NISTIR 7003

Semiconductor Industry IT Needs:

Lessons Learned from Across the Engineering Chain

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INTRODUCTION

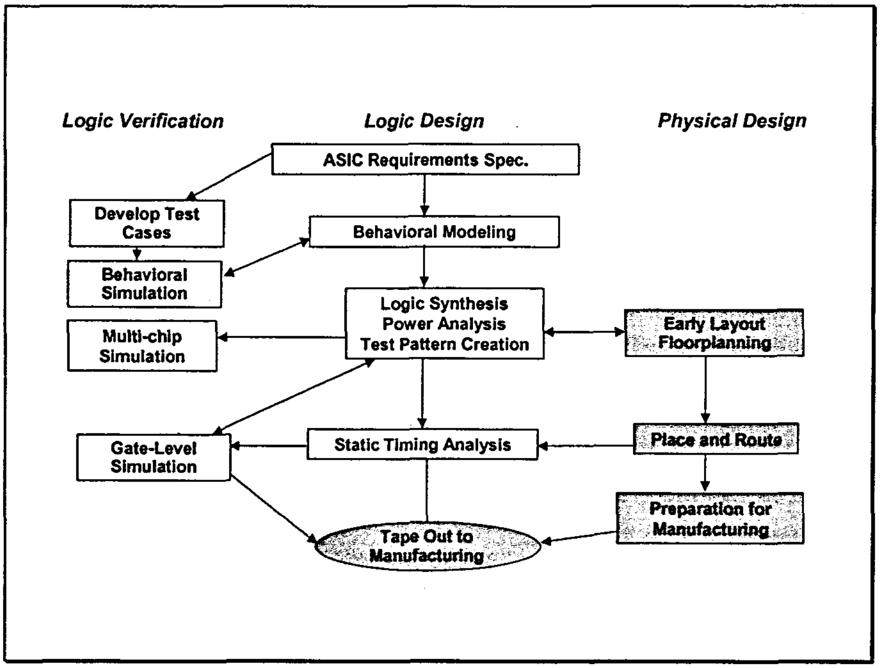
This paper presents information gathered during a series of site visits conducted by National Institute of Standards and Technology (NIST) staff between December 2001 and July 2002. A total of six companies were visited, including:

- Four Integrated Device Manufacturers (IDMs)
- One Photomask Supplier
- One Design Firm

The purpose of the site visits was to understand the impact of competitive and economic pressures on current IT practice in the semiconductor industry, to identify industry IT standardization needs, and to contribute this assessment as guidance for federal research investments and as input to industry roadmap efforts.

Note that all information provided reflects the practices, opinions and perspective of the experts from the companies visited, and as such do not reflect their entire company's viewpoint nor the viewpoint of the industry in general.

DESIGN

DESIGN	
Current Landscape	**General Design Stages (as provided by site visit host):**  **Design Handoff to Fab / Foundry:** • "Tape out" to manufacturing is typically accomplished through transferring data in GDS II format – a de facto standard for graphical design data used to describe mask geometry. • Fabs validate GDS II files against a Design Rule Checking (DRC) deck to correlate fab capabilities and manufacturing requirements of the design. Fabs may also perform Electrical Rule Checking (ERC), and validation of the physical design against the netlist. • Test data may also be exchanged if the fab is expected to run test as well.

Issues	• **Concurrent Design:** There's a need to merge logical and physical design with intelligent early floorplanning.
	• **Physical Limitations:** The physical limitations of nature are more prevalent as linewidths decrease in size.
	• **Design Complexity:** has led to large files that are cumbersome and time-consuming to process. This could be helped by hierarchical rather than flat file formats.
	• **Best of Breed Capability:** Due to inadequate standards available for translating between software tools, designers find it hard to mix and match preferred software applications and thus settle for tools that "fit the flow".
	• **Limited Intellectual Property (IP) Core Exchanges:**
	  • Due to security concerns over IP protection, cores are distributed as object code instead of source code, rendering them harder to integrate and adapt.
	  • Compiled VHDL models of virtual components are tool-specific.

DESIGN	
Future Vision	• **Effortless Mapping:** Ability to easily map internal design specifications to manufacturing specifications. • **Routing:** Ability to easily maintain routing requirements throughout the design and manufacturing process flow. • **Best of Breed:** Ability for designers to use mutli-vendor, best of breed software tools. • **Minimal Feedback Loops:** in the design flow.

Standards Needs	• **Standards for Design Constraints:** A consistent mechanism is needed for specifying design constraints between different vendor tools.
	  • Timing constraints: are becoming more significant as linewidths decrease, and are required for both logical design (synthesis) and timing-driven physical design.
	  • Power
	  • Noise
	  • Clock Domain Definitions
	• **Standards for Test:** Needed standards include those for test requirements, results and limitations of tester.
	• **Foundry Ground Rules:** A standard mechanism is needed for foundries to describe their capabilities / ground rules for designers to work from.
	  • Same words may have different meanings, for example:
	    • Gate length – could refer to as-drawn or as-manufactured.
	    • Channel Length – could refer to electrical or physical.
	• **Supply Chain Coordination:** Mechanism is needed for mapping customer specifications to designer specifications.
	• **Plug and Play Design Standards:** are needed to enable interoperability between multi-vendor, best of breed design tools.
	• **Pattern Stimulus Standard:** is needed to support logic simulation and hardware test.
	• **Floorplanning Standard:** Companies would like a standard way to exchange early floorplanning of design blocks, to better coordinate early placement decisions.

MASK MANUFACTURER

Mask Manufacturer	
Current Landscape	• **High Mask Costs:** Current generation chips can require up to 40 masks, which could cost well over $1M and contribute $10 per chip to the cost of production. • **Global Consolidation of the Photomask Industry:** Some foundries offer their own photomask services, and because they can bundle mask production into broader service contracts, they contribute significant downward pressure on mask prices. Independent photomask firms are at a disadvantage and are pressured to merge either horizontally, with other mask shops, or vertically, either with a foundry or a supplier of Electronic Design Automation (EDA) tools or equipment. • **Competitive Landscape:** Mask production volume is Application Specific Integrated Circuit (ASIC)-driven. The majority of ASIC production is moving to foundries, and since some of foundries also supply masks, this move is exacerbating the difficult business climate for independent mask producers. • **High Cost of Lithography Equipment:** The cost of next generation lithography tools is discouraging IC manufacturers from upgrading their equipment.
Issues	• **Supply Chain Communication:** Communication and information gaps between design, photomask production and IC fabrication lead to inefficient resource utilization. Full supply chain resource planning is needed for effective manufacturing. Data is the most valuable raw material, and data interchange methods are inefficient and error prone. • **Over-Constrained Designs:** Designers and manufacturers, independently factoring in safety tolerances, are providing over-constrained photomask specifications to their mask supplier. • **Mismatch Between Technology and Design:** Masks reflect the designer's assumptions about the equipment that will eventually be used in production. The equipment actually used in production may not be the same generation for which the mask was designed. Such gaps between design goals and process capability exist even within single companies. • **Mask Complexity:** Manufacturers are finding it too expensive to migrate to the next generation of lithography tools, and are compensating for the limitations of their current tool set by designing greater complexity—and thus cost—into the mask set. • **Data Volume:** Data volume is increasing, driven by lithography limitations and increasing design complexity. A single mask can require *55 gigabytes of data, an hour to transfer, and days to process*. Aggressive optical proximity correction (OPC) dramatically adds to data volume. File size is going up to *terabytes*; at this rate mask transfer could become the "killer app". • **Broken Business Model:** The photomask production business model is unsustainable. Independent mask producers aren't earning their cost of capital while at the same time R&D costs are increasing. Market forces, such as competition from foundries, cap product prices.

Future Vision	• **Single Day Turnaround Time:** for high-end masks (as opposed to the current manufacturing time of 4 days.) • **Evolving Business Models:** *Vertical* and *horizontal* mergers can help formerly independent mask shops meet new technology and business demands. • **Integrated Supply Chains:** foster greater innovation and more time/cost efficient production. Better integration of foundries and designers with photomask providers will enable total integration from design data to ship. • **Improved Process Control:** may help mask producers meet the demands and constraints of their customers. • **Communication IT Infrastructure:** The use of the Internet for global supply chain collaboration and communication will remain key.
IT Standards Needs	• **Updated Mask Data Interchange Format:** The commonly used standard is 20 years old. A new standard is needed to preserve both *hierarchy* and *data integrity*. • **Data Exchange Standards:** Standards are needed that keep file size to a minimum and are efficient to process. • **e-Diagnostics:** may enhance the ability to predict equipment maintenance and service. Cross-enterprise system connections for e-manufacturing, e-diagnostics and data exchange require agreed-upon standards and security protocols.

IC Manufacturer

IC Manufacturer	
Current Landscape	• **Data Complexity:** Advances in IC technology have dramatically increased the amount and complexity of data that is exchanged during the chip manufacturing process. Chip speed has increased and size has shrunk while at the same time functionality has been expanded through the development of system on a chip (SoC) technology. • **300mm Manufacturing:** The shift towards 300mm manufacturing is driving the need for advanced automation capabilities, such as: automated material handling, advanced process control, wafer-level and eventually die-level tracking, remote access to suppliers, equipment self-monitoring, and spare parts management. Efficient automation tools will be mandatory to achieve cost-effective volume production. • **e-Business:** Companies are implementing e-manufacturing in a variety of ways, with varying levels of sophistication. MES systems, some based on SEMI's Computer Integrated Manufacturing (CIM) Framework, are used to coordinate various aspects of the e-manufacturing system in the fab. IT communications infrastructure also varies among companies. Some use a publish/subscribe paradigm by having the MES broadcast information to other IT software components on the fab floor using a message bus, while others are using point-to-point communications, which requires a messaging layer. Companies have begun to see a need for improvements in the communication protocol between software and tools, and are evaluating a transition from the SECS/GEM protocol to a newer, more web-based protocol. • **Process Control:** Chip manufacturers in general have implemented effective process control based on either in-house or commercial tools, but without the benefit of broadly adopted standards. Some companies have been able to use best of breed tools via their own company interface specification. Commercial tools are typically integrated using custom built interfaces. • **e-Diagnostics Still In Its Infancy:** Current e-Diagnostics systems are typically "home grown", although some commercial implementations have sprung up. Fab managers are waiting for the industry to address the security and data ownership issues before pursuing full-scale implementation. • **Increase in Outsourcing:** In the current climate in which companies increasingly depend on outsourcing, mergers and joint ventures, the ability to communicate among disparate IT systems is more critical than ever. With independent device makers (IDMs) focusing on niche products and the rise in the number of fabless companies, the industry has become increasingly reliant on foundries. Some manufacturers off-load their cheaper logic to foundries and avoid sharing their process technology, while others are entering high-risk partnerships where even their "crown jewels" of process and system technology are shared in order to optimize manufacturing yield. Sharing of process and design knowledge may lead to ambiguities in data ownership, as it is difficult to prevent a partner from using the knowledge as a competitor in the future. • **Limited Commercial Supply Chain Management Tools:** Most companies develop custom solutions. While some manufacturers are able to track resource, demand, and availability, the data is often not automatically available to systems on the fab floor to optimize production volumes, or easily accessible by manufacturing partners' systems.

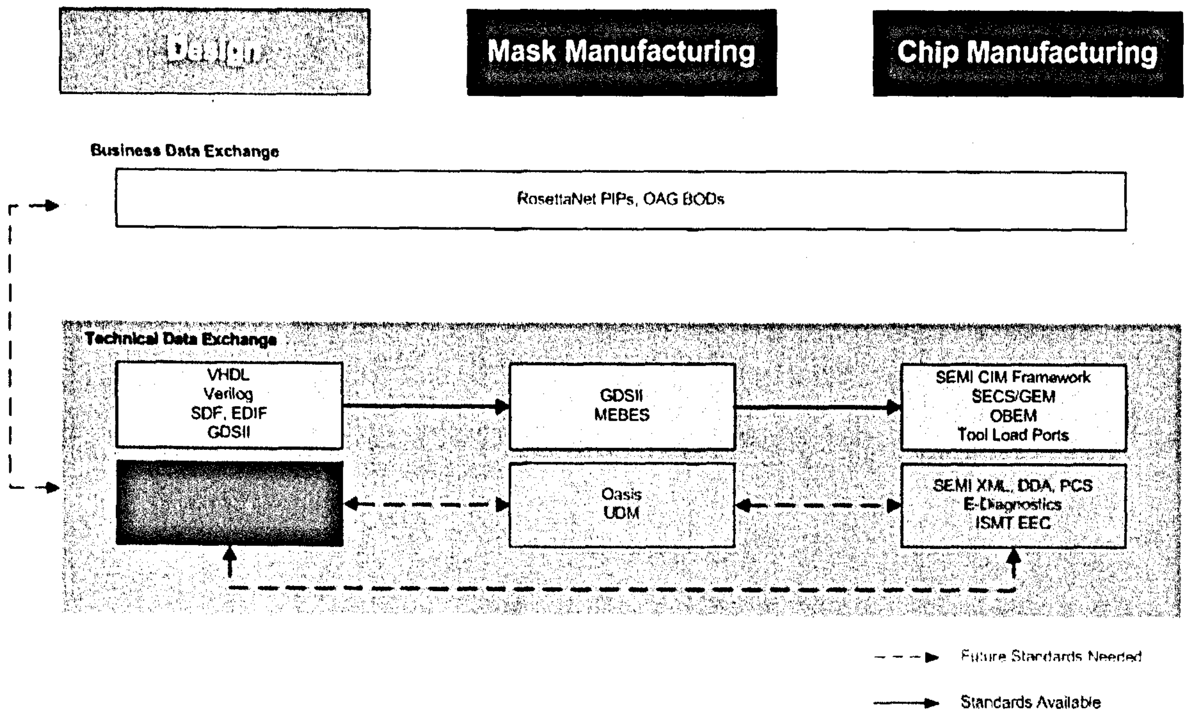
Issues	• **IT Integration:** The integration of software within a fab and between manufacturing partners has become increasingly complex. Global acquisitions and multiple technology environments give rise to heterogeneous software environments. Some companies have spent as much as ninety percent of their IT resources on software integration, leaving a mere ten percent to build IT-based competitive advantage. Furthermore, to enable the use of best-of-breed software, many companies have developed their own "standard" interfaces for tool integration, which are inflexible and costly to maintain. • **Data Integrity:** Data exchange is futile without data integrity. Key aspects of data integrity include traceability, precision, security, and accuracy. *Traceability* is the ability to determine the source and track the path of the data acquired, which is useful for accountability and tracking down the source of a problem. *Precision* refers to the number of decimal places, which often varies among disparate systems. *Security* would ensure the data is not readily obtained, viewed, or corrupted by outside agents. *Accuracy* is needed to ensure the data being obtained are the data that were queried for. Accuracy may be in question, for example, when fabrication equipment queues up requests for data before responding, and thus may be providing data unsynchronized with the request. • **Data Accessibility:** refers to getting the right data to the right place at the right time to make good business decisions. Manufacturers feel they lack the capabilities to perform sufficient revenue and customer support scenarios. *Modeling scenarios* could provide some foresight as to which product mix and fab schedule would yield the best revenue streams. The ability to make intelligent decisions on what product to manufacture is a more critical supply chain issue than inventory control, and would require market visibility throughout the distribution channel and inventory visibility from supply chain partners. In addition *better integration* of enterprise level and manufacturing level information systems would be needed. Intellectual property concerns, such as the release of yield data from foundries, lead to restricted sharing of supply chain data. • **Data Protection:** Greater reliance on outsourcing and partnerships potentially exposes companies to new risks. In joint ventures, design, photomask, and process technologies are swapped among participating companies. It is difficult to ensure that shared data won't be used in the future by partners-turned-competitors. Manufacturers, for example, are pushing tools to their limits and would like to protect their equipment usage information, which many consider more sensitive even than recipes, from other companies including their equipment providers. Protecting this type of information works against the potential benefits of e-Diagnostics. • **Technology Synchronization:** Even within an IC Manufacturer, design engineers and manufacturing engineers experience difficulty aligning the design window with the process window. Designers often base their work on the current tool set, which can evolve to newer technologies by the time fabrication starts. Taking steps to promote effective communication among designers, mask manufacturers, and chip manufacturers would ensure the final end product would utilize the available technology to the fullest capacity. • **Wafer Level Control:** Equipment needs to be adjustable between wafers, not runs, in order to salvage more wafers and increase yield. • **Die-Level Tracking:** offers improved security and tighter control, but contributes substantially to IT overhead and data volume. • **Single Wafer Lots:** increase the volume of production data 25x, and, especially where wafers can move between Front Opening Unified Pods (FOUPs), increase the complexity of that data. Single wafer tracking forces a re-engineering of all production software applications. • **Non-Product Wafers (Monitor, Test):** still need to be scheduled, planned, tracked and delivered. The rising cost of fabs has lead to production facilities serving double

	duty as research facilities. Equipment reconfigured for R&D wafers must be reset for production – a task that is far from trivial. Test wafers, just as production wafers, need to be cleaned and re-characterized. Much more data is generated from test than production wafers. Some manufacturers claim to have a *2:1 non-product: product ratio* in their fabs. • **Workflow Automation:** needs to be augmented to realize its promise of minimizing the number of manual processes, and to better automate exception handling. • **Design for Manufacturability:** Engineers may be over-constraining their designs due to lack of communication with both mask manufacturers and chip manufacturers. Clearer communication concerning required tolerances could reduce both time to market and production costs. • **Troubleshooting and Exception Handling Capabilities:** IT systems are not currently robust enough to automatically detect and fix errors without requiring human intervention to re-route lots after a system has been down. • **Pervasive Computing:** The use of wireless networks and equipment offer tremendous maintenance benefits within a clean room, but some manufacturers are concerned about their potential interference with sensitive equipment. The industry would benefit from an open discussion concerning implementation practices and results. • **Material Handling:** is evolving to accommodate lots going directly to tools rather than stockers, but supporting software lags behind the implementation need. • **Inadequate Software Capabilities:** Process technology has outpaced software suppliers, and commercial tools are lagging world-class practices. • **Sweet Spots:** Knowledge of optimal equipment settings tends to be non-documented. Hundreds, sometimes thousands, of parameters must be monitored; all of which have a tendency to drift. The ability for equipment to be automatically adjusted to maintain their "sweet spot" could potentially increase yield and reduce production time.
Future Vision	• **Pervasive (or Ubiquitous) Computing:** would combine the current technologies of wireless, voice recognition, Internet, and software intelligence to create a network of devices where the connections are always available and unobtrusive. • **Fully Automated Fab:** with complete integration of *Material Control System (MCS), AMHS Software, Recipe management, APC and agent-based scheduling* to update dispatch schedule at meaningful transaction points. The fab would require full deployment of e-Diagnostics where equipments could be monitored and controlled remotely for troubleshooting and self-repair. A minimal amount of human intervention would be required in such an environment. • **Revenue/Customer Support Scenario Generation Capabilities:** for better demand planning. This requires greater *market visibility* and communication among ERP systems, fab tools, and supply chain partners' IT systems. • **"Wafer Jeopardy":** rather than "lot jeopardy" to minimize risks involved in manufacturing. Production flaws would be quickly detected and fixed. • **Tool Monitoring Vs. Wafer Monitoring:** to minimize impact on wafer cycle time of equipment problems. • **Plug and Play Integration:** of best of breed software with fab equipment, making the time to deploy new software negligible.

IT Standards Needs	• **e-Diagnostics Features and Data Standardization:** would provide the ability to:
	  • Characterize tool performance/behavior based on historical data.
	  • Develop equipment signatures and characterize behavior with events and alarms.
	  • Gather diagnostics remotely while protecting proprietary and sensitive data.
	• **Equipment Standards:**
	  • SECS/GEM needs to be updated to accommodate new tools and process technologies, and/or to be more web-compatible.
	  • An equipment/software standard infrastructure, such as the CIM Framework, is needed.

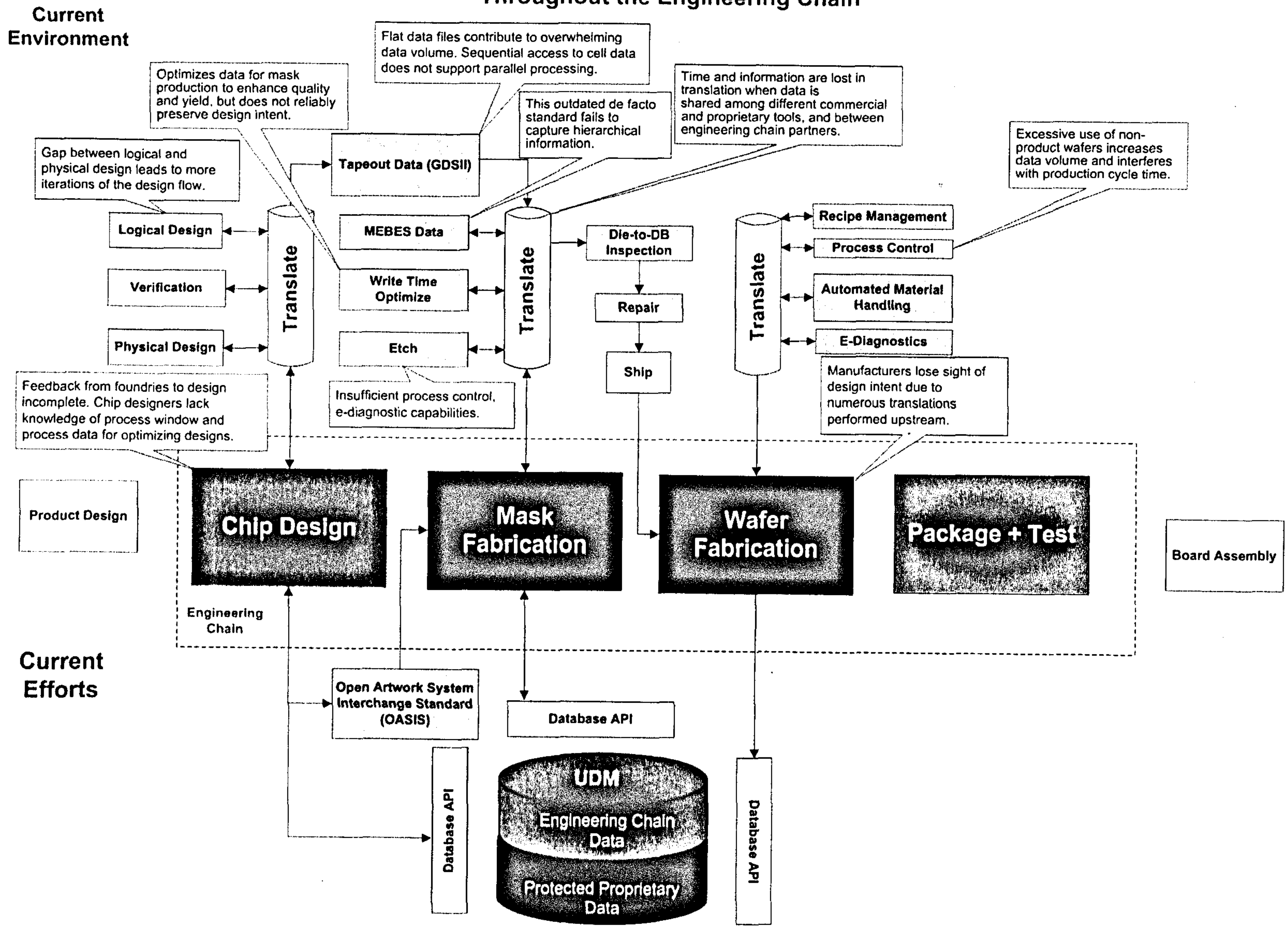
	• **Human Interface:** Most companies are currently using a browser based approach. • **Engineering Chain/Supply Chain Standards:** are needed for better data visibility throughout the supply chain and distribution channel. Technical data exchange standards are also needed for process and mask definitions as well as back-end data. Standards for database access would promote information visibility throughout the engineering chain. Software compliance to industry standards must occur for the benefits of standards to be realized. • **Data Integrity:** The capability to guarantee data quality is needed for effective data exchange. There is a need to synchronize requests and responses to data queries.

Appendix A: IT Standards Background

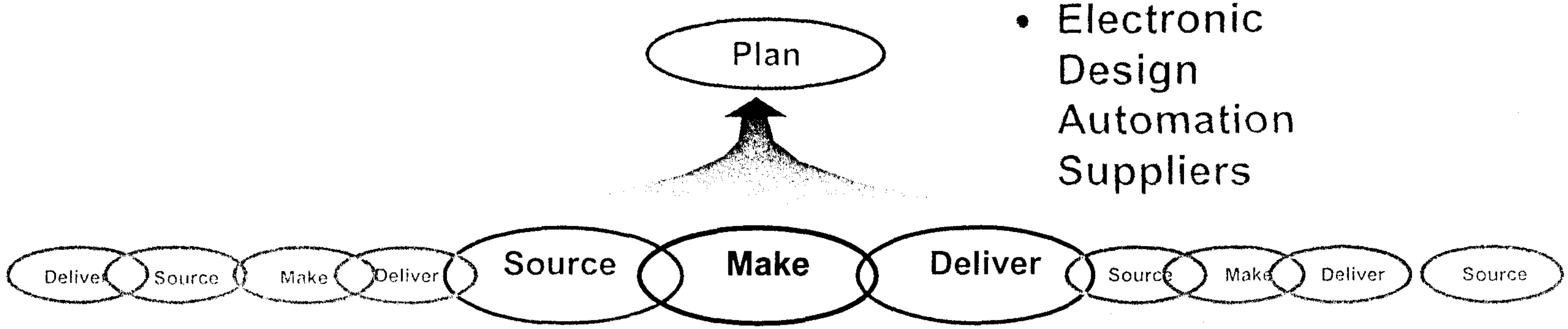


Appendix B: Opportunities for Improvements

Opportunities for Improvement in Cost of Ownership and Cycle Time Throughout the Engineering Chain



Appendix C: Semiconductor Supply Chain



- Design Foundries
- Electronic Design Automation Suppliers

- Substrate Manufacturers
- Chemical & Gas Suppliers
- Equipment Suppliers
- Foundries
- Photomask
- Assembly & Packaging
- Semiconductor Manufacturing Services
- Automation/Software

Semiconductor Manufacturers
- **Integrated Device Manufacturers**
- **Fabless Device Manufacturers**

- Distributors
- Electronics Manufacturing Services

Based on the Supply Chain Council's Supply-Chain Operations Reference-Model (http://www.supply-chain.org/)