goals is to develop lightweight components and structures, and improved aerothermodynamic design, with particular emphasis on heat transfer in order to achieve the higher maximum and combustion-initiation temperatures required.

Program direction for IHPTET is effected by the DoD/NASA IHPTET Steering Committee with representatives from ODDR&E, the Services, DARPA, and NASA. Representatives of the U.S. aircraft gas turbine industry are invited to attend open sessions of committee meetings. The IHPTET Steering Committee, with inputs from industry, reviews program progress and directs corrective actions in the event that progress lags in specific technology areas.

Progress toward achieving the established goals of the program has been excellent. However, 2 years ago, the Steering committee identified two specific technology areas that needed further emphasis: titanium-based metal matrix composites for compressor components needed for the Phase II goals, and ceramic matrix composites for turbine components needed for Phase III goals. Accordingly, increased efforts in the development of these materials, including addressing the basic producibility and manufacturability of certain components, are being conducted. The IHPTET program does not include efforts devoted to high-yield process development, however. This is a matter of concern because no manufacturing technology program exists to provide a natural follow-on to S&T efforts.

The Task Force recommends that manufacturing technology programs focused on titanium-based metal matrix composites and ceramic matrix composites be established within the context of the overall IHPTET program. The purpose of these programs would be to provide funding to determine the critical manufacturing processes associated with the

components fabricated from these materials. In addition, specific process capability indices should be modeled or measured to determine growth maturity.

## **4.2 DEMONSTRATION OF DUAL-USE-MANUFACTURING CAPABILITIES**

Three primary experiments are proposed to promote and understand dual-use-manufacturing.

### **4.2.1 Advanced Electronics**

The Advanced Electronics experiment will identify either, or both, GaAs devices (military and commercial) or multi-chip modules (military and commercial) and produce them on the same production line. Substantial engineering must be invested to ensure that the idiosyncrasies of the device can be accommodated on a shared line. Further, a modified cost accounting system will be needed to accurately trace each device's cost. The expectation is that military devices will enjoy the lower overhead costs and higher yields characteristic of commercial products. Additional savings should occur due to the high volumes of the combined runs.

### **4.2.2 Conventional Electronics**

The Conventional Electronics experiment is designed to (1) characterize the performance of commercial devices in the military environment; (2) characterize the performance of subassemblies built using commercial practices in a simulated military environment; and (3) quantify the benefits gained using commercial design rules and manufacturing processes in a major electronic subassembly. Following design and manufacture, the subassembly would be tested in the full military environment to ascertain performance limitations.

### **4.2.3 Shipbuilding**

The Shipbuilding experiment is to implant best commercial practices, currently represented by a German firm, into U.S. shipbuilding. The essence of the practice is to design and build modular, common, major components that can be constructed in a shore production facility instead of being hand-fitted on a floating ship. Three modules are proposed: (1) a reverse osmosis distilling plant; (2) a sanitary unit; and (3) a ventilation fan room. These modules can be inserted easily into a floating hull, and should provide

substantial cost savings from a manufacturing and a procurement standpoint. Additionally, replacement and modernization can be accomplished with enormous time savings. Modern design techniques, such as the use of CAD, will also be introduced.

#### **4.3 DEMONSTRATION OF THE SUPPORTING TECHNOLOGY BASE AND INFRASTRUCTURE**

Demonstrations in this area will focus on providing connectivity for the Science and Technology (S&T) Thrusts 1 through 5. Demonstrations in infrastructure will focus on two major areas: (1) Information Infrastructure and (2) Design Integration. The first applies to advanced technologies and techniques in the design and implementation of new integrated capabilities for information systems and the second concentrates on applying advanced methods and techniques to the integration of existing information and systems. The demonstration will provide for a common interface between the S&T Thrust Areas to tie together, improve, and transfer data and information concerning cost, schedule, and other technical information. It is felt that these infrastructure improvements would assist in the generation of prototypes, provide for the modeling of requirements and reduce redundancy in development efforts across the Thrust Areas.

**Appendix A**

**TERMS OF REFERENCE**



DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

WASHINGTON, DC 20301-3010

25 JUN 1992

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference - Defense Science Board (DSB) Task Force on Engineering in the Manufacturing Process

I request you initiate a DSB Summer Study Task Force to identify new and innovative manufacturing methods that can meet Department of Defense's (DoD) future needs for rapid transition to production on demand, and economic low volume manufacturing.

The point of departure for this study should be the Deputy Secretary of Defense's memorandum of December 19, 1991, on "Defense Science and Technology (S&T)" and subsequent Director, Defense Research and Engineering (DDR&E) S&T strategies which set the initial course toward meeting these future needs. The study should focus on technologies, methods, and a technical framework for integrated product and process development and manufacturing of DoD products. The Task Force should develop recommendations, and provide an assessment of the cost implications, based on the following considerations:

- o Requirements for advanced simulation, visualization, design of experiments and dynamic control technologies at levels ranging from detailed product and process design to overall manufacturing enterprise control. Coordinate with the DSB Task Force on Simulation, Readiness and Prototyping in addressing the interface between detailed engineering simulations and higher level simulations in the synthetic battlefield.

- o Best approaches to reduce production and life cycle costs considering use of concurrent engineering tools and environments, soft and hard tooling, and flexible manufacturing systems. Recommend engineering criteria that can be used to validate that the proposed systems are producible and operationally suitable.

- o Minimum demonstration requirements for scalable manufacturing processes in 6.2 and 6.3A programs, and technical criteria to assess progress in maturing these processes in 6.3B and 6.4 development programs. Consider industry practices and criteria regarding the timing and investment models to move from technology to production of first article (e.g., design characteristics, learning curve, yield projections, and unit production cost analysis).

- o Alignment of DoD's technology plans with best commercial manufacturing trends and practices, including lean and agile production visions. Distinguish, for key industrial sectors, the technology areas where advances will be driven primarily by commercial investment from those where DoD investment is needed to meet defense needs on a timely basis. Rank order technology investments and engineering practices that will enable DoD to take better advantage of commercial manufacturing capabilities.

The Task Force may define additional objectives for its consideration beyond the summer study time frame. For any such follow on objectives, specific plans and schedules should be included in an interim report at the conclusion of the summer study.

The Director, Defense Research and Engineering and the Assistant Secretary of Defense (Production and Logistics) will co-sponsor this study. Dr. Kent Bowen and Mr. Noel Longuemare will serve as co-chairmen. Dr. Michael McGrath of the Defense Advanced Research Projects Agency will be the Executive Secretary and Colonel Elray Whitehouse, USA, will be the DSB Secretariat representative.

  
Victor H. Reis

**Appendix B**

**MEMBERSHIP**

## **Appendix B MEMBERSHIP**

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**Mr. R. Noel Longuemare**  
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VP, Texas Instruments

**Mr. Herm Reininga**  
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**Mr. James Kinnu**  
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**Mr. George Peterson**  
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**Appendix C**

**GLOSSARY**

## Appendix C

### GLOSSARY

AAHS	Automatic Ammunition Handling System
AFAS	Advanced Field Artillery System
APL	Approved Parts List
ATC	Affordability Through Commonality
ATD	Advanced Technology Demonstration
BOM	Bill of Material
CAD/CAE	Computer Aided Design/Computer Aided Engineering
CALS	Computer-Aided Acquisition and Logistics Support
CAV	Composite Armored Vehicle
CDRL	Contact Delivery Requirement List
C <sub>p</sub>	Process Capability Index
C <sub>pk</sub>	Process Performance Index
CSIS	Center for Strategic and International Studies
DAB	Defense Acquisition Board
DARPA	Defense Advanced Research Projects Agency
DDR&E	Director of Defense Research and Engineering
DEM/VAL	Demonstration/Validation
DoD	Department of Defense
DSB	Defense Science Board
DSMC	Defense Systems Management College
DepSecDef	Deputy Secretary of Defense
EMD	Engineering and Manufacturing Development
FCBM	Fire Control/Battlefield Management
GaAs	Gallium Arsenide
GEU	Guidance Electronics Unit
GPS	Global Positioning Satellite
HBT	Heterojunction Bipolar Transistors
HEMT	High Electron Mobility Transistors
HM&E	Hull, Mechanical and Electrical

<b>HVAC</b>	<b>Heating, Ventilation, and Air Conditioning</b>
<b>IC</b>	<b>Integrated Circuit</b>
<b>IDA</b>	<b>Institute for Defense Analyses</b>
<b>IG</b>	<b>Inspector General</b>
<b>IPDT</b>	<b>Integrated Product Development Team</b>
<b>IPPD</b>	<b>Integrated Product and Process Development</b>
<b>JIT</b>	<b>Just in Time</b>
<b>LCV</b>	<b>Light Contingency Vehicle</b>
<b>LRIP</b>	<b>Low Rate Initial Production</b>
<b>MS&amp;T</b>	<b>Manufacturing Science and Technology</b>
<b>MCM</b>	<b>Multi-Chip Module</b>
<b>MESFET</b>	<b>Metal-Semiconductor Field Effect Transistors</b>
<b>MIL-SPEC</b>	<b>Military Specification</b>
<b>MIL-STD</b>	<b>Military Standard</b>
<b>MMIC</b>	<b>Millimeter-Microwave Integrated Circuit</b>
<b>MODAR</b>	<b>Modular Radar</b>
<b>MOFA</b>	<b>Multi Option Fuse—Military</b>
<b>MRF</b>	<b>Multi-Role Fighter</b>
<b>MTBF</b>	<b>Mean-time-between-failure</b>
<b>MTBR</b>	<b>Mean-time-between-repair</b>
<b>NAVSEA</b>	<b>Naval Sea Systems Command</b>
<b>OEIC</b>	<b>Optical Electronic Integrated Circuit</b>
<b>OEM</b>	<b>Off-Highway Equipment Manufacture</b>
<b>OT&amp;E</b>	<b>Operational Test and Evaluation</b>
<b>P&amp;L</b>	<b>Production and Logistics</b>
<b>R&amp;D</b>	<b>Research and Development</b>
<b>RLPG</b>	<b>Regeneration Liquid Propellant Gun</b>
<b>RO</b>	<b>Reverse Osmosis</b>
<b>ROA</b>	<b>Return on assets</b>
<b>S&amp;T</b>	<b>Science and Technology</b>
<b>SCN</b>	<b>Ship Construction, Navy</b>
<b>SEI</b>	<b>Software Evaluation Institute</b>
<b>SIMNET</b>	<b>Simulation Network</b>
<b>SPC</b>	<b>Statistical Process Control</b>
<b>TOR</b>	<b>Terms of Reference</b>

**Appendix D**

**HOW DID WE GET TO WHERE WE ARE**

**Harold E. Bertrand**

## **Appendix D**

### **HOW DID WE GET TO WHERE WE ARE**

To better understand the manufacturing plight that the Department of Defense (DoD) faces, we should first define the circumstances that led to the situation as it now exists.

At the end of World War II, the United States was the world's only industrial nation whose industry base survived intact. In fact, the U.S. industrial base that fed the postwar demand for consumer and commercial goods was the same base that met our wartime needs, ostensibly a 1920 to 1930s industrial base. In the rebuilding process, our World War II allies and enemies took advantage of the opportunity to modernize their replacement facilities and manufacturing processes, frequently with the assistance of U.S. industry. U.S. industry, on the other hand, was too busy filling peacetime demands for both domestic and export use to take the time to modernize. As worldwide markets stabilized and former allies and enemies became competitors of U.S. industry, U.S. industry tried to remain competitive by selectively modernizing some industrial sectors and going to foreign suppliers for others, first to take advantage of lower labor rates and, finally, because off-shore sourcing had put domestic sources out of business.

Building upon procedures established during World War II to discourage fraud, waste, poor quality, price manipulation and gouging, and internal theft, DoD continued to buy equipment and systems through a product design, development, and acquisition process that became more and more involved in the day-to-day business of its suppliers. Taking the form of reviews, checks, testing, detailed accounting, and technical and contractual audits, this involvement became so pervasive that industry found it easier to isolate military product development and manufacturing than to try to co-mingle the development and manufacturing of military and commercial products in the same facility.

As DoD continued to buy massive quantities to replace supplies lost during the war, as well as supplies for the Korean War, Vietnam, Cold War contingencies, and foreign military sales, industry found little need to encourage the combining of military and commercial product development and manufacturing. The profit earned on military contracts, although a small percentage of sales, was for the most part guaranteed. However, by the time a military system was fielded, its technology was behind that of the

commercial industrial world. Changes, modifications, and updates to the systems followed the same procedures that caused the technology lags in the first place. The net result was that the cost of military systems increased faster than commercial products, even with increasing military procurements. The practice of retaining military systems for upwards of 30 years compounded the technology age issue and the associated increased costs. Today, in an era of military downsizing and reduce acquisitions, the DoD market is not large enough to sustain a large, unique, industrial base.

Following are some of the steps that DoD has taken to exercise control over the acquisition process:

- Adding milestones—and therefore delays—to the DSARC process and its successors.
- Establishing the requirements “pyramid” which grows stated requirements from a few top-level ones when a system is conceived to thousands when it goes out for a competitive bid.
- Adding Military Specifications (MIL-SPECs) and Military Standards (MIL-STDs) tied to the thousands of requirements to ensure quality control and contractor contractual compliance.
- Promulgating laws designed to enforce accountability.
- Giving the accountants and the contracting officers precedence over the engineers and production experts in designing and acquiring defense systems—resulting in the loss of control over innovation and responsiveness to new technological advances (not an issue of who should “be involved” but who should “be in charge”).

So here we are! There have been exceptions to the rule. Industries supporting defense from the late thirties through World War II were modeled on methods of mass production. Hardgood items, including weapon systems, were made through a series of steps, each disconnected from the next. For a select few times, however, the idea of an integrated product and process design was applied. The Lockheed Skunk Works is a good example: A close-knit team of design and process engineers, production personnel, and users, all colocated and working together, led to spectacular technical success on time and within budget. But again, this was an exception.

What can be done today to undo where we are? In broad terms, DoD’s involvement in the management of systems acquisitions has led to its complexity and inefficiency. DoD should try to backtrack through the system to undo some of the self-inflicted damage. It should:

- Free up the design and production system to be able to make its own decision about how to meet DoD's needs.
- Greatly reduce the importance of the MIL-SPFC and MIL-STD system. Gradually work out of it. Leave it to the producers to decide how to produce.
- Return to the 3 basic decision milestones: Do we need the system? Are the technologies mature enough to be considered for production? Are the product design and manufacturing processes ready for production?

While this list is by no means exhaustive, accomplishing these recommendations would go a long way toward undoing those things that brought the defense industrial base to where it is today. Given the freedom to act in its own best business interest, it will then be up to industry to incorporate those changes needed to remain competitive in light of the shrinking defense budget.

**Appendix E**

**PROCESS CAPABILITY AND PERFORMANCE INDICES**

**Arthur Fries  
Karen J. Richter**

## Appendix E

### SOME PROCESS CAPABILITY INDICES

When a process is in statistical control (i.e., with no drift or sudden changes) and a measure of the product from that process follows a Normal probability distribution, then various metrics can be used to determine the capability of that process to yield products conforming to prescribed specification limits. These metrics thus relate the process parameters, sigma and mu, to the engineering specifications. Sigma,  $\sigma$ , is the standard deviation of the process under a state of statistical control, and  $6\sigma$  is the measure of the process spread or variation—called the natural tolerance in the quality literature. Mu,  $\mu$ , is the process mean. The nominal specification, or target value, is generally the centerline between the upper and lower specification limits, USL and LSL. When these limits are set at  $\pm 3\sigma$ , the process output is normally distributed, and the process mean is centered on the nominal specification, 99.73 percent of production is expected to be conforming (Figure E.1). In practice, USL and LSL can be defined to be independent of  $\sigma$  when the specification limits have some inherent physical basis (e.g., the diameters of drilled holes in printed circuit boards may be required to be within a range of, say, 60 to 62 mils, independent of the process  $\sigma$ ). Two metrics are used to determine the ratio of the tolerance limit (USL-LSL) to the process capability ( $6\sigma$ ) and to determine the relative distance of the process mean,  $\mu$ , from the target value— $C_p$  and  $C_{pk}$ , respectively. For the situation shown in Figure E.1, both these metrics have a value of 1.0.

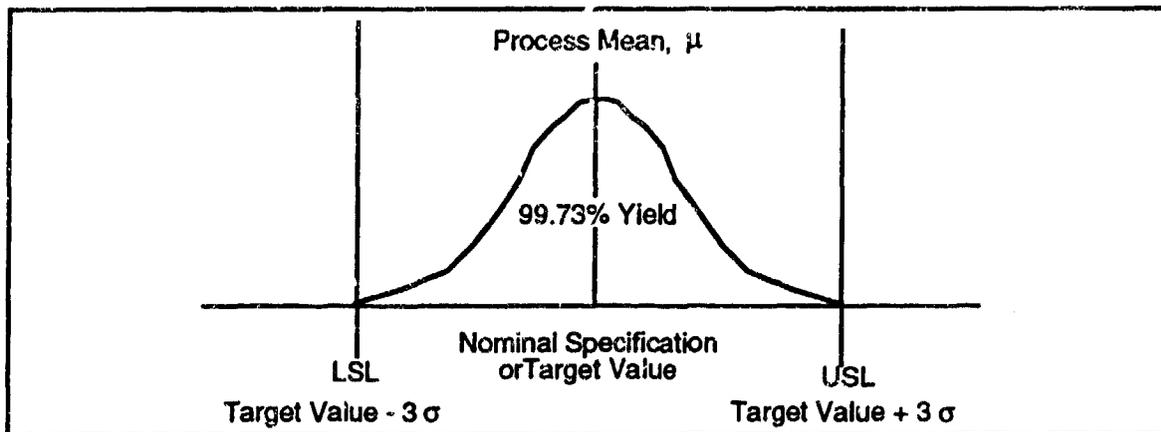


Figure E.1. Planned Process Output

$C_p$  relates the allowable process spread (part tolerance) to the actual process spread (natural tolerance,  $6\sigma$ ), but does not take into account where the process is centered. It is calculated as follows:

$$C_p = \frac{USL - LSL}{6\sigma}$$

$C_{pk}$  uses the process mean, so it addresses the "centering" of the process. It is calculated as follows:

$$C_{pk} = \min \left| \frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma} \right|$$

The preceding equations for  $C_p$  and  $C_{pk}$  are expressed in terms of the true unknown process parameters  $\mu$ , the mean, and sigma ( $\sigma$ ), the standard deviation. In practice,  $C_p$  and  $C_{pk}$  must be estimated from observed process outcome data, a procedure which necessarily involves the estimation of both  $\mu$  and  $\sigma$ . The corresponding sample estimates based on  $n$  observed values,  $X_1, X_2, \dots, X_n$ , are  $\bar{X}$  and  $s$ , respectively.<sup>1</sup>

The sample average,  $\bar{X}$ , is the sum of the observed values divided by  $n$ :

$$\bar{X} = \frac{X_1 + X_2 + \dots + X_n}{n}$$

It is an estimate of the process mean  $\mu$ .

The standard deviation can be estimated as

$$s = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n-1}}$$

or expressed in a form more convenient for computation purposes:

$$s = \sqrt{\frac{\sum X_i^2 - (\sum X_i)^2/n}{n-1}}$$

where  $\Sigma$  in both formulas means the sum of a value from  $i = 1$  to  $i = n$ .

Sample calculations for  $C_p$  and  $C_{pk}$  are shown in Figure E.2.

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<sup>1</sup> Each  $X_i$ ,  $i = 1, 2, \dots, n$ , can represent an actual process outcome or be the mean of a small group of outcomes observed in sequence (e.g., following a pattern of averaging 5 consecutive outcomes, eliminating the next 1 or 2 outcomes from the analysis, averaging the next 5, etc.). In this way, the underlying assumption of mutually, statistically independent  $X_i$ 's is more tenable. Correlations between successive  $X_i$  "observations" are reduced by systematic skipping of process outcome values. When the individual subgroups exhibit drastically different behaviors, e.g., highly variable averages, modified procedures are required to estimate the overall  $\mu$  and  $\sigma$  parameters.

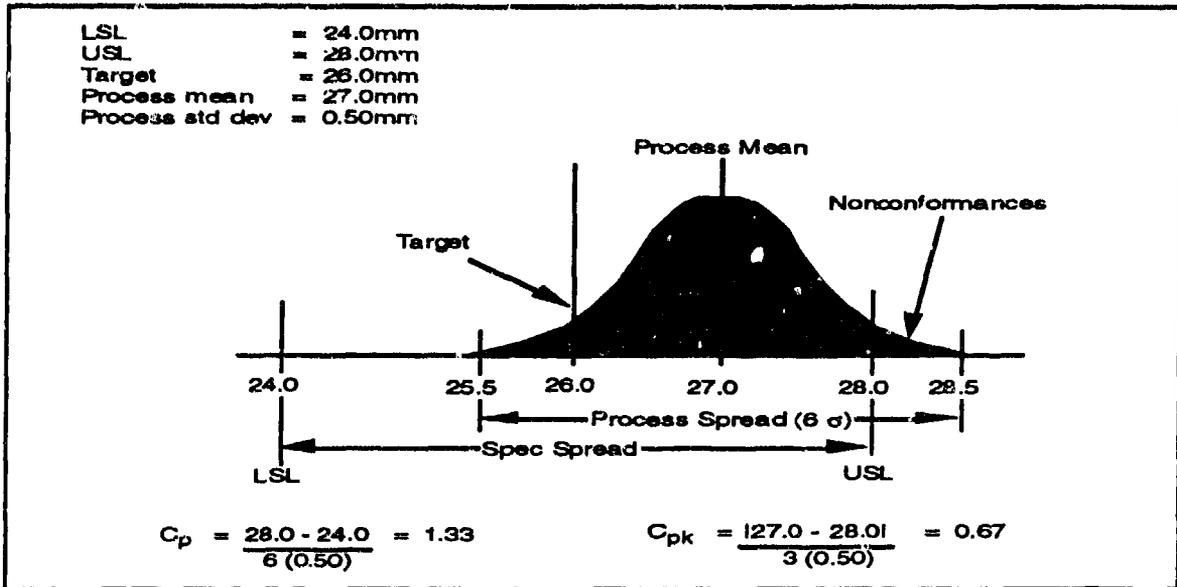


Figure E.2. Example Calculations of  $C_p$  and  $C_{pk}$

If the  $C_p$  value is less than 1.0, the process is said to be “not capable.” The minimum value of 1.0 to indicate process capability was chosen as a benchmark to relate this index to the standard  $6\sigma$  spread indicated on quality control charts. A minimum value of 1.33, however, is generally chosen as a better indicator for preventing nonconforming product, because it allows for more variation in the process. The  $C_p$  value alone does not take into account the fact that the process may be “off-center” from the nominal specification. Figure E.3 illustrates a  $C_p$  value of 1.0, but a  $C_{pk}$  of only 0.67. Both  $C_p$  and  $C_{pk}$  need to be at least 1.0 for the process to be labeled “capable.”

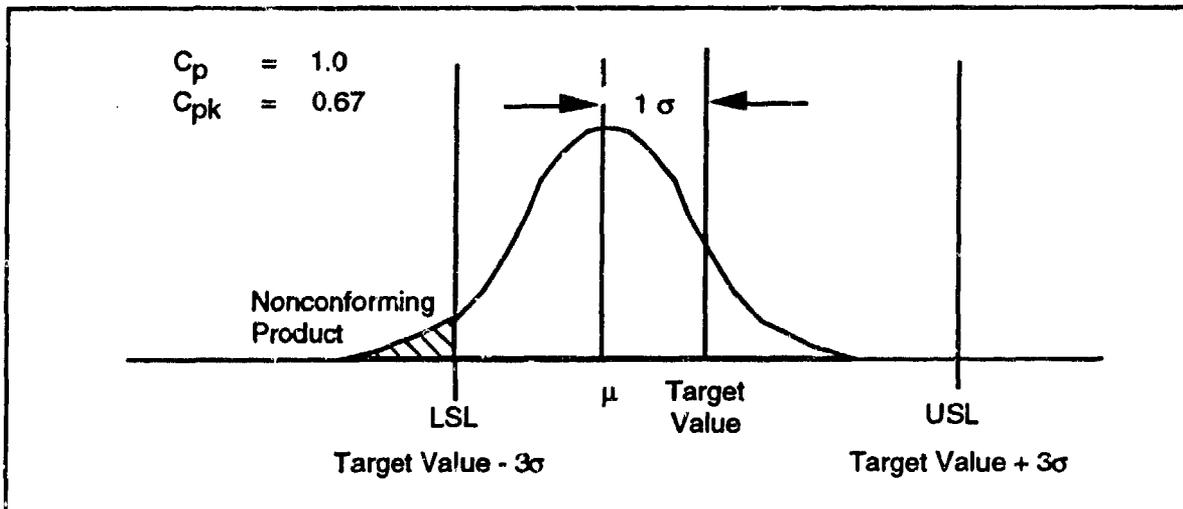


Figure E.3. Process “Not Capable”

Various methods can be used to improve process capability—some relating to the design of the product, others to improving the manufacturing process itself. Design for manufacturability shifts the target value to the process mean. Robust design is a methodology that assumes wide tolerances for the “noise” factors and gets the mean function on target to minimize the effects of variation in the process. Improving the process shifts the process mean to the target. Figure E.4 illustrates a capable process with robustness built in.

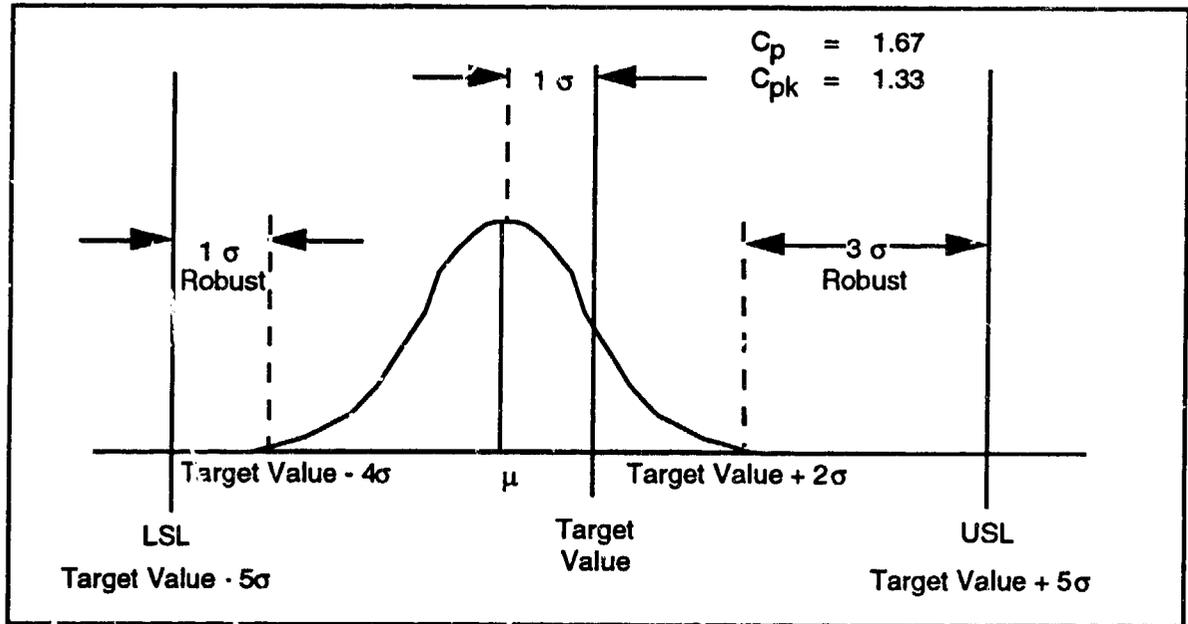


Figure E.4. Robust Design

Whatever particular capability indices may be contemplated for tracking process improvement, the question naturally arises as to how large of a sample of process output will be needed. Several approaches for determining sample size requirements are possible. In the context of statistical hypothesis testing, e.g., for choosing between two competing hypotheses of “capable process” or “not capable process,” one can draw upon standard procedures associated with Normal distribution theory. Kane, for instance, derives sample size relationships for hypothesis tests based on the  $C_p$  index.<sup>2</sup> Similar types of computations can be undertaken for determining sample size requirements for the analogous hypothesis tests based on the  $C_{pk}$  index.

<sup>2</sup> Victor E. Kane, “Process Capability Indices,” *Journal of Quality Technology*, Vol. 18, No. 1, January 1986, pp. 41-52. Required sample size is a function of specified consumer and producer risks (accepting a process as “capable” when it is in fact “not capable,” and declaring a process to be “not capable” when in actuality it is “capable,” respectively).

Alternatively, statistical confidence or tolerance interval approaches can be used to specify required sample sizes. A confidence interval is computed from the data and indicates the uncertainty in an estimate of a capability index, say of the true  $C_p$  or  $C_{pk}$ . It encloses the true value with a specified high probability value—larger intervals corresponding to higher probabilities. A tolerance interval has a similar interpretation, except that it covers, with a prescribed high probability, some specified proportion of all future process outputs (assuming no drift or change in the underlying population). For both types of intervals, tradeoffs can be established between required sizes and prescribed interval lengths and confidences or probabilities. Kane illustrates the procedure for the estimation of  $C_p$  with certainty expressed via tolerance intervals.<sup>3</sup> Similar types of computations can be undertaken for  $C_p$ -based confidence intervals and for  $C_{pk}$ -based confidence or tolerance intervals.

Due to the intrinsically high variability of the  $C_p$  and  $C_{pk}$  estimators, however, relatively large sample sizes are generally required for any of the approaches outlined above.<sup>4</sup> Estimates based on small samples are potentially misleading. Unfortunately, the extent of available sample sizes from a stabilized process in the S&T phase is often quite limited. One potentially promising statistical set of techniques that may have utility in this context is the application of Bayesian methodologies. In this framework, statistical estimation and hypothesis testing incorporate additional information beyond solely the observed outcomes. These can include, for example, expert opinion derived from subjective assessments or experience from comparable product, as well as particular data values observed in previous testing of the subject process or related processes.

Bayesian methodologies have been developed for the spectrum of statistical problems and their application is now widespread (although not universally accepted).<sup>5</sup> Singpurwalla has recently proposed that the Bayesian perspective provides a rational framework for unifying the many aspects of quality engineering and tolerance design.<sup>6</sup> All of the capability index estimation, interval, and hypothesis testing procedures alluded to above can be addressed with Bayesian methodologies. Sample size requirements can also

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<sup>3</sup> *ibid.*

<sup>4</sup> *ibid.*; Bert H. Gunter, "The Use and Abuse of  $C_{pk}$ ," Parts 1-4, *Quality Progress*, March-June, 1989.

<sup>5</sup> J. O. Berger, *Statistical Decision Theory and Bayesian Analysis*, 2nd. ed., New York: Springer-Verlag, 1985; Harry F. Martz and Ray A. Waller, *Bayesian Reliability Analysis*, New York: John Wiley and Sons, 1982.

<sup>6</sup> Nozer D. Singpurwalla, "A Bayesian Perspective on Taguchi Approach to Quality Engineering and Tolerance Design," *IIE Transactions*, Nov. 1992, pp. 18-27 (with discussion and response, pp. 28-32).

be determined. Lindley and Singpurwalla have addressed a related acceptance sampling problem via Bayesian techniques.<sup>7</sup> (A direct correspondence is possible between their "accept" and "reject sample" hypothesis and hypotheses stated in terms of "satisfy" or "don't satisfy" S&T exit criteria.)

The extent to which a Bayesian framework reduces sample size requirements from those obtained via more classical approaches depends primarily on the perceived definitiveness of the prior information to be subsequently weighted by observed process outcomes. Stronger belief in the validity of the assumed prior information leads to smaller sample size requirements. The accuracy of the resultant capability index estimates, intervals, and hypothesis tests, however, is clearly dependent on how accurate the prior information is. That is, lacking extensive observed process data, accurate statistical results can only be obtained if the assumed prior information is reasonably consistent with the actual true parameters. Sensitivity analyses can and should be undertaken before data are collected to assess the potential relative influences of the prior information and the expected data.

The Bayesian paradigm can also be naturally extended to encompass sequential sampling strategies in which process outcome data continue to be collected until satisfaction of a prescribed exit criterion is first attained (or until some prespecified maximum number of samples is observed).<sup>8</sup> Such an approach has been endorsed previously for reliability demonstration and may offer, at least in theory, the most dramatic means of reducing sample size requirements.

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<sup>7</sup> Dennis V. Lindley and Nozer D. Singpurwalla, "On the Evidence Needed to Reach Agreed Action Between Adversaries, with Application to Acceptance Sampling," *Journal of the American Statistical Association*, Vol. 80, No. 416, Dec. 1991, pp. 933-937.

<sup>8</sup> Sequential sampling techniques can also be introduced in the context of classical, i.e. non-Bayesian, statistics. See, for example, "How to Use Sequential Statistical Methods," Thomas P. McWilliams, *The ASQC Basic References in Quality Control Statistical Techniques*, Vol. 13, ASQC, Milwaukee, WI, 1989.

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<sup>9</sup> All Figures in this Appendix were adopted from a briefing given by John Fenter, AFWL/MT, to the Thrust 7 Technical Team.

**Appendix F**

**BEST PRACTICES FOR INTEGRATED PRODUCT  
AND PROCESS DEVELOPMENT**

**Joseph A. Heim**

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## Appendix F

# BEST PRACTICES FOR INTEGRATED PRODUCT AND PROCESS DEVELOPMENT

### INTRODUCTION AND SUMMARY

This report provides an overview, by example, of best practices for integrating product and process activities in the U.S. industrial manufacturing base. The systematic approach to considering the interface and coordination of all facets of product design, process development, manufacture, in-field support, and eventual disposal is commonly referred to as concurrent, or simultaneous, engineering. An early and thorough examination of the subject is found in *The Role of Concurrent Engineering in Weapons System Acquisition*,<sup>1</sup> a 1988 study for the Department of Defense (DoD). Best practices for integrating the product and process activities in the civilian manufacturing sector are believed to be applicable to design and manufacturing operations associated with products supporting the missions of the DoD. Accordingly, the best practices discussed in this appendix are based on domestically manufactured products for civilian and military applications.

In this appendix best practice is distinguished from typical practice because (1) the practice has been identified as a major contributor to the success of particularly noteworthy projects or products, and (2) it deviates from the customary manner (company and industry) used to accomplish similar objectives. These best practices for product and process integration include formal procedures, techniques, and technologies whose objectives are to—

- (1) Identify component, subsystem, system, and process interactions, dependencies, and constraints.
- (2) Articulate and increase visibility of downstream constraints to the upstream product realization activities.

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<sup>1</sup> Robert I. Winner, James P. Pennell, Harold E. Bertrand, and Marko M. G. Slusarczuk, *The Role of Concurrent Engineering in Weapons System Acquisition*, IDA Report R-338, Alexandria, VA, December 1988.

- (3) Convey upstream constraints, goals, information, and data to downstream activities and efforts needed to complete the product realization process.
- (4) Shorten the product realization process cycle time, increase quality, and reduce costs.

Although organizational efforts crucial to product and process integration are recognized as important to the success of these best practices, the examples focus primarily on the technologies that contribute to linking activities throughout the product realization process. The most significant such technologies detailed in this appendix are:

- (1) **Rapid prototype development.** A collection of technologies and methodologies that create a physical or mechanical prototype directly from the CAD data model. No model builders or drawings are used. Engineers use rapid prototyping technologies to provide immediate audits of the product design.
- (2) **Non-destructive testing.** Simulation of product and material performance characteristics prior to construction of complex physical prototypes for destructive testing.
- (3) **Discrete event simulation.** A technique used to schedule production capacity and release of jobs into manufacturing facilities.
- (4) **Advanced CAD imaging systems.** Systems used to replace prototype construction for qualitative evaluation of product characteristics relating to appearance (e.g., highlight and reflectance).
- (5) **Knowledge-based systems.** Systems used to support rational consideration of complex tradeoffs among product performance goals, design alternatives, materials, process constraints, and finished goods packaging and distribution.

## **APPROACH**

### **Background**

The DoD directed the Institute for Defense Analyses (IDA) to identify leading implemented examples of product and process integration and to collect information about the methodologies and technology the companies used, the results obtained, and the major lessons learned from their integration efforts. The companies surveyed are predominately large commercial firms providing a variety of consumer and industrial products.

## **Objective**

The intention of this quick-reaction study was to assess the state of product and process integration practices and gain a sense of the level of performance and capability exhibited by U.S. manufacturers. The study summarizes a series of interviews conducted by telephone and draws conclusions based upon those interviews.

## **Scope**

This study characterizes best practices for product and process integration by focusing on noteworthy products, or projects, and identifying the technologies, management approaches, and work organizing methodologies that supported the successful completion of these efforts.

## **Methodology**

A limited literature survey was conducted to identify appropriate cases for inclusion in the study and to provide a basis for structuring the materials included here. The target companies were selected on the basis of reports in the literature concerning development of new products or processes, extremely rapid product introduction, revolutionary product and process improvements, novel application of technologies, and implementation of new organizational techniques for structuring work and tasks associated with design, production, distribution, and marketing of new products. From the literature and subsequent discussions with members of the manufacturing community, a subset of companies were then identified for extended telephone interviews. The results of these interviews are summarized in the following sections.

## **BEST PRACTICES INTERVIEWS**

Telephone interviews with the companies identified in Table F.1 were initiated during the period 7-24 July 1992. Although most of the products and projects in Table F.1 had been identified by the interviewer as appropriate subjects for discussion prior to the actual telephone interviews, the participants were also asked to discuss other products and projects that they believed employed best practices for integrated product and process development. The nature of the study provided time to collect sufficient information about a subset of the products and projects in Table F.1. Those projects and products are described in the following sections.

**Table F.1. Companies, Products, and Projects Targeted**

Motorola	"Bandit" Pager Project
AT&T	"Safari" Laptop Computer
Ford	Crash and vehicle simulation
Saturn	Production and Design Teams
SEMATECH	Process Simulation
John Fluke Instruments	Product Design Teams
Ingersoll-Rand	Process Tooling
Chrysler	Automobile Hood
Boeing	CAD/Teams/Video Conferencing
Compaq	ProLinea product development
DEC	Production/process integration
Honda	Production/process-stamping
Bose	Vendor and supplier integration
GE Appliances	Production/process integration
Cummins Engine	Simultaneous Engineering Teams
Ingersoll Milling	Systems builder
Carrier	Knowledge engineering
Whirlpool	World Washer project
General Dynamics	Integrated product development
Ingalls Shipbuilding	Discrete event simulation
TRW	Concurrent Engineering program and metrics
Johnson Controls	Rapid prototyping
3M	CAD integration
Polaroid	Product Integration (film and camera)
GE Medical	Magnetic Resonance Imaging
Intel	486 design and production
Xerox	Small Copiers
Black & Decker	Coffeemaker new product development
IBM	Low cost laser printers
HP	Kittyhawk disk drive
Interleaf	Integrated documentation
Teledyne WaterPik	CAD/teams

When questioned about best practices in product and process integration, most of the survey participants used the term concurrent engineering in reference to the collection of practices and actions they employed for the projects and new products mentioned. But when queried for their definition of concurrent engineering and their expectations for its application, a range of characteristics and objectives were forthcoming.

From those discussions the following list of goals for product and process integration were developed. Note that the factors (best practices) identified are cross-cutting; that is, they can contribute to the accomplishment of several objectives:

**Reduce Ambiguity.** Use common data model and global standards. Minimize number of suppliers. Use teams with broadened constituency and increase opportunities for interaction.

**Eliminate Delays (faster decisions).** Collocate functional groups; minimize data handling, conversion, generation, verification. Perform activities in parallel rather than sequentially.

**Eliminate Activities.** Reduce model building and prototype construction. Use nondestructive testing and automatic data extraction for downstream activities (e.g., work packets, routings). Eliminate paper drawings. Minimize secondary processes (e.g., chrome plating or painting).

**Reduce Risks.** Use simulation to minimize unknown risks and acquire critical information earlier in the product realization process. Use generic products and components and modular design. Move environmental risks upstream where there are opportunities for greater control.

**Reduce Costs.** Use integrated product and process models and common data model to support entire product life cycle. Consider material and process alternatives, design for assembly and manufacture (reduce number of components and materials). Benchmark to establish performance metrics.

**Increase Quality.** Improve designs by examining tradeoffs among alternative parameter values; lower the number of engineering change requests during new model startup.

While most of the interviews concentrated on the technological aspects of product and process integration, all of the company personnel spoken with emphasized the importance of organizational and cultural concerns for the successful adoption of best practices: To be effective, technology strategies must be congruent with organizational structures and practices. For instance, as part of one firm's efforts to increase the effectiveness of its product and production process activities, it undertook the development of a consolidated data base for the groups involved. The company did not, however,

resolve responsibility for data base correctness, maintenance, and change. The result was conflict among the participating functional departments, project cost overruns, and significant frustration with the integration process.

### **Whirlpool Corporation World Washer Project**

During a 3-year period, a collocated multifunctional team representing marketing, product design, product engineering, process design, and quality assurance developed a new international product for the Whirlpool Corporation called the "World Washer." During this period the team also designed, built, and commissioned factories in Brazil, India, and Mexico. The World Washer was designed in a modular manner so that the product could be customized locally for regional market conditions. The development team investigated most of the techniques proposed at the time for high quality, customer input, and vendor and supplier participation; they adopted those appropriate: design for manufacturability (DFM), Taguchi methods for designing experiments, quality function deployment (QFD), conjoint analysis, and extensive cross-cultural training.

Engineers from those countries where new production facilities were to be built were moved to Michigan to participate directly in the design and engineering activities so that they would be able to effectively support the product and its production facilities. Domestic engineers at the same Michigan design facility received relevant training for the cultural issues they would encounter in the countries where they would be working and with the foreign engineers representing those Whirlpool facilities.

Whenever possible, and subject to local conditions, no secondary production processes were used: no chrome or porcelain was used and no molded or painted parts were used when appropriate substitutes were available. For instance, in Brazil and India a stainless steel basket is used while a porcelain-covered steel basket was designed for Mexico. Although the cost of materials was sometimes higher, the capital investment was minimized and the opportunity for quality problems with intermediary processes was reduced.

Wash cycles, temperature, and water use differ among regions and countries where the product is manufactured and sold. Whirlpool engineers developed generic controller software with parameters that reflect country and market specific characteristics to effectively support changes at the distributed production facilities.

Whirlpool Mexican, Indian, and Brazilian production facilities for their World Washer have no incoming inspection of purchased parts or materials, and all incoming materials flow directly to their point of use when received. Procured materials are received at one dock, and raw materials arrive at another dock. Most plants do not use fork trucks for material handling at the production line, and the majority of material movements are managed with simple kanban methods.<sup>2</sup> The plant in Brazil bought their own fleet of trucks to manage purchasing logistics. They provide local "milk runs" that make scheduled pickups to assure just-in-time (JIT) delivery of vendor products. Production lot sizes are limited to minimize finished goods inventory.

When it began the World Washer project, Whirlpool benchmarked its processes extensively against the automotive industry, and followed the auto industry's lead in forming product development teams. Whirlpool also adopted the Japanese technique of "freezing" design specifications and not adding changes or enhancements until the next model release.

Production capacity for each of the new plants was based on market studies that determined the amount of product they would be able to sell. The manufacturing facilities were built to supply 150 percent of this market share. Because the production lines are modular, the throughput of machines on existing lines is not increased to gain additional production. When capacity increases are necessary, they will be accomplished by duplicating the entire production line in parallel to the existing line.

Technology used for product and facilities design was very basic: 2-D CAD system, QFD, DFM, and some simulation work on plastic flow for analysis of large molds.

Whirlpool's new manufacturing production systems are 10 times less complex than previous facilities. Factories are designed for simplicity, market size, and capital minimization. Many concepts are considered very early in the product design phases—amount of product they can expect to sell, facility layout, product modularity, and local requirements. Simplicity leads to less complexity to understand and manage and, therefore, less design simulation for production facilities is needed to be confident of capacity and throughput.

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<sup>2</sup> "Kanban" is the name for a specific Japanese inventory replenishment system developed by Toyota.

## **Ford Motor Company Automotive Design**

### **Vehicle Crash Simulation**

Ford has used computer simulation to significantly reduce the amount of physical crash test required to meet government regulations and the time required to accomplish certification tasks. Simulation efforts include occupant restraint, roof-crush, front- and rear-impact, offset car-to-car, and some side impact. Ford also believes that it has developed a good correlation between simulation models of vehicle rollover and physical tests.

The application of simulation models to the design process now precedes even the construction of parametric "work horse" prototypes—physical models that are used to provide crash data on very rough-cut vehicle body designs. With simulation, the amount of physical test for front barrier crash has been reduced by about one-half, but changes in regulations continue to require new work.

Ford noted that while it is difficult to estimate savings in terms of direct investment, the reduction in time to obtain results from early design efforts and the opportunities to increase the number of alternative designs is believed to have been significant. Although the development of parameterized models is slow, such models are infinitely reusable. The ratio of time for prototype-build to that for computer-build is about 15:1. Changes in sheet metal take about 15 to 20 times longer than equivalent changes in simulation models. The Ford simulation group has also begun to recognize the importance of maintaining the currency of models rather than discarding older product models. Most products are derivatives, so there are benefits to be gained from upgrading simulation models developed for the previous year's vehicles.

### **Virtual Reality (Synthetic Environments)**

As would be expected, Ford's experimentation with virtual reality has focused primarily on its application to visualization of automobile interiors and exteriors. Ford does, however, expect to apply these advanced simulation techniques to its manufacturing environments (such as assembly sequencing) and hopes to minimize the number of engineering changes in the later phases of product introduction.

### **Rapid Prototyping (Free Form Fabrication)**

The development of solid model CAD systems provides better visualization of the design, but the increased costs associated with solid modeling has been difficult to justify until the availability of "desk top manufacturing" systems for rapid prototyping of component designs. The integrated model is used to generate the information needed for finite element analysis (FEA) and kinetics, mass properties, and center-of-gravity analyses, and it will be needed to participate in virtual reality scenarios. The adoption of rapid prototyping technologies has reduced by 50 to 80 percent the time involved in getting prototype parts. By generating the parts on the "desk top" directly from the CAD data model, the "time to part" can be significantly less than that required for cutting a purchase order for the prototype to be manufactured in the usual manner (i.e., model shop). An additional benefit is a direct cost savings because model builders are not involved in the construction of the prototype. In fact, this was cited as one of the most significant issues concerning reformulation of task and responsibility that engineering must undergo: a mental change required on the part of engineering as the free form fabrication (FFF) becomes the auditor and printer for the design world to determine whether the design is functionally correct. Interpretation of a design by model builders takes time, is error prone, and generally requires multiple cycles to accomplish correctly. For instance, when a throttle body design was sent to a prototype shop for construction of a physical model, it took more than a month to clean up the design-model despite the assurance by the model builder that his conversion from 2-D drawings to 3-D part was correct. Free form fabrication means that the detailer or checker is not needed. The design engineer accomplishes the checking function by generating a prototype component and thus immediately determines design veracity.

One example of rapid product development at Ford was a new automobile engine crankshaft. Changes were made to the constraint parameters of the engine data model. A prototype crankshaft was quickly generated with a FFF system and checked for dimensional accuracy. This prototype was then used to create sandcast molds; iron was poured; the castings were X-rayed and then machined. The crankshaft was placed in a motor and tested—2 days had elapsed from the time the design was undertaken on the computer until a new crankshaft was installed and tested in an engine. No drawings were generated and no pattern-makers were involved in the prototype process.

### **Parametric Linkage of Product Design Models**

A substantial number of the subsystems and component designs in the automotive industry are variants of previous efforts. Ford (as well as many other manufacturers) is increasing its investment in design models, concentrating particular effort on parameterizing designs and using the CAD systems to logically link components via computer data models. These logical links between product components support automatic changes throughout the related system of elements. As engineers or designers make changes to one component, the appropriate accompanying changes are made to all coupled components, and the designs and specifications for the necessary tools and fixtures are generated automatically.

For instance, the designs for appropriate dunnage (the material handling fixtures such as hangers) are changed automatically when kinematic modifications are made to an associated engine component. When these designs are not linked in the CAD data model, engineering change requests (ECRs) are the means of eventually synchronizing fixtures and product.

### **Ingalls Shipbuilding**

Ingalls builds surface ships in a 600-acre production facility. The company follows an assembly-line methodology that joins plates to create assemblies, combines assemblies into modules, and then connects the modules to create a ship. Subsequently, the ship is floated and remaining fitting-out accomplished. Ingalls has begun to use discrete event simulation to efficiently schedule the release of jobs in the production facility and to allocate machines, equipment, and skilled personnel for the multi-year shipbuilding efforts.

### **Scheduling and Encumbering Resources via Simulation**

Ingalls has developed generic shipbuilding discrete event simulation models to determine monthly resource requirements for the entire production facility. Each month, work orders for the next 5 years of production (200,000 line items) are extracted from a mainframe data base and downloaded to a personal computer simulation data base in the production scheduling department. The simulation models determine the skills hiring and machining resource requirements for the facility in the next period. Each shop is a cost center with certain levels of productive capacity and associated manpower requirements. The simulation model currently schedules for 1-month increments (20 working days) using various constraints defined by the customer as well as the facility. Schedules are

regenerated each month because priorities often change from month to month among customer orders.

Because of the complexity, variability, and contingency among its many jobs, Ingalls has to use simulation instead of simply adopting a simple fixed scheduling methodology. Besides coordinating and planning for skilled labor and machine-based resources, Ingalls must also be able to consider the effect of strikes, decreased contract funding, and contract acceleration on the production schedule.

Models function at the facility level, but Ingalls has also developed low-level models to represent individual shops, machines, and equipment. Eventually these shop models will generate the inputs for the aggregate model of the facility.

### **CAD Data Model Interference Checking and Supporting Numerical Control (NC) Tools**

Extracting all working papers from the CAD data model is new at Ingalls. The current SA'AR 5 Corvette Program is the first major warship construction by Ingalls to be accomplished using a 3-D, interference checked, computer-based design.

A primary consideration in modular design and construction is resolution of interference among subsystems and components. The manner in which the ship is assembled is meant to minimize the amount of work that must be performed once the ship is "floated." Obviously then, major construction delays and material cost overruns can result from improper validation of fit among subsystems prior to scheduling their assembly in the ship yard. The CAD data models are also used to generate the data stream needed to drive NC plasma arc cutters to maximize number of pieces from plate and minimize scrap. The pipe shop uses NC pipe benders driven from the CAD data model to bend and cut to length pipes up to 16 inches in diameter. Design engineers currently use wireframe shading software to create visualization assistance and define installation sequences and follow-on support of distributive systems. Virtual reality would support the process planner in defining "kits" that would allow more work to be accomplished in the shops rather than "on the ship" to take advantage of the additional room and support facilities.

A need identified by Ingalls design engineers concerns establishing constraints within the CAD data model that would be maintained for downstream processes, e.g., defining pipe size, material properties, and load requirements at the design stage that cannot be arbitrarily changed by production personnel when the product enters the manufacturing process.

One of the most significant benefits of using a full CAD data model to design and construct vessels is the support provided for the complete life cycle of the ship over its 20- to 30-year career. The CAD data model contains a comprehensive data base of component objects used in the construction of the vessel (valves, gas turbine engines, decks, lights) and the criteria for supporting the maintenance of the ship (component source, value constraints, location), an electronic record of changes made to the original design, and an up-to-date 3-D CAD model of the ship and its subsystems.

### **Measuring Increased Productivity**

To gain a better understanding and quantitative measure of the efficiency and contribution of a full 3-D CAD data model, Ingalls compares the number of bills (work instructions) started and completed with the number of engineering change notices to fix errors. This is expected to support comparison across ships of various size. The Company's qualitative measure is based on the reactions of the various disciplines and skilled crafts in the shipyard. These groups are meeting their budgets and time schedules; therefore, they are happy with the new system. Ingalls expects that there will be no savings in design the first time through the product realization cycle, but the second or third time they expect to see benefits from the learning curve experienced. A simple example is in the use of the CAD system. Originally, users went to extremes in the level of detail—trash cans (both open and closed) and coat hooks—incorporated in the CAD models. Ingalls believes that its most significant savings will result from decreased time to assemble the ships rather than radically decreased time to design ships.

### **Impediments to Adopting Best Practices**

As is often noted, one of the biggest obstacles to adopting new technologies and work methods is cultural resistance at all levels of an organization. Ingalls found that to effect the changes and technologies needed to achieve a more efficient and effective organization, not only did its senior executives have to understand the importance of the integrated CAD systems and be committed to their success, but also the managers reporting to them had to be motivated to make the system work.

Problems encountered during the adoption of a CAD-based design system led to false starts. One of the primary reasons that CAD technology met resistance was involvement of the wrong personnel. The functional managers of each design and production group that would be the primary users of the CAD system selected the wrong individuals to participate in the initial operation of the system. In many instances, the

employees selected were not able to contribute effectively because they were either too junior managerially or they did not have the correct technical expertise needed to make appropriate decisions.

In a manner similar to that discovered to be effective for automotive design and manufacture, Ingalls found it necessary to select one person to coordinate and lead engineering, manufacturing, and planning activities, someone with political as well as technical savvy. Ingalls also used pilot programs to introduce the enabling technology and to provide a learning experience for working through the kinks and problems that could then be foreseen in larger application.

## **Chrysler**

### **Automobile Hood-Stamping Project**

After styling approval for automobile sheet metal, the availability of prototype parts usually takes a minimum of 30 weeks. There are several contributors to such an extended lead time, but one primary reason is the difficulty encountered in transitioning the stylists' design artifacts into rigorous product engineering and manufacturing form.

Stylists conventionally create initial body panels manually, modeling clay to get the exact form they want. The clay models are followed by the construction of polished hardwood prototypes that are used to check surface reflectance and highlights. The final step from design prototype to sheet metal parts is the development of the mathematical representations of the panel surfaces by product engineers. These surface definitions are in turn used to design the multicomponent dies used to stamp and form the sheet metal body parts and cut appropriate flanges for vehicle assembly.

This cycle of using clay, then wood, then soft metal dies may be performed several times before the prototype panels created with these dies satisfy the design constraints of the stylists and meet the constraints for manufacturing (e.g., no wrinkles in the metal). The lead time from styling approval to prototype sheet metal parts typically was about 30 weeks.

In an effort to radically reduce this lead time, Chrysler exploited a new rendering software to directly generate a CAD data model from the design created by the body stylists using screen-based tools. The mathematical surface definitions were derived from the resulting CAD data base and used to generate cutter paths for NC machine tools. The same cutter paths were used to construct the clay models that were previously sculpted by hand

as well as the soft metal stamping dies for the production of several hundred prototype sheet metal parts.

Production engineering historically requires 4 or 5 iterations to develop cutter paths that produced sheet metal surfaces duplicating the hand-sculpted clay models. But when rendering software is used to create CAD-based models, the mathematical definitions of the surfaces are available before the clay models are constructed. Chrysler found that the quality and fidelity of the reflectance and highlight software allowed styling to "buy off" on the milled clay surface and completely bypass development of the hardwood model. Synchronizing styling design and production engineering was significantly simplified and the time to reach a final design understanding was notably shortened.

In addition to the direct production of clay models from a CAD data model, computer flow models were used to evaluate the die design parameters to assure correct metal flow. Flanges for joining the sheet metal parts were computer generated and a laser trimming technique was used to accurately cut flanges instead of additional trim dies. High speed NC milling machines were also used to manufacture the soft metal dies.

The entire elapsed time from stylist signoff until first prototype parts were in hand was reduced from 30 weeks to just 109 hours. One engineer noted that the entire process could have been accomplished in 3 days instead of 109 hours, except that someone shut down one of the NC machines, and a thermal offset occurred when it was restarted.

### **LH Vehicle Platform**

Chrysler adopted a colocated, common CAD system, team approach for the development of a new high-volume production vehicle platform. The company had previously followed the historical model of sequential, phased development that required acceptance by one functional group before initiating work by the next. In the LH platform, all elements of the organization participated in parallel: marketing, manufacturing, production engineering, sales, styling, and service. Chrysler estimates that they used about one-half the number of people at peak (750 vs. 1500) and needed 3.5 years instead of the usual 5 years to develop a platform and 3 models.

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**Appendix G**

**COMMERCIALIZATION IN THE DEFENSE  
ELECTRONICS INDUSTRY**

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## **Appendix G**

# **COMMERCIALIZATION IN THE DEFENSE ELECTRONICS INDUSTRY**

### **THE CHALLENGE TO COMMERCIALIZE**

A siege mentality has been settling in on the Defense Industry ever since the fall of the Iron Curtain. Major changes have already begun to occur with massive layoffs, major divestitures, and mergers among the industry giants. One of the perceived bright spots in these gloomy times has been the potential for the Defense Electronics Industry to unleash its powerful engineering resources and vast array of glittering high technologies on a technology-starved commercial market place. This potential has unfortunately proven to be very elusive.

There appear to be as many reasons for this apparently slow transition to the commercial market place as there are opportunities to enter. Not the least of these has been the "culture-shock" for those in defense industry who have ventured out of the structured military procurement environment into the electronics bazaar of the real world. The different business rules (or total lack of rules), the different values, criteria for success, protocols, and even basic manners have all contributed to some monumental misunderstandings between one-time defense contractors and commercial customers. Sometimes, it seemed easier to sell a multi-billion dollar air defense system to a bankrupt dictator from the Third World than to sell new policies to the City of Chicago.

After much pain, embarrassment, and failure, however, some members of the Defense Electronics Industry have begun to adapt and are developing a new cadre of commercial entrepreneurs that can effectively communicate with and sell to the eclectic collection of customers that constitutes the commercial market. What has not so readily changed has been the corporate engineering, manufacturing, and product support organizations that must design, build, and repair these new products.

Past practices that had treated engineering, manufacturing, and product support as only loosely coupled disciplines have already begun to change over a decade ago. Team approaches and organizational restructuring have begun to break down the traditional walls

between these different functions. However, many engineering organizations still believe that initial product development is still their exclusive realm and that manufacturing and product support are functions to be at best tolerated. This attitude, a holdover from the good old days of unfettered technology development on DoD cost plus contracts, is seldom found within successful commercial electronic manufacturers. Technology seldom has intrinsic value in the commercial market place. Customers demand quality, value, and service. Customers almost never pay for development. Customers never buy cost plus. This environment is compounded by a wide array of ready and able competitors, many being long-standing, trusted, commercial electronics suppliers with in-place sales and support networks and technology that is not that much behind the best in the defense industry.

To survive in this environment, defense electronics manufacturers must develop the means to rapidly develop new products at their own expense with minimum investment; smoothly transition the product to production as orders materialize; guarantee on-time delivery of the product with high quality and reliability from the very first units off the line; and provide prompt, high quality, affordable service with excellent warranties. Unless they are choosing to exit the defense electronics business entirely, however, they must also continue to invest scarce R&D dollars in sustaining the military product technology base. The technology and manufacturing base needs of the two market areas can often appear to be in direct conflict, forcing management to make some very hard choices.

### **DUAL USE TECHNOLOGY: A STRATEGIC CHOICE**

One alternative that has emerged in the last several years can simplify these investment choices; it is the strategic selection of products and technologies that are applicable to both military and commercial applications. These "dual-use" technologies and product bases capitalize on the high technology and superior performance advantages of today's military systems but produce with commercial material and production practices. Where achieved, such as the Modular Radar (MODAR) family of radars described later, the defense electronics manufacturer can maintain core competencies while entering new nontraditional markets. This market diversification will be essential to survive the worldwide decline in defense spending without turning away completely from the defense business. Additionally, the manufacturer may well find new military markets for dual-use technology as the armed forces try to squeeze more capability from their dwindling resources.

## **A KEY TO ADAPTING: THE INTEGRATED PRODUCT DEVELOPMENT TEAM**

All of the product development issues and elements described in the first section of this appendix demand rapid reaction, excellent communication and a high degree of teamwork. These attributes are at the heart of the Integrated Product Development Team (IPDT) approach. IPDTs are not a new concept in commercial industries. However, they have had a wide range interpretations and levels of success. In general, IPDTs bring together all of the functional elements of the product development process (marketing, design engineering, manufacturing, support) at the beginning rather than the traditional sequential approach. Depending on the product complexity, a number of IPDTs would be formed around major elements of the product family tree (systems engineering, hardware subassemblies, software, etc.) with the purpose of concurrently maturing the product design, development, and manufacture. Each team's charter is to apply a total quality process and to "do right things right the first time." This process may be more difficult to manage initially than the segregated approaches of the past, but the benefits downstream in the development process are very substantial.

A successfully implemented IPDT process will result in several measurable benefits.

- **Reduced Cycle Time.** The time required from product inception to production deliveries can be dramatically reduced through concurrent processes and improved internal communication.
- **Fewer Revisions.** Fewer changes required as the product moves from design through development to production.
- **Improved Reliability and Supportability.** MTBF, MTBR, and other metrics can be substantially improved by earlier identification of failure modes and critical parts as well as designing and developing repair and support approaches up front.
- **Lower Development and Production Cost.** All of the above factors as well as the ability to focus all of the product development functions on cost. Particularly improves cost trades between development, production, and support allowing design-to-cost objectives be more readily met.

Thus, IPDTs can have a direct effect on those factors that improve a company's or an industry's competitiveness in the marketplace--rapid response to market opportunities, reduced investment in product development, and greater product value. The challenge that lies ahead is to structure and manage IPDTs to gain their full potential.

## **THE MODAR PRODUCT DEVELOPMENT: AN EXAMPLE**

The Westinghouse Electronic Systems Group has been transitioning to a better balance in its commercial and military products over the last several years. One significant product development opportunity that arose during this time serves as a good example for developing a commercial product line from a military technology base. This development, the Modular Radar (MODAR) program, was an excellent benchmark case to evaluate the benefits of IPDTs. MODAR was an excellent choice for this evaluation because it was an entirely new, internally funded product based upon resident tools and technologies but relying on no previously developed hardware or software. Intercepting the targeted commercial market required a rapid development cycle with low development investment that resulted in a new radar product with substantially reduced production costs and an order of magnitude increase in reliability.

The MODAR family of radars is a new generation of X-band commercial pulse doppler airborne radars targeted at commercial aviation and low-cost military aircraft markets. The radars are based on a modular architecture that provides easy adaptability to a wide range of applications. The initial product entry point was with a new ARINC 705 compatible pulse doppler weather radar with the ability to detect low altitude windshear with at least 30 seconds of advanced warning. This product drove the radar packaging (~ 0.5 cubic feet, plus antenna), requiring pulse doppler detection performance as well as over 2,500-hour serial MTBF. It also had to be producible at a price competitive with today's noncoherent pulse weather radars (< \$100K).

The product development plan began with the specification, design, fabrication, and test of two prototype units with the ability to rapidly transition into production as sales opportunities emerged. The program was organized around a program manager and an engineering manager with individual IPDTs for each module or major family tree element. Each IPDT had a designated team leader responsible for all aspects (engineering, manufacturing, reliability, supportability, schedule, cost, documentation) of the sub-product development. Each IPDT was staffed by representatives from all program supporting disciplines. Some team members supported multiple IPDTs wherever possible. Each IPDT team leader along with key support staff also formed a master IPDT that steered the overall product development.

The overall objective of the organizational structure was to force ownership of the entire product down to the lowest level in the program team and across all product development disciplines. Additionally, objectives associated with reliability, availability,

maintainability, producibility, production cost, and schedule were also dealt with concurrently by the individual board and component designers as they strove to meet the technical performance specifications.

This concurrent engineering approach can be a severe culture shock if the designer receives inadequate support from the other disciplines outside his or her expertise. The solution is to gain commitment from the engineering, manufacturing, and support functions to support the process totally at the outset, and to insist on it every day. Further, every team member must believe (and be continually reminded) that this process is worth the extra intellectual effort.

The results of the MODAR program were quite startling. The product development cycle for a new prototype was reduced by more than 50 percent (from 12 months to 5 months). The prototype development cost was also reduced by 50 percent. Hardware integration and harmonization took 2 weeks instead of 8. The radar worked and performed all of its basic functions in its first flight test 22 weeks after program start.

Eight months after program start, the radar and its testbed aircraft were deployed to Orlando, Florida, to hunt windshear. In four days of testing, in very severe weather, over 100 windshear events were detected in real time (and confirmed by ground-based Terminal Doppler Weather Radar) without false alarm. These flight tests were the first successful demonstration of a real-time processing, operationally ready, windshear detection, airborne radar. In October, one of the prototype radars was installed onboard a Continental Airlines A-300 airbus to begin inflight operational evaluation. After 8 months of testing and over 3,000 hours of flight time, the radar has operated without failure and with virtually no support.

These technical achievements were impressive and indicative of the "getting it right the first time" power of the IPDT. Even more impressive, however, have been the results associated with the producibility and unit cost reduction aspects of the program.

With every IPDT supported directly by manufacturing operations and material acquisition personnel from the beginning, the designers were able to rapidly converge on the lowest cost, most producible design for the very first prototype. Design compromises at the board-level that did not violate the architecture, primary functions, and performance were permitted, particularly in the selection of components and material for the first units, to maintain the rapid prototyping schedule.

Substantial savings in production material costs (> 75 percent) were found by developing a common sense approach to material specifications and quality that allowed departures from Military Specification (MIL-SPEC) material without sacrificing reliability or quality. This tailored MIL-SPEC approach, when coupled with a comprehensive long-term warranty (placing product quality standards back on the shoulders of the manufacturer where it belongs), has been the norm in the commercial electronics industry and is gaining acceptance with some military customers.

Manufacturing labor costs were similarly attacked by eliminating unnecessary test and inspection steps that have been shown to only add cost without increasing quality. As a result, assembly and test times have been reduced by over 90 percent from conventional military practices. Manufacturing engineers participated directly in every detail of the radar design to ensure the producibility and test of every subassembly as well as the entire system. To further accelerate the development of the production processes, the first prototype units were fabricated, assembled, and tested on the production floor by the manufacturing engineers and production staff to gain valuable insight in the hardware producibility. This process reduced the number of revisions required later as the hardware moved to production.

This hard look at production cost has resulted in very large savings compared with the cost of best military practices used today. As a comparison, the nearest performance radar to the MODAR is the Westinghouse APG-66 radar for the F-16. The MODAR receiver, exciter, signal data processor, and antenna complexity and capability are very similar to the APG-66. The major exception is the transmitter—the MODAR uses a 160-watt all solid-state transmitter over the high power TWT transmitter in the APG-66. Taking this difference into consideration, the unit production cost of the MODAR weather radar is 80 percent lower than its military cousin. This reduction in cost also comes with an order of magnitude increase in reliability. These two factors alone allow the introduction of sophisticated pulse doppler radar technology into markets that would have been impossible to enter before.

A case in point has been the successful sale of a MODAR family member of the U.S. Air Force for the C-130. Here, a big brother of the commercial weather radar utilizing identical, common, commercial modules for all of the core radar subsystems (receiver, exciter, transmitter, signal data processor, and power supply) has been developed and is now entering production. This radar provides a substantially increased capability in modes and performance at 10 times the reliability and two-thirds the cost

without any compromise in its availability or compatibility with the C-130 operational environment. A similar capability in a conventional, fully-military-qualified design would have been out of reach for the available budget.

## **SUMMARY**

The defense electronics industry possesses the advanced technology and engineering know-how to create an incredible array of new products and services for the commercial market sector if it is willing to make some fundamental changes in the way it does business. These changes include new management techniques, such as IPDTs to reduce the product development cycle-time and investment, while increasing the product value, and the development of "dual-use" technologies and product lines that permit market diversification and sustained sales in core competency areas. The key to successfully implementing these changes will be a little bit of management vision and a lot of leadership with the rank and file who must ultimately embrace these new ideas. The successes are summarized in Table G.1.

**Table G.1. Integrated Product Development Team (IPDT) Success Story**

<ul style="list-style-type: none"><li>• &gt; 50 percent reduction in cycle time (from 12 months to 5 months)<ul style="list-style-type: none"><li>— First flight test in 22 weeks</li></ul></li><li>• 50 percent reduction in prototype development cost</li><li>• 75 percent reduction in material cost</li><li>• 90 percent reduction in labor cost</li><li>• 80 percent cost reduction over equivalent current military system</li><li>• Common hardware and software across commercial and military products</li></ul>
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**Appendix H**

**COMMERCIALIZATION IN THE  
SHIPBUILDING INDUSTRY**

## Appendix H

# COMMERCIALIZATION IN THE SHIPBUILDING INDUSTRY

Integration of commercial strategies and practices with naval ship requirements has the potential to reduce the acquisition and life cycle cost of the Navy's future ships. Achieving this benefit, however, requires the development of design and manufacturing techniques and an acquisition process that takes advantage of modern technology to produce complex ships in a more efficient manner. Controlled design and manufacturing experiments will provide the necessary feedback and lessons learned to develop these techniques and processes.

Identification of commercial strategies and practices as a potential means toward more affordable ships was one of the results of a study performed by the Navy. The Affordability Through Commonality (ATC) project was formed within the Naval Sea Systems Command (NAVSEA) to investigate methods to reduce the cost to build, operate, and maintain ships. The ATC project surveyed U.S. and foreign shipbuilding approaches and examined nonshipbuilding industries to determine what was being developed throughout the world to build more competitive products. The commercial trend is toward more efficient production and wider applicability. Producibility studies have determined that more efficient ship production can be achieved by emphasizing in-shop production of ship subassemblies. Future fleet studies conducted by the ATC project identified areas of commonality among future ship classes. Performing specific experiments involving subassemblies, or modules, that will have multi-class applicability will allow development of techniques for efficient ship production that will be applicable to virtually all future ship classes and result in a more affordable fleet.

A good example with several parallels with NAVSEA was studied by the ATC project. It involves the attempts of the Boeing Corporation to improve its competitiveness in its commercial aircraft division. Boeing was spurred by its failure to win several Full-Scale Development (FSD) procurements during 1978 to 1985. Although the Company received high scores for technical merit and product quality, its costs were too high, and Boeing lost the procurements to others. This initiated a corporation-wide

program to reduce costs and improve efficiency through a variety of techniques. The results have been significant, and Boeing is one of the top businesses in the aircraft industry, despite international and subsidized competition. This corporate renewal revised the way Boeing designs and builds airplanes. Instead of designing a given system for a given airplane, Boeing designs the system for the widest applicability within its product line. For example, 40 percent of the parts required for the Boeing 757 are common to the 767. This has obvious production advantages but also generates operating cost savings due to common maintenance, training, and ground support requirements. Boeing also revised the way it builds airplanes to become an assembler of large subassemblies. It no longer makes all the parts of the aircraft. Boeing subcontracts major portions, such as the wings, and assembles them on the airplane when they arrive at the assembly plant. The net result is a competitively produced airplane that enabled Boeing to be one of the world's leaders in aerospace technology and sales. The parallel with the Navy is that the Navy's ships are high quality, highly capable weapon systems, but they cost too much to build, operate, and maintain. The lessons Boeing learned have applicability to what the Navy is trying to do even though Boeing is a more centralized organization than the Navy and industry team that designs and produces ships, and production rates are lower for ships than for aircraft.

A similar example exists in the shipbuilding industry with the Blohm and Voss shipyard. This German shipyard developed the MEKO corvette and frigate system. This system involves the modularization of a great number of ship subsystems that can be tailored to an individual ship's requirements. This capability permits a compressed construction schedule, maximization of in-shop production, and commonality across different ship classes. Blohm and Voss reports a 5 percent reduction in construction costs over traditional methods and claims reduced life cycle costs because modular payloads permit easier and, therefore, less expensive modernization. This claim exists despite only partial modularization (primarily in combat systems) and a focus on modularization for rapid reconfiguration of base designs to attract foreign military sales, vice palletization for ease of construction and cost savings. Figure H.1 portrays how the shipbuilding schedule is compressed.

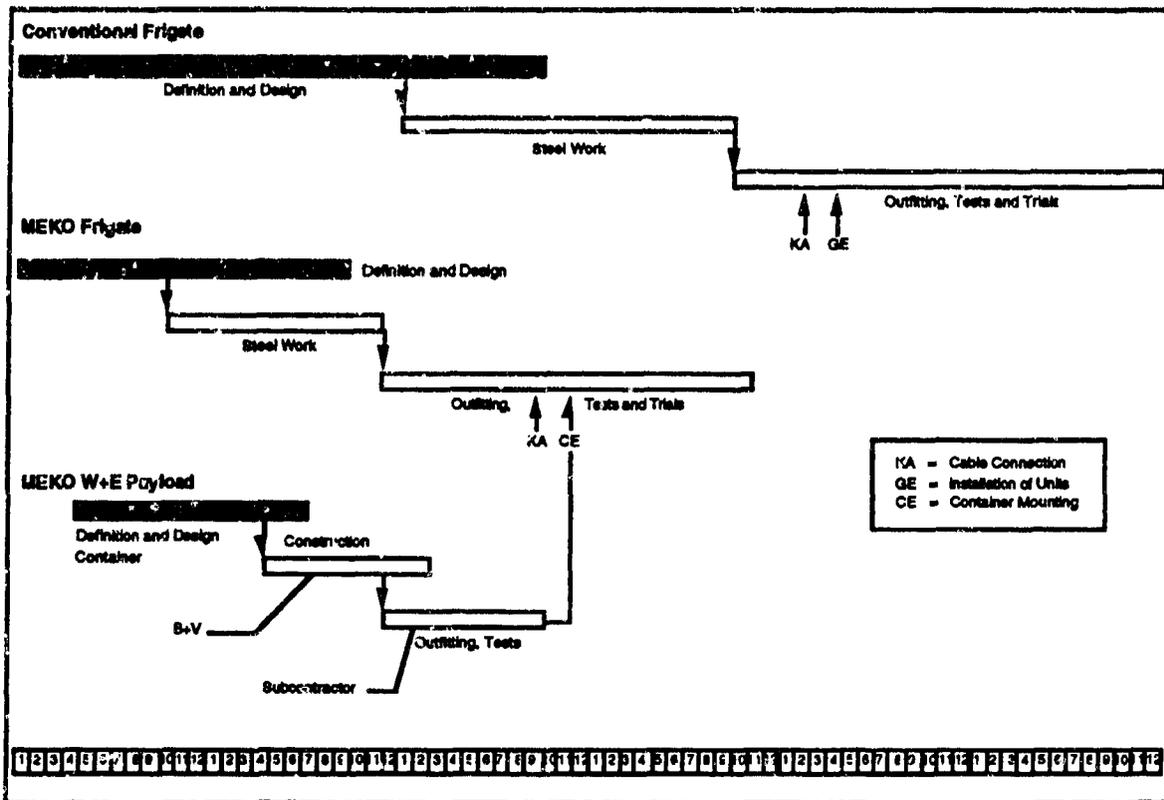


Figure H.1. Blohm and Voss Frigate Schedule Comparison

Some of the benefits gained from implementing a common and standard module approach are outlined below:

#### Design and Acquisition Phase

- Lead ship design costs are reduced (after initial fleet investment in reusable design elements).
- New ship technical and programmatic risks are reduced due to use of reusable design elements.
- Program acquisition costs are reduced due to procurement of fewer unique components.

#### Manufacturing, Construction, and Testing

- Assembly of large subassemblies “in-shop” vice “on-ship” will permit more efficient use of labor.
- Construction costs are reduced due to productivity improvements brought about by parallel assembly, critical path elimination, and faster throughput.

- Overhead and contract delivery requirement list (CDRL) costs are greatly reduced due to shorter construction time.
- Testing costs are reduced due to "off ship testing of Stages 1 through 5" (minimum onboard testing).

#### **Life Cycle Support and Modernization**

- Present Approved Parts List (APL) proliferation will be reversed.
- Infrastructure costs for spare maintenance and training will be reduced due to greater standardization.
- Modernization costs will be reduced. Greater standardization and modularization will simplify future modernizations.
- Flexibility in mission and technology upgrade will facilitate change in a more graceful, less costly, and more timely way.

Achieving these benefits requires careful selection of the ship features to be modularized. To assist in the selection process, several systems engineering efforts were performed. One involved defining a spectrum of future fleets for various levels of Ship Construction, Navy (SCN) budgets. This defined the range and quantities of ships that could be expected. These fleets were investigated for the degree of commonality among the various ship classes. This refined list defined potential candidate modules and the quantities likely to be required for each type. Ship construction costs are being studied to determine which of the candidate modules would have the most effect on cost. When the cost effect and quantities of the candidate modules are determined, the modules with the most potential to save cost on a fleet-wide basis can be determined.

The commercial world is moving toward greater component commonality within a product line while retaining the flexibility to match components to requirements for tailoring a product for a specific purpose. Adopting this commonality strategy for the design and construction of future ships will yield cost savings. Specific experiments will provide the lessons needed to apply this approach on a fleet-wide level.

Initial implementation of these acquisition process and commonality concepts via pilot or experimental programs is crucial to the success of the ultimate implementation of improved ship acquisition and support. The milestone-driven nature of the ship acquisition process precludes shipbuilding programs as a means for research and development of modular systems with fleet-wide applicability. These systems must be designed, tested, and developed, off-line from the ship acquisition process and, after they are proven,

introduced into new construction, conversion, or modernization programs at the feasibility and preliminary design stage, for module production as part of the ship acquisition program. Computer-aided design, engineering, and manufacturing and newly available three-dimensional product modeling technologies enhance the repeat usage of standard modules and their flexible reuse in follow-on ship acquisition programs with subsequent savings in time and money.

The experiment proposed in Section 3.6 will be utilized to:

- Develop and validate a common acquisition strategy and production process necessary to identify and resolve both the technical and programmatic issues and requirements associated with developing modular systems and the implementation and integration of these systems into the ship design, acquisition, construction, and life cycle support process.
- Develop three modular systems to the point where they can be incorporated into ship acquisition programs.

More importantly, the method by which this occurs, and the standards and specifications modifications developed to implement these three prototype development projects, will serve as a vital first iteration of a ship design and construction process improvement. This first iteration is a necessary step toward future (independent funding being pursued) process evolution by which subsequent modules and the architectural oversight required to utilize their potential for affordability benefit are implemented for long term and lasting benefit.

**Appendix I**

**EXPERIMENTS**

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## **Appendix I EXPERIMENTS**

### **RECOMMENDED EXPERIMENTS IN INTEGRATED PRODUCT AND PROCESS DEVELOPMENT**

#### **Composite Structure for the Composite Armored Vehicle (CAV)**

The advantages of composite armor as an integral part of a combat vehicle has been demonstrated in various prototypes. Designing vehicles using composites keeps sharp corners to a minimum and thus reduces radar cross-sections. It also cuts down significantly on welding of heat-treated metal alloys and armor for the overall vehicle. Since the number of parts and joining operations is reduced, fewer templates and tools are necessary, resulting in less required floor space, lower energy costs, and fewer man-hours per finished vehicle. However, taking the step from prototype fabrication to a manufacturing capability of at least 60 vehicles per month demands, at the least, a conservative, planned approach centered on a capability using wide, thick, composite broadgoods.

The first experiment proposed is to develop the critical manufacturing process associated with the composite material that will meet the Army's critical weight and threat requirements. Manufacturing the type of composite structures that will meet the requirements of the CAV involves laying down many layers of woven, ballistic fabric prepregnated onto a complex tool. The current technique for accomplishing this task is labor intensive; however, incorporating various levels of automation into the manufacturing process would reduce future production costs. Some types of automated equipment that handle wide broadgoods have been developed over the past 15 years, but none have proven to be reliable. Some of the problem areas that have been identified are methods of cutting material, proper tape alignment and tension, inertia problems due to the mass of the tape dispensing head when covering various contours, and quality of the tape itself.

What is required is the development of a flexible manufacturing fabrication cell that is designed for producing both thin and thick composite structures. The separate

components available for this integrated fabrication cell have been shown to be reliable and are currently in use in the aerospace and automotive industries. These components require modification and integration, however, to handle wide composite broadgoods of the type needed to meet the CAV requirements (i.e., broadgoods required to build the thick, large, composite structures needed for major components of the next-generation family of armored vehicles).

A related development effort would be to modify reliable composite fabrication equipment by integrating automated broadgood cutting equipment with semi-automated overhead dispensing equipment, tailored for wide broadgoods to be laid down onto equally wide tools. In this way, material could be cut to order on an as-required basis directly off wide rolls that could be carried to an overhead dispenser automatically. Positioning, laydown, and debulking of each ply at a specified pressure could be accomplished either manually or by a sequence of machine operations. These critical processes could then be measured to determine process maturity growth and to estimate process capability indices, e.g.,  $C_{pk}$ , for this process in CAV applications.

### **Advanced Field Artillery System**

The Advanced Field Artillery System (AFAS) ATD comprises two subsystems: (1) an automated ammunition subsystem and (2) the armament subsystem. The automated ammunition subsystem consists of the ammunition supply mechanism, projectile magazine, and ammunition control hardware. The armament subsystem consists of the turret drive and controller hardware, 52-caliber 155-mm Liquid Propellant Gun, and turret structure. The major thrusts in AFAS program include the advanced fire control, extended range and accuracy suite, automated ammunition handling, advanced propellant, and extended range and high-rate-of-fire armament.

The current focus of advanced technologies is on the following AFAS hardware:

- Regeneration Liquid Propellant Gun (RLPG) System
- Automatic Ammunition Handling System (AAHS)
- Fire Control/Battlefield Management (FCBM)
- Multi Option Fuze—Artillery (MOFA)

The Task Force suggests three areas of the AFAS ATD for potential IPPD experiments: metal forming and coating, liquid propellant, and the platform electronics. All of the areas involve critical manufacturing processes or have integration problems that require baselining and the determination of cost impacts.

Because of heat generated by the faster projectile, higher propellant charge, and increased rates of fire, the gun tube and chamber will require plating. Cadmium plating has been used in the past for this application. However, due to environmental problems associated with Cadmium, new, alternative cost-effective approaches will need to be developed.

The Liquid Propellant (LP) is a new technique for artillery, and new facilities will be required for its production. Basically, Hydroxyl Ammonium Nitrate (HAN), Tri-ethanol Ammonium Nitrate (TEAN), and water are mixed together to produce the combustible liquid propellant. The critical process parameters for the manufacturing of LP need refinement to eliminate problems associated with operational requirements. The chemical processes associated with the manufacturing of LP present an excellent opportunity for defining process metrics, conducting designed experiments, and using the results as a maturity growth indicator.

The platform electronics include a projectile tracking system and a muzzle velocity management and prediction system. Both systems are in the early definition phase and will use advanced electronics to meet their intended use (e.g., millimeter wave technology and neural networks). The Task Force felt that an IPPD approach to problem solving and defining critical processes will be of significant benefit to the overall program.

### **Integrated High Performance Turbine Engine Technology**

The goal of the Integrated High Performance Turbine Engine Technology (IHPTET) program is to double gas turbine propulsion system capability by around the turn of the century for a wide range of aircraft and missile applications, including all DoD needs. The program is in three time-phased steps, so that technology will be available for near-term system needs. Accomplishments will lead to durable high performance (i.e., high output and weight, low fuel consumption) engines, capable of built-in stealth. The program will have a great effect on both military aircraft superiority and commercial aircraft competitiveness. The approach to achieving these goals is to develop lightweight components and structures, and improved aerothermodynamic design, with particular emphasis on heat transfer in order to achieve the higher maximum and combustion-initiation temperatures required.

Program direction for IHPTET is effected by the DoD/NASA IHPTET Steering Committee. The committee is co-chaired by OSD (ODDR&E) personnel with representatives from the Services, DARPA, and NASA. Representatives of the U.S.

aircraft gas turbine industry are invited to attend open sessions of committee meetings. The IHPTET Steering Committee, with inputs from industry, reviews program progress and directs corrective actions in the event that progress lags in specific technology areas.

Progress toward achieving the established goals of the program has been excellent. However, 2 years ago, the Steering committee identified two specific technology areas that needed further emphasis: titanium-based metal matrix composites for compressor components needed for the Phase II goals, and ceramic matrix composites for turbine components needed for Phase III goals. Accordingly, increased efforts in the development of these materials, including addressing the basic producibility and manufacturability of certain components, are being conducted. However, the IHPTET program does not include efforts devoted to high-yield process development. This is a matter of concern because no manufacturing technology program exists to provide a natural follow-on to S&T efforts.

The Task Force recommends that manufacturing technology programs focused on titanium-based metal matrix composites and ceramic matrix composites be established within the context of the overall IHPTET program. The purpose of these programs would be to provide funding to determine the critical manufacturing processes associated with the components fabricated from these materials. In addition, process metrics should be modeled or measured to determine growth maturity.

#### **RECOMMENDED EXPERIMENTS IN MODELING AND SIMULATION**

Four ATD-based experiments are proposed to demonstrate and accelerate adoption of modeling and simulation in the IPPD process. These experiments, which address all aspects of the vision presented in Chapter 2, are summarized in Table I.1. The first three experiments, shown schematically in Figure I.1, build on specific ATD applications to enhance their cost effectiveness. The fourth experiment seeks to demonstrate an infrastructure for integrated modeling and simulation that can support a broad range of Thrust 1-5 ATDs. Detail on these experiments is given in the following subsections.

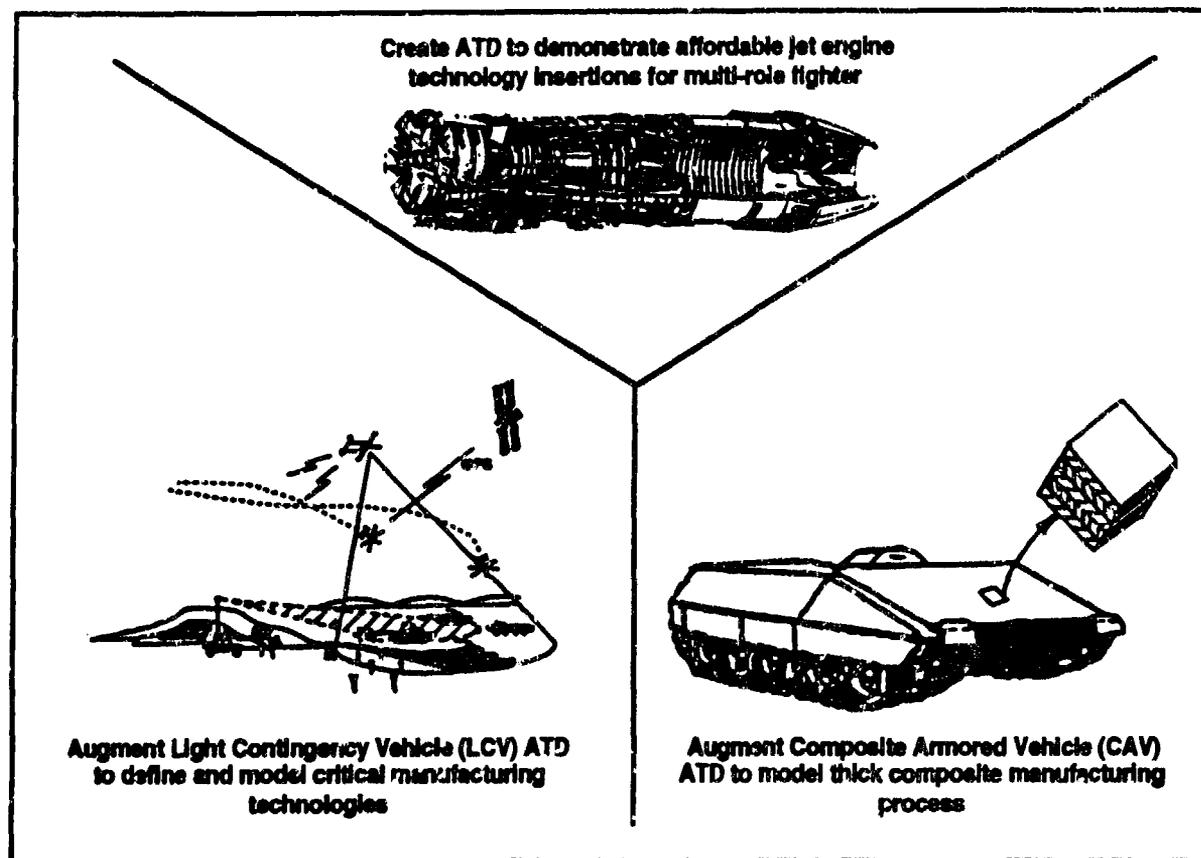
**Table I.1. Recommended Modeling and Simulation Experiments**

Demonstration	Benefit
<p><b>LIGHT CONTINGENCY VEHICLE (LCV)</b>                      Augment LCV ATD to define critical manufacturing technologies and to model and simulate them to define performance bounds dictated by available manufacturing processes.</p>	<ul style="list-style-type: none"> <li>• Define limitations imposed by manufacturing processes on subsystem performance.</li> <li>• Define warfighting effectiveness and cost tradeoffs.</li> <li>• Reduce subsystem costs.</li> </ul>
<p><b>MULTI-ROLE FIGHTER ENGINE (MRF)</b>                      Create an ATD to define and demonstrate affordable technology insertions for a derivative jet engine for an Air Force MRF.</p>	<ul style="list-style-type: none"> <li>• Reduced time, cost, and risk in demonstrating a derivative engine for a weapons system.</li> <li>• Development of detailed design, manufacturing process, and factory models for key technology insertions.</li> </ul>
<p><b>COMPOSITE ARMORED VEHICLE (CAV)</b>                      Augment CAV ATD to model thick composite manufacturing processes, relating feasible designs to weight, protection, signature, etc.</p>	<ul style="list-style-type: none"> <li>• Create knowledge and data base to complement CAV demonstration point design.</li> <li>• Enhance system and process design, reduce cost, and support production base analysis.</li> </ul>
<p><b>INFRASTRUCTURE FOR IPPD</b>                      Demonstrate open architecture and integration technology as a common element of several ATDs. Start with interface standards and network services to integrate IPPD environment, both internally and with synthetic battlefield.</p>	<ul style="list-style-type: none"> <li>• Facilitate rapid iteration of product/process design analyses, resulting in better designs and shorter cycle times.</li> <li>• Avoid unnecessary duplication among selected ATDs.</li> <li>• Provide incremental, open set of capabilities for future ATDs.</li> </ul>

### **Light Contingency Vehicle**

The Light Contingency Vehicle (LCV) ATD involves a revolutionary new weapon system concept that will require fundamental tradeoffs between performance, manufacturing, cost, and operational tactics. The LCV, which represents a departure from conventional heavy forces, is one of three vehicle ATDs being pursued in Thrust 5, *Advanced Land Combat*. Its objective is to demonstrate how emerging technologies can be integrated to show that a credible force can be rapidly projected into future contingency operations. The LCV is a joint DARPA-Army-Marine Corps ATD with a large user base that seeks to develop an 8- to 10-ton survivable vehicle with numerous automated and semi-automated modes of operation for use in surveillance and weapon delivery. Current ATD plans call for significant modeling and simulation effort in consideration of numerous technical and operational alternatives, each involving fundamental performance, manufacturing, cost, and operational tradeoffs. Appropriately augmented with modeling

and simulation of critical manufacturing processes, this ATD will exercise the full capability of the modeling and simulation vision for IPPD presented in Chapter 2. This experiment will provide an excellent test ground for creating critical manufacturing process models that can be used to meet Thrust 5 objectives, enhance Thrust 7 objectives of technology for affordability, and exploit the synthetic battlefield environment of Thrust 6. Planners of this ATD have incorporated some elements of the efforts needed in their project plan. Augmentation of this ATD, to create a joint ATD between Thrusts 5 and 7 that uses the synthetic battlefield environment created by Thrust 6, will be a productive and cost-effective experiment.



**Figure I.1. Schematic of Augmented and New ATDs To Demonstrate Modeling and Simulation in IPPD**

### **Multi-Role Fighter Engine**

A new ATD is suggested to define and demonstrate affordable technology insertions into a derivative engine for an Air Force Multi-Role Fighter (MRF). The objective is to demonstrate that time, cost, and risk of a derivative engine for a weapon

system can be significantly reduced by appropriate use of modeling and simulation technology. The synthetic battlefield would be used to define the benefits of stealth characteristics, speed, range, maneuverability, etc. Engine system requirements, such as radar cross section, installed thrust, specific fuel consumption, weight, etc., will be generated. Design models will then be used to determine the nature and degree of the required technology insertions to the present baseline production F-16 engine (e.g., ceramic thermal barrier coatings, advanced super alloy turbine blade, and multi-hole laser drilled combustor liner). Process models, factory models, and cost models for the technology insertions will then be developed. A risk analysis of the latter models will determine the degree of validation required. By using an advanced derivative of a current production engine, the detailed design, manufacturing process, and factory models that need to be developed will be limited to those related to the technology insertions. Through use of existing data for the remainder of the engine, the entire feedback and feed-forward capabilities involving IPPD will be demonstrated.

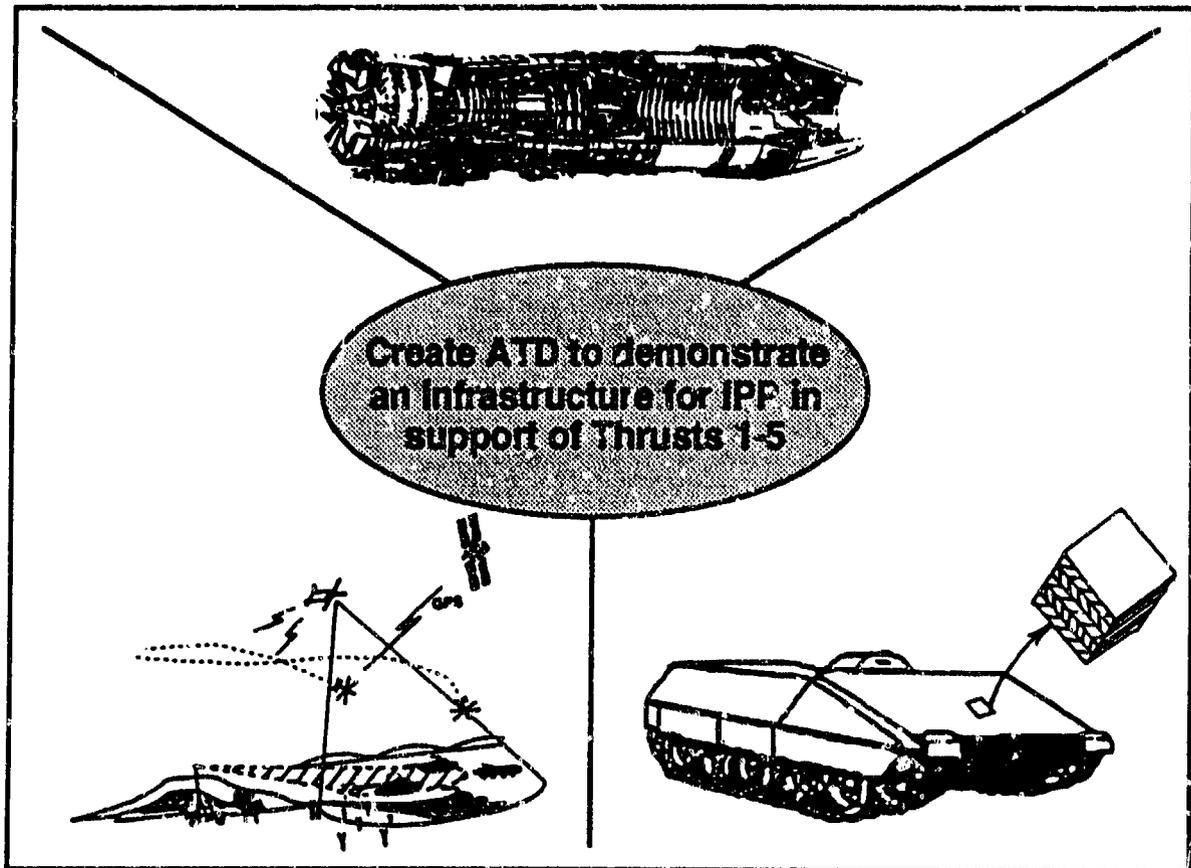
### **Composite Armored Vehicle**

The Composite Armored Vehicle (CAV) ATD involves fundamental manufacturing technology constraints, as well as significant tradeoffs between performance and operational tactics. The CAV, being developed by the Army in Thrust 5, represents an operational concept associated with a scout function that is carried out by a lightweight combat vehicle with substantial armor protection provided by composite materials and substantial firepower. While the operational concept for this vehicle is more conventional than for the LCV, fundamental design, performance, stealth, vulnerability, manufacturing, and cost tradeoffs must be addressed in this ATD. Augmentation of the current CAV ATD to develop models and simulations of thick composites for armor and support structures will permit performance, cost, and production quantity tradeoffs to be made, based on thick composite manufacturing capabilities. This extension of the CAV as a joint ATD between Thrusts 5 and 7 provides an outstanding opportunity to test and guide development of effective tools and technologies associated with affordability in a project with fundamental manufacturing considerations and tradeoffs.

### **Modeling and Simulation Infrastructure for IPPD**

An information exchange infrastructure is critical to achieving the IPPD vision defined in Chapter 2. A Thrust 7 ATD, shown schematically in the center of Figure I.2, is recommended to demonstrate an open architecture that links modeling and simulation tools

within the IPPD environment to support iterative product and process design. The architecture will link the ATD environment to both the synthetic battlefield and the industrial base, providing the missing electronic linkages noted in Chapter 2. Standards will be adhered to in linking modeling and simulation tools and facilities that will be applied in Thrust 1-5 ATDs. Broad use of the infrastructure developed in Thrust 1-5 ATDs will validate its effectiveness and accelerate its transfer to DoD contractors.



**Figure I.2 Thrust 7 ATD To Demonstrate a Modeling and Simulation Infrastructure for IPPD**

## **RECOMMENDED EXPERIMENTS IN DUAL-USE-MANUFACTURING**

Three primary experiments are proposed to promote and understand dual-use manufacturing (Table I.2).

**Table 1.2. Experiments to Promote Dual-Use-Manufacturing**

Experiment	Benefits
<p><b>ADVANCED ELECTRONICS</b></p> <p>Implement coproduction of military and commercial devices/modules on single production line (GaAs MMIC, multi-chip module).</p>	<ul style="list-style-type: none"> <li>• Co-leverage technology lead.</li> <li>• Reduce cost 5 to 10x.</li> </ul>
<p><b>CONVENTIONAL ELECTRONICS</b></p> <p>Evaluate true performance/cost comparison of electronic sub-assemblies designed and produced by commercial processes and components as compared to the traditional military approach.</p>	<ul style="list-style-type: none"> <li>• Explore cost, schedule and performance implications of current military-specific acquisition.</li> </ul>
<p><b>SHIPBUILDING</b></p> <p>Transfer commercial state-of-the-art design and manufacturing practices to U.S. shipbuilders.</p>	<ul style="list-style-type: none"> <li>• Lower design and unit costs.</li> <li>• Increased flexibility/speed.</li> <li>• Upgrades U.S. industry.</li> </ul>

The Advanced Electronics experiment will identify either, or both, GaAs devices (military and commercial) or multi-chip modules (military and commercial) and will produce them on the same production line. Substantial engineering must be invested to ensure that the idiosyncrasies of the device can be accommodated on a shared line. Further, a modified cost accounting system will be needed to accurately trace each device's cost. The expectation is that military devices will enjoy the lower overhead costs and higher yields characteristic of commercial products. Additional savings should occur due to the high volumes of the combined runs.

The Conventional Electronics experiment is designed to (1) characterize the performance of commercial devices in the military environment; (2) characterize the performance of subassemblies built using commercial practices in a simulated military environment; and (3) quantify the benefits gained using commercial design rules and manufacturing processes in a major electronic subassembly. Following design and manufacture, the subassembly would be tested in the full military environment to ascertain performance limitations.

The Shipbuilding experiment is to implant best commercial practices into U.S. shipbuilding. The essence of the practice is to design and build modular, common, major components that can be constructed in a shore production facility instead of being hand-fitted on a floating ship. Three modules are proposed: (1) a reverse osmosis distilling

plant; (2) a sanitary unit; and (3) a ventilation fan room. These modules can be inserted easily into a floating hull, and should provide substantial cost savings from a manufacturing and a procurement standpoint. Additionally, replacement and modernization can be accomplished with enormous time savings. Modern design techniques, such as the use of CAD, will also be introduced.

## Advanced Electronics

### Flexible Gallium Arsenide Integrated Circuit Production

The first proposed experiment in the area of advanced electronics is flexible Gallium Arsenide (GaAs) integrated circuit (IC) production for dual-use-manufacturing. The problem is shown by the contrast between military and commercial needs (Table I.3) Two questions are raised:

1. Can military/space and commercial GaAs IC production coexist in the same factory?
2. How would leading edge military GaAs IC technology benefit the commercial sector? What are the return benefits to support military needs?

**Table I.3. Flexible GaAs IC Production for Dual Use—  
Military vs. Commercial Needs**

Military	Requires only low-volume GaAs ICs, but many different products at noncontinuous (sporadic) intervals. Needs state-of-the-art prototype chips and a 15- to 20-year life-cycle supply. Chip cost must be affordable (\$30 to \$100 per chip), but the total DoD-limited demand is insufficient to pay the cost of even one GaAs production line on a stand-alone basis. Furthermore, DoD specification practices, along with diversity of chip types, tend to drive up chip costs beyond range of affordability. Lack of volume and standardization will eventually cause DoD needs to be of decreasing interest and priority to GaAs chip manufacturers.
Commercial	Requires high volume GaAs ICs at very low unit cost for a small number of products. Needs state-of-the-art prototypes and early volume production with preplanned improvements and cost reductions over a short 3- to 6-year life cycle. Needs increasing volume as market grows 20 percent a year.

Additional contrasts between the military and commercial requirements and production practices are shown in Table I.4.

**Table I.4. Military vs. Commercial GaAs IC Contrast**

	Military		Commercial	
<b>Requirements (1995)</b>				
• Volume (chips/month)	Low	$\leq 10^5$	High	$> 10^7$
• Market growth (%/year)	None	0	High	20%
• Chip cost (\$/chip)	Medium	30-100	Low	1-10
• Product life cycle (years)	Long	15-20	Short	3-6
• Degree of product customization (types)	High	Thousands	Low	Tenths
<b>Production Practices (1990)</b>				
• Continuity	High—build to inventory		Low—build to order	
• Flexible production line	Yes—but low volume only		Low—build to order	
• Packaging	Custom high cost packages		Standard low cost packages	
• Test	100%		Minimum sample test	
• Design to production cost	Performance considerations prevail		Real driver	

The approach for this experiment is to develop a large-scale flexible GaAs IC production line. A large-scale flexible GaAs IC production line has high potential for permitting military and commercial manufacturing to coexist, while simultaneously providing significant benefits to both sectors. Characteristics of a large-scale flexible line include the following (detailed in Table I.5):

- Multiple technology/process types which encompass most GaAs IC applications (except pure digital gate arrays): analog, microwave, millimeter wave, optical electronic integrated circuit (OEIC).
- Ability to produce any product mix combination upon demand, with no startup delays.
- High commonality among technology process types; no compromise in cost or performance.
- Ability to scale quickly from medium to large volume upon demand.
- Cost competitive in commercial market; simultaneously qualified for military applications.
- Rapid transition of new GaAs IC technology from military R&D to full scale production.
- Automated manufacturing and business-management systems to accommodate large product set for many diverse customers.

**Table I.5. Description of Large Scale Flexible GaAs IC Line**

Characteristic of Large-Scale Flexline	Description
1. Multiple processes for broad GaAs IC applications—military, commercial	<ul style="list-style-type: none"> <li>• MESFET, HEMT, HBT, OEIC processes</li> <li>• 0.1 to 100 GHz; 1 mm<sup>2</sup> to 200 mm<sup>2</sup> chip size</li> <li>• Small signal, power, mixed function, ADC</li> </ul>
2. Arbitrary product mix	<ul style="list-style-type: none"> <li>• 1 to 95% range per process type</li> <li>• Rapid change of product mix (1-4 weeks)</li> </ul>
3. Maximum manufacturing commonality	<ul style="list-style-type: none"> <li>• 70% or greater common processes, equipment</li> <li>• SPC based on common processes</li> <li>• As constructed, commonality without performance or cost compromise</li> </ul>
4. Medium to large volume capacity flexibility	<ul style="list-style-type: none"> <li>• Capacity dynamic range 20:1</li> <li>• 50 to 1000 wafers/week</li> <li>• 100,000 to 20 million chips per year—value to \$100M</li> </ul>
5. Simultaneous commercial/military competitiveness	<ul style="list-style-type: none"> <li>• 50 to 90% output to commercial</li> <li>• Meets intent for military environments</li> </ul>
6. Rapid technology transition	<ul style="list-style-type: none"> <li>• 10 months LRIP, 24 months full scale</li> </ul>
7. Automation for production and diverse market base	<ul style="list-style-type: none"> <li>• GaAs wafer cost → silicon wafer cost</li> <li>• Customer set ≥ 1000 worldwide.</li> </ul>

The benefits to the military of such an experiment include the following:

- Assured U.S.-based supply of GaAs ICs for next 20 years.
- Reduced IC cost by 3x to 5x.
- Outlet for DoD R&D which significantly benefits U.S. competitiveness in worldwide electronic markets.

The benefits for the commercial sector are:

- Technology push from DoD activities will drive commercial products.
- Retain early (current) lead in millimeter-microwave integrated circuit (MMIC) products as worldwide market emerges.
- Multiplier effect on OEM related products x 100.

This experiment is summarized in Table I.6.

**Table I.6. Proposed Experiment for Flexible GaAs IC Production**

<b>DESCRIPTION</b> Demonstration of an extremely flexible manufacturing approach for GaAs chips that encompasses most military and commercial applications. Flexline must achieve high process commonality for broad product sets without compromising performance, cost or quality, achieve rapid response to product mix and production rate, and achieve rapid transition to market of new DoD technology. Must lead the way to overcome very high cost military specifications and practices for IC assembly, test, and qualification.
<b>BENEFIT</b> Provides effective solution to assured supply of military GaAs ICs for next 20 years at 5x reduced cost. Military GaAs technology will have a rapid response commercial outlet and benefit U.S. worldwide competitiveness in electronics market. Permits DoD to be a strong but shrinking customer in a rapidly growing critical industrial base area.

### **Multi-Chip Modules**

The second area under advanced electronics is that of multi-chip modules (MCMs). The proposed experiment is shown in Table I.7, and a proposed vision and plan for the late 1990s are described below.

**Table I.7. Proposed Experiment for Multi-Chip Modules**

<b>DESCRIPTION</b> Silicon integrated circuit performance is currently limited by the effects of conventional packaging and interconnect technology. Multi-chip modules (MCM) offer reduced volume and improved performance over conventional PWBs. This program would expedite the development of the MCM industry with first emphasis on development of a robust commercial market.
<b>BENEFIT</b> MCM cost will fall dramatically with the appearance of strong commercial demand. Military applications of MCMs will access greater performance, lower volume, at an affordable price based on a strong commercial market.

### **FUTURE VISION**

The following vision represents what might be reported in 1997 as a result of experiments that DoD could start now: *In 1997, the domestic multi-chip integration industry will record its highest rate of annual sales growth yet reported. Estimated at \$4 billion annually, the U.S. MCM industry is largely a result of the comprehensive development plan funded initially by Congress in the 1993 fiscal year budget. The demand for multi-chip modules has increased at an annual rate of 30 percent for the last 3 years, with U.S. MCM technology widely acknowledged as responsible for returning a positive balance of trade to the U.S. semiconductor industry. Applications of MCMs became*

widespread in the workstations beginning in 1994 and expanded to include most major electronic products in 1996. The early introduction of MCM technology is viewed by most observers as the key element responsible for the dominant worldwide market share enjoyed by Sun Microsystems and Hewlett-Packard.

The success of the U.S. MCM industry is largely the result of an unprecedented federal program initiated in 1993. In the spring of 1992, more than a dozen firms from the then fledgling MCM industry approached Congress with the potential of multi-chip integration to revolutionize the world of electronics. In 1993, Congress appropriated \$170 million to begin a 3-year intensive effort to rapidly develop U.S. MCM capability. At the beginning of the 3-year program, the U.S. industry had developed slowly with little coordination to develop supplier and equipment infrastructure commensurate with the needs of the handful of MCM foundries that were planned. Potential users of the MCM technology knew well the potential MCMs offered, but design tools were virtually nonexistent, and most electronic equipment manufacturers were reluctant to adopt this immature technology.

Beginning in 1993, however, with the initial Congressional appropriation, DARPA coordinated a comprehensive plan to simultaneously develop supplier infrastructure, foundry capability to produce MCMs in volume at a competitive price, and user acceptance. DARPA, working closely with the newly formed MCM industry association, provided funding to industry in four broad categories. A number of tasks that were of significant benefit to the MCM industry as a whole were identified and funded as process-independent infrastructure developments. As a result of this activity, industry standards for testing methods, packaging, and industry specifications for known good die were adopted in 1994. This 24-month effort was awarded to an industry consortium after a competitive process in which four teams proposed comprehensive standardization programs.

Also beginning in 1993, DARPA funded 4 industry foundry teams to develop the supplier base and design tools to support their specific MCM technology approach. CAD/CAE tools were developed to support each foundry and were widely distributed to industry in preparation for the third element of the development program. Foundry and infrastructure teams provided investment in capital equipment, facilities, and training in order to meet the volume and price requirements of the user community.

The third and most crucial phase of the program funded initial application of MCMs in a wide variety of electronic products. In this program, DARPA solicited candidate industry products for MCM insertion. Selected product insertions received government

*funding for 50 percent of the nonrecurring engineering, on a cost shared basis. Insertion programs were funded in super computers, workstations, automotive, telecommunications, and military computers. This 50/50 cost share program for MCM insertions is widely acknowledged as the most successful effort of its type to date, and is credited with paving the way for the widespread acceptance of MCM today.*

*in a fourth element of the government effort, university research was accelerated to develop advanced second generation MCM techniques including three-dimensional packaging, diamond substrates, and advanced memory packaging. Additional efforts have also resulted this year in the emergence of the first silicon integrated circuits designed exclusively for use in multi-chip module applications.*

*Government funding, which continued through the 1995 fiscal year budget, totaled \$500 million over the 3 years. Figures assembled by the MCM association for the same period indicate that industry investment in capital, facilities, research, and technology development exceeded \$1 billion. Figures recently published indicate that 275,000 jobs in the United States are currently directly supporting the MCM industry.*

*The rapid emergence of the U.S. MCM industry as the dominant world supplier has confounded analysts who predicted further erosion of the U.S. electronics industry with often-predicted Japanese dominance in MCMs. The government funding injected in the mid-1990s is widely credited with providing the cornerstone of an emerging national strategy to regain a dominant position in electronics. Many observers feel that early Japanese success in MCMs would have further undermined the U.S. position as a leading supplier of high technology commercial, industrial, medical, and defense electronics.*

## **Conventional Electronics**

The purpose of this experiment is to evaluate the possibility of using commercial components, assemblies, and practices in a military application by—

- Characterizing the performance of commercial components and assemblies in military environments.<sup>1</sup>
- Quantifying the benefits gained using commercial design rules and manufacturing process on a major subassembly.

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<sup>1</sup> Shock, vibration, humidity, reliability.

The anticipated benefits include:

- Potential ten-to-one cost savings, but some environmental restrictions.
- Demonstration of the possibility of dual-use-manufacturing production lines.
- Acquisition of hard data to promote deployment.

The proposed areas for this experiment (shown in Tables I.8 through I.10) include:

- Commercial IC Reliability.
- Commercial Javelin Guidance Electronics Unit (GEU).
- "Best commercial practice" Paveway electronics.

**Table I.8. Proposed Experiment for Commercial IC Reliability**

<b>DESCRIPTION</b> Conduct extensive data search on commercial IC reliability data. Use this data to select the environmental screening required and the potential expected failure modes to focus the system environmental screening.
<b>BENEFIT</b> Most semiconductor vendors have data available for commercial IC reliability. Based upon this extensive data, specific environmental tests can be developed to identify differences in commercial plastic and military ceramic IC reliability. With this data and subsequent system-level tests (experiment #2) on applicability, matrix for commercial plastic IC use in military systems can be developed.

**Table I.9. Proposed Experiment for Commercial Javelin GEU**

<b>DESCRIPTION</b> Design and build a Javelin guidance electronics unit (GEU) using parts and processes of "best commercial practice." Evaluate against a MIL-STD GEU for performance, reliability, and potential production price.
<b>BENEFIT</b> A "best commercial practice" GEU could offer significant cost and weight advantages. Actual performance differences can be estimated but design, fabrication, and thorough evaluation of three "commercial" GEUs would provide hard test data.

**Table I.10. Proposed Experiment for Best Commercial Practice Paveway Electronics**

<b>DESCRIPTION</b> This program would design, fabricate, and test a Paveway GCU built with commercial components and assembled and tested to commercial standards. The resulting units would be evaluated for performance and reliability against existing MIL-STD GCUs. Cost estimates, based on the commercial approach, will provide a benchmark against current cost of MIL-STD units.
<b>BENEFIT</b> Commercial practices and components offer substantial cost savings over current MIL-STD parts. Actual performance and reliability shortcomings are not well defined. Likewise, cost savings of commercial versus military are often quoted but seldom quantified by actual design and implementation of a system.

### **Shipbuilding**

Detail for the proposed experiment in employing reusable design elements in shipbuilding is shown in Table I.11.

**Table I.11. Proposed Experiment for Advanced Manufacturing Processes Transfer to Shipbuilding**

<b>DESCRIPTION</b> The proven commercial manufacturing process of employing reusable design elements that are common across product lines is transferred to Navy shipbuilding. This transfer is accomplished through: (1) standards development, (2) design, (3) construction, (4) testing, and (5) documentation (three-dimensional product model) of candidate modules.
<b>BENEFIT</b> Twofold: (1) Acquisition, support, and infrastructure cost savings. (2) Improve U.S. shipbuilding commercial viability. Specifically, the transfer of this proven manufacturing process should help shipbuilders move further toward rapid assembly of larger (and fewer) subassemblies, thus reducing construction time. The Navy's supply, maintenance, and training infrastructures can be reduced based on fewer components that are common across ship classes. The commercial viability of U.S. shipbuilding is improved primarily by the reduction in construction time, which reduces overhead costs and potentially improves the shipyard's ability to complete commercially. If successful in getting commercial work, overhead costs to the Navy will be further reduced.

## **Selection of Candidates for Advanced Manufacturing Processes Transfer**

To prove the claims for ship production benefits of modularized equipment and to develop design, production, and test techniques for Hull, Mechanical and Electrical (HM&E) modules, three specific module experiments are proposed:

- Auxiliary and habitability items usable on new construction ships (initially, amphibious and auxiliary ship classes).
- A Reverse Osmosis (RO) Distilling Unit, a Ventilation Machinery Unit (fan room).
- A Sanitary Unit (head).

These modules were selected from an initial list of candidate modules using multi-element criteria. Initially, the candidate modules were segregated based on ship architectural impacts into three categories: single-function stand-alone modules, single-function system modules, and multi-functional zone subassemblies. A candidate module was selected from each category based on consideration of what is feasible to accomplish in the 3 years allotted and the following criteria:

- Potential cost savings.
- Potential for accelerating construction schedule by taking advantage of parallel module construction.
- Potential throughput in planned future fleet construction.
- Labor content.
- Trade diversity involved.
- Learning curve advantages from quantity production.
- Testing required in stages 1 through 5 (material receipt to infrasystem testing).
- Complexity of the design.
- Secondary impacts on related ship systems.
- Past life cycle component failure rates [Navy Maintenance System (3-M) "Top 25"].
- Approved Parts List (APL) proliferation.

The initial list of candidate modules considered is shown in Table I.12.

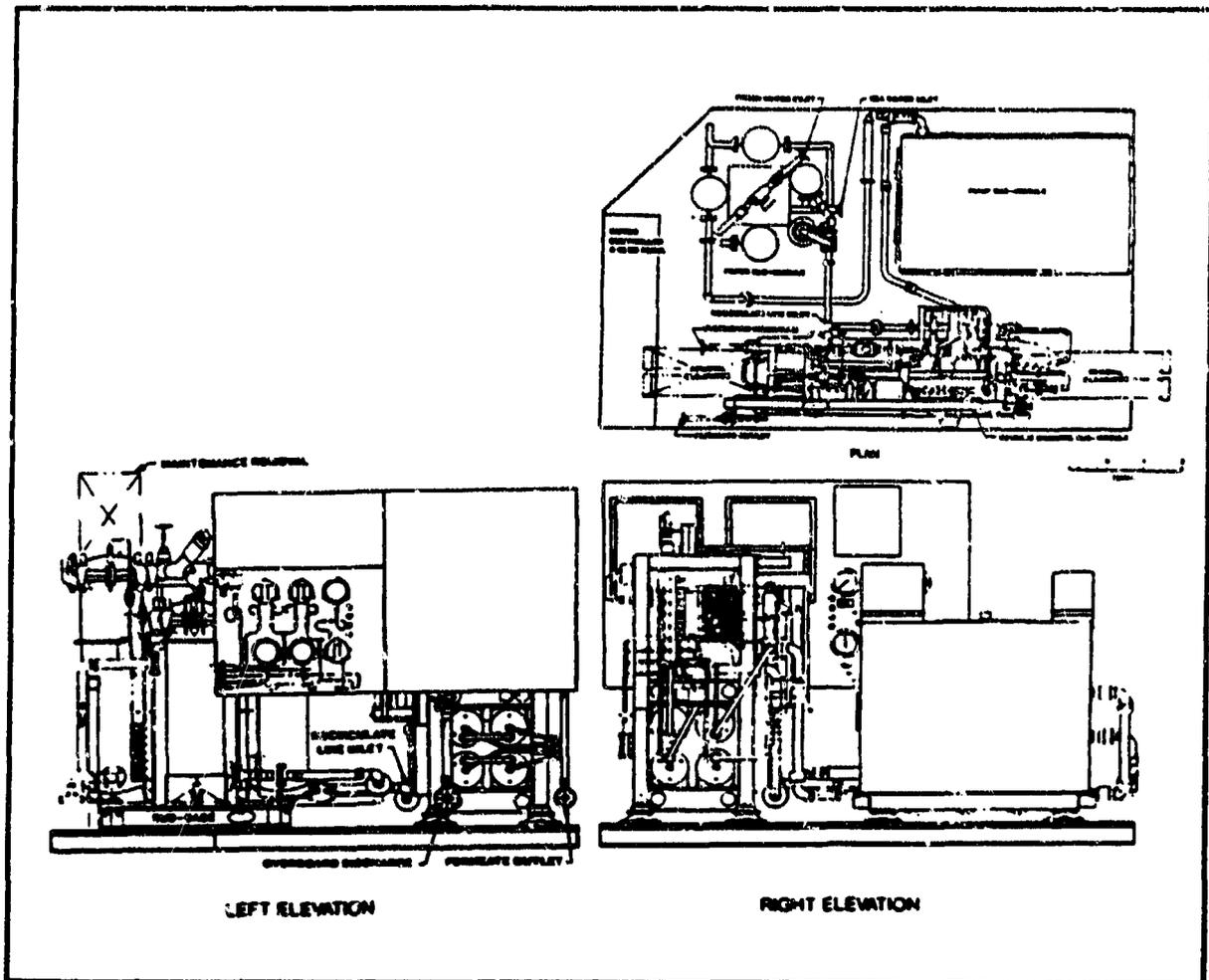
**Table I.12. Candidate Modules**

Diesel propulsion	Propulsion ancillaries
Electric power distribution	Waste processors
Centrifugal pumps	Firemain
Chilled water	Auxiliary sea water
Hydraulics	Compressed air
Winches	Ballast system
Food service (microwave galley)	Modular offices
Damage control lockers/stations	Decontamination station
Modular berthing (crew, troop, and officers)	Sanitary unit (head)
Modular service spaces (library, ship store, barber shop, etc.)	Reverse Osmosis Distilling Unit
Ventilation of Machinery Unit (HVAC, fan room, collective protection)	

**Description of Candidate Experiments for Advanced Manufacturing Processes Transfer**

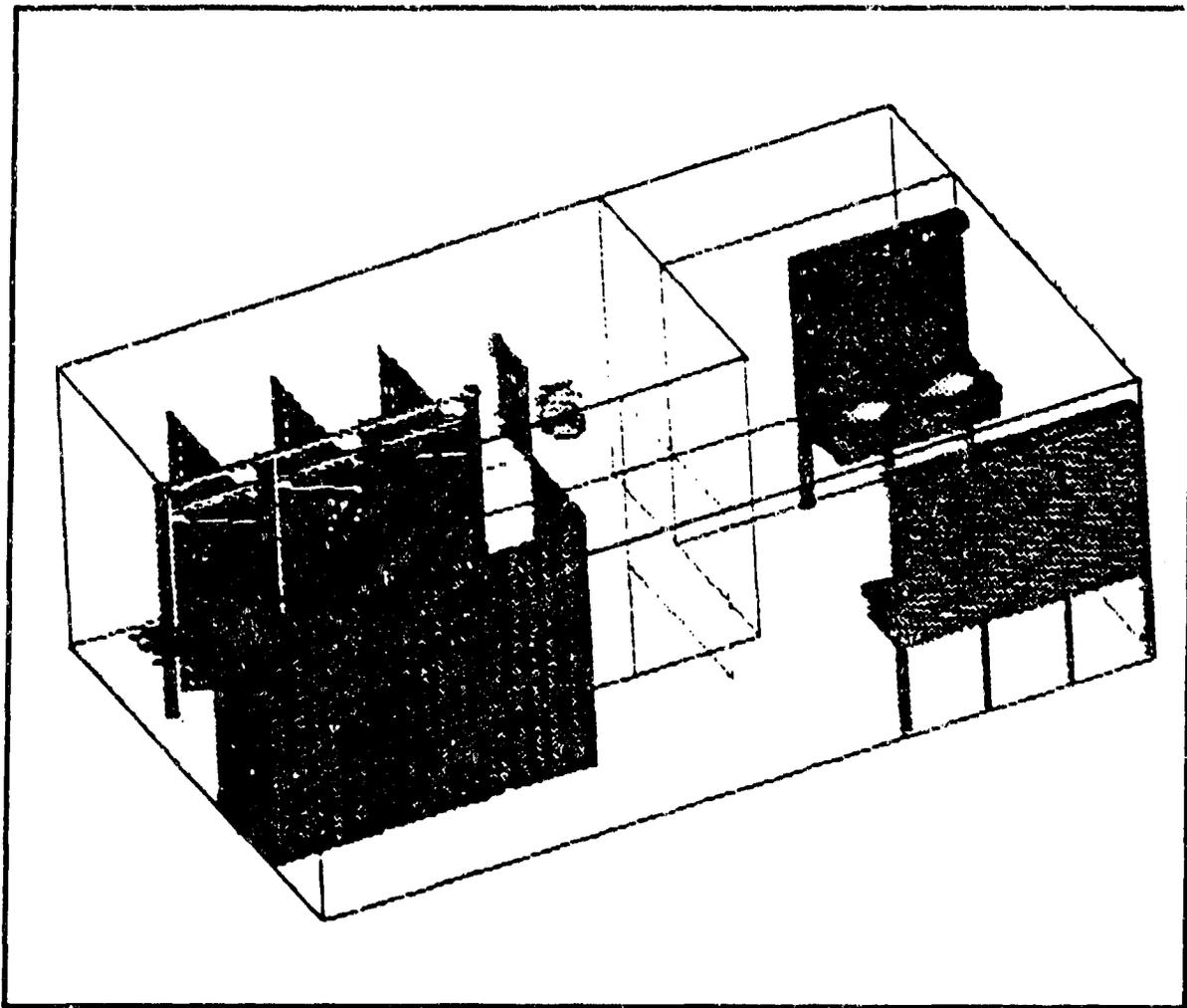
**Reverse Osmosis (RO) Distilling Unit (single function-stand-alone).**

The purpose of the RO unit is to turn sea water into potable water for shipboard use through the reverse osmosis desalination process. The unit will be developed around the new Navy standard level III drawings for a 12,000-gallon-per-day plant. Ancillary devices (pumps, motor controller, gage panel, filters) as well as internal piping will be packaged with the distiller to form the unit. This unit's selection is primarily based on its commonality across all ship classes and types, its labor intensity, its high reliability compared to existing units, and the desire to speed incorporation of the Navy standard design into the fleet. Figure I.3 provides a rough sketch of the unit's proposed configuration.



**Figure I.3. Reverse Osmosis Module Concept**

**Sanitary Unit (multi-functional zone subassembly).** This enclosed module will contain sinks, showers, urinals, and commodes and will be completely furnished, including mirrors and racks. All distributed systems [plumbing, electrical, heating, ventilation, and air conditioning (HVAC)] within the module will be completely outfitted in-shop. Early ideas envision a single location along the module's boundaries to serve as a connection point to all ship system services. Internally, the design will be geared toward using commercial marine furnishings and will emphasize accessibility to components for easy maintenance. This unit's selection is primarily based on its large proliferation on diverse ship types, its multi-trade labor intensity, and the knowledge that the majority of this type of outfitting is completed today onboard ship (vice on-block or in-shop). Figure I.4 provides an artist's impression of the unit's three-dimensional arrangement.



**Figure I.4. Sanitary Space Module Artist's Concept**

### **Approach for Advanced Manufacturing Processes Transfer Experiments**

For each of these critical experiments, the Naval Sea Systems Command (NAVSEA) will carry out a planning and preliminary engineering effort that will produce a bid package for the experimental prototype module that can be competed. The winning bidder will be awarded a contract for detail design and fabrication. In addition to the prototype hardware, the Navy will receive unlimited data rights and level III manufacturing drawings. The detail design and fabrication phase will be followed by stand-alone testing and finally by a trial shipboard installation.

The approach delineated by this plan will be applied to each of the three modules. Some specifics of the elements of the plan are discussed below.

**Task 1.0 Initial Engineering.** This is a planning and preparation task that will establish module capacity, rating, and size; define interface requirements with other HM&E systems; develop draft set of design requirements and initiate the acquisition planning process. This initial planning effort will incorporate a best assessment of the needs of future shipbuilding programs based on future fleet analyses that have been developed by the Affordability Through Commonality project.

**Task 2.0 Preliminary Designs.** This task will complete the technical input to the bid package for the prototype detail design and fabrication. It will include sufficient engineering studies to establish that the bid package represents a feasible concept and that it is sufficient to guide the bidders to produce the intended product without over constraining the bidder and thereby stifling innovation.

**Task 3.0 Bid Package.** This task will prepare the actual bid package and source selection plan.

**Task 4.0 Contract Award.** This task will support the activities required to award the detail design and fabrication contract.

**Task 5.0 Detail Design.** This task will be largely carried out by the winning bidder; however, a concurrent effort by NAVSEA will be required to manage the vendor effort and plan for the subsequent phases.

**Task 6.0 Fabrication.** This will consist of construction by the vendor of a prototype module, inspection and acceptance by NAVSEA, and preparation and delivery by the vendor of level III manufacturing drawings of the unit. NAVSEA will retain all data rights to this package to facilitate physical modifications to the module during the test and evaluation phase, and to allow future acquisition to be made on a competitive basis.

**Task 7.0 Test and Evaluation.** Testing will go on in two phases. The initial round will consist of stand-alone testing of the unit at a shoreside facility. Pending satisfactory results and rectification of any problems that arise, the unit will be installed on-board a test ship to assess functionality, durability, and maintainability in a shipboard environment. The products of this phase and the program will be reports documenting issues and lessons learned and defining the specific steps required to bring the unit into volume production.

**Funding Requirements for Advanced Manufacturing Processes  
Transfer Experiments**

Total funding requirements for the proposed experiments to develop three prototype modules and thereby a module development methodology were shown in Table 3.11.

**Management Responsibility for Advanced Manufacturing Process  
Transfer Experiments**

The Ship Technology Development Group of the Naval Sea Systems Command (SEA 05R) will manage the Advanced Manufacturing Process Transfer experiments in conjunction with its startup Affordability Through Commonality project. A team leader, nucleus team, and site are already available for commencement in FY 1993.