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INFORMATION INFRASTRUCTURES FOR INTEGRATED ENTERPRISES

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May 1993

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PREFACE

This document was prepared by the Institute for Defense Analyses (IDA) under the Advanced Research Projects Agency (ARPA) Assignment A-160, DARPA Engineering and Manufacturing, and fulfills an objective of the task, "to assist DARPA in planning its approach to engineering and manufacturing process technology." The work was originally sponsored by the Computer-Aided Acquisition and Logistics Support Directorate of the Office of the Assistant Secretary of Defense (Production & Logistics) in cooperation with the U.S. Air Force Manufacturing Technology Directorate and the Software and Intelligent Systems Technology Office of ARPA, under Task Order T-B5-849, Defense Industrial Information Infrastructures.

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SUMMARY

The Department of Defense (DoD), as a large, complex set of enterprises, as a purchaser of complex systems, and as a partner with industry in the development of those systems, stands to gain a great deal from the efficiencies and effectiveness of more integrated activities. There is an opportunity for both industry and government to explore the approaches and issues within enterprise integration and industrial information infrastructures and to accelerate solutions.

The DoD tasked the Institute for Defense Analyses (IDA) to assess industry efforts establishing and using information infrastructures to help integrate activities in enterprises. Specifically, IDA was to determine why companies are investing in integration, what progress leading companies are making, what the key issues are and their implications for DoD, what progress relevant cooperative and standardization efforts are making, and what a vision of the future in the year 2001 might be. The intent of this report is to act as a starting point for an open discussion of rationales, approaches, and issues. A set of recommendations for DoD action is proposed for discussion.

Enterprise Integration

The basic idea of integration is to increase the interaction among the various actors (people and machines) in previously separate processes. Concurrent engineering is an example of process integration. Previously separate product and process engineering activities, characterized by sequential execution and batched, "over-the-wall" information flows, are being increasingly integrated into processes with intensely interactive information flows. The resulting integrated product and process engineering yields significant quality, cost, and schedule improvements. An effective and efficient information flow is recognized as an important factor in establishing integrated activities. Applying integration to processes throughout the value-chain, across functional organizations and company boundaries, yields enterprise integration. The set of capabilities aggregated to support the required integrated information flow is the industrial information infrastructure. All 22 companies studied for this report are attempting to create or use information infrastructures to support integration in various ways and to various degrees.

Industrial Results

Companies reported significant improvements realized from integration of activities supported by information systems. Most of these improvements fall into categories of cost reduction or avoidance, cycle time reductions, quality improvements, and capacity increases (see Table S-1). The division of results into these categories is somewhat artificial since most improvements can be thought of as belonging in more than one category. For example, most of the reported quality improvements resulted in significant cost savings or avoidance.

Table S-1. Improvements by Business Function

	COST	CYCLE	QUALITY
Enterprise Integration and Streamlining (Overall)	SATURN: 20% across the board savings (est.). DEC: 30% ROI from CIM. CROSS AND TRECKER: 30% return on new integrated system. PRATT AND WHITNEY: reduction in bid savings $10M in one area and $20M in another. MARTIN MARIETTA: reduction of work force by over 40% while business increased by 3%.	NEXT: product shipped in 11 months, 5 months before competitors. MOTOROLA: cellular product cycle reduced 50%. NATIONAL SEMICONDUCTOR: time to market reduced from 2 years to 9 months in some cases.	
Engineering and Design	DEC: 90% reduction in design data admin staff; 83% reduction in design data coordinators.	MOTOROLA: 50% reduction in design cycle for products using ASICs MARTIN MARIETTA: reduced board development iterations from 2.5 to 1.5.	DEC reduced release version errors to zero MARTIN MARIETTA reduced from 4 changes per drawing to [illegible] TI reduced mask version release errors from [illegible] to [illegible] ($800,000 savings/yr.)
Test and Mock-ups	MARTIN MARIETTA: reduction from 2,100 hours to 900 hours engineering time for mock-up.	FORD: on track with reduction of physical models by 90%.	NORTHROP integrated CAD led to error-free mock-up of many [illegible] components
Manufacturing Engineering, process planning, tool design	TI: 90% reduction in order entry labor for mask. MARTIN MARIETTA: reduction of 10 tool designers to 4	MOTOROLA: time to bring up complex pager manufacturing line reduced by order of magnitude, based on integrated, reusable software	
Operations including materials management	FORD: 10-15% reduction in sheet metal operations. SATURN: work in process reduced from 5 days to 30 minutes. DEC: reduced assembly line work force from 250 to 70 workers. GM: increase of fraction of inventory in use to 98%.	MOTOROLA: 5-week to 1 week reduction in PCB supply and assembly cycle FORD: reduction of sheet metal manufacturing time by [illegible]% with improved quality	

Table S-1. Improvements by Business Function (Continued)

	COST	CYCLE	QUALITY
Business Operations		[illegible]	
Information Systems Design/Implementation	[illegible]		
Data Generation and Delivery		[illegible]	

[illegible]

Significant benefits attributed to integration supported by information systems included the following:

- Large-scale, [illegible] cost avoidance as high as 20% (hundreds of millions of dollars per year) compared with typical North American practice in the given sector.
- [illegible] reductions in administrative and data management labor in certain engineering processes.
- [illegible] reductions in time-to-market.
- Orders of magnitude improvements in particular key processes such as design distribution ([illegible] weeks to [illegible] hours), establishing a new electronics manufacturing line (order of magnitude reduction), provisioning list release (6 months to 1 hour), and order entry ([illegible]% reduction).
- Quality improvements such as first-time-fit rates (started at 5%, went to 50%, now at [illegible]%), error-free mock-ups, and 55% decreased drawing changes.
- Manufacturing labor productivity improvements as high as a factor of 15 to 20 compared with competing companies (in sales per manufacturing touch-labor

hour[2]), increases in fraction of inventory actually in use (was 5%, now 95%), and similar decreases in work in progress.

In general, integrated activities in the design and production of complex products, when supported by a relatively integrated information infrastructure, have proved to result in higher quality processes, designs, and products.

Significant process improvements are reported in the ability to manage change, making the enterprise more agile. Changes range from large and broad (introduction of a new product or abrupt changes in demand for an existing product) to focused (introduction of a design change to a product already in full-scale production). Some people regard this agility as the most important underlying reason for investing in information infrastructures for enterprise integration.

Why Information-Based Integration Works

The fundamental reason that information-based integration works is fairly simple. Previously, computers have been used to centralize information, logically if not physically, about such organizational data as payrolls and bank accounts. Errors are prevented and processes accelerated to a great extent because logically centralized information can be coordinated. Enterprise integration extends the application of this concept to the product life cycle. Consider all the information about a product—its design, the engineering analyses, the design intent, the parts codes, costs, maintenance data—and the processes that surround the product—assembly modeling, process planning, manufacturing process description, simulation, purchase scheduling, logistics planning. Now consider the discipline required to coordinate all that information among a large number of people, especially where the information is distributed and on paper. Integrating the information on computer systems causes a new level of discipline in coordinating the myriad of information related to the products of the enterprise.

Making the information easier to coordinate, in turn, relieves the enterprise from using a divide-and-conquer solution for control of its activities. That means the people who execute the activities can work together and coordinate their thinking rather than being artificially separated for the purpose of controlling the information they produce.

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2 "Sales per manufacturing touch-labor hour" is a measure of manufacturing productivity. It is calculated as the total sales volume in monetary terms (e.g., dollars) divided by the total number of person-hours required to produce the products being sold. Person-hours count only those people who directly interact during manufacturing with the product, its components, or with the machines that process the product.

All this is borne out in the cases described in the report and its appendices. For example, if a centralized, three-dimensional computer model of a product exists, it is relatively easy to plan part assemblies in the same model. It is hard to miss that two parts will not fit or that they will interfere. The discipline required for this kind of coordination of effort is fundamentally different—quicker, less costly, and less error-prone—from mylar drawings and paper assembly plans having to be mated to create a product.

The activities of product design, manufacturing, and assembly can be coordinated to a much greater degree because of the ability to integrate information flow. Large numbers of people can work together to reach a common goal. These people can be in separate but cooperating companies to the extent that cross-company, integrated information infrastructures have been put in place.

DoD Interests

DoD has three roles connected with enterprise integration and information infrastructures:

- As a customer for enterprise integration and infrastructures for its own internal systems and processes, for example, acquisition, logistics, financial planning, and management.
- As a partner with industry in weapon development and procurement and thereby a member of an inter-organizational team with a need for streamlined processes.
- As a customer concerned with the effectiveness of its contractors in teaming to produce affordable weapons systems in a timely fashion.

In these roles, the DoD is a customer for systems and tools that enable streamlining and change management and which are effective in a multi-enterprise environment. The DoD, as a customer for information and systems, can help focus government-industry requirements in order to create focused market pull.

The DoD needs to be a part of a larger process of developing information infrastructure capabilities for enterprise integration along with commercial industry. Declining budgets dictate as cost efficient an approach as possible. Defense requirements for enterprise integration are not so unique that they drive the DoD to a unique infrastructure solution. The advantages to be gained by the ability to acquire capabilities from a responsive open market are considerable. Conversely, DoD can accelerate the formation of the market in ways that are appropriate: technology push, technology and practice demonstration, requirements pull, and standardization assistance.

Principal Findings

Extent of enterprise integration. Companies are making significant commitments and executing large efforts toward enterprise integration. Significant results are being achieved, and companies now realize that achieving more is feasible.

Justification for enterprise integration. Justifications reported for investing in enterprise integration tended to be intuitive, expressed in terms of competitive necessity and a sense of potential quality improvement and cost reduction, rather than traditional cost-benefit analysis.

Incremental approach. Most of the companies studied are implementing an incremental "continents of integration" strategy to support integration goals. Factors dictating this strategy include a general lack of experience and scientific knowledge relevant to integration, the need to include legacy systems, and the existing organizational environment.

Current culture, infrastructure as barriers. Corporate culture and current infrastructure are widely perceived as the dominant barriers to progress in enterprise integration. The companies visited want more integrated infrastructure both because the current infrastructure is viewed as a barrier to integrated activities and because an integrated infrastructure would facilitate the information sharing on which integrated activities depend.

Roles of management sponsor. Several companies reported that a high-level sponsor is critical for success in enterprise integration. The sponsor can act to resolve impasses between groups and smooth management liaison between the project management level and the sponsor's level. The sponsor tended to be the meeting point of the chains of command above the groups to be integrated. Only very strong, consistent, and visible top leadership can overcome cultural barriers of the sort commonly encountered.

Change management a critical problem. Management of change and the required evolvability of information infrastructures are critical problems for all companies studied. Most implementers regard coming to grips with change management as a key goal of information integration. They require system solutions that are designed and implemented to facilitate change in the infrastructure itself.

Role of standards. None of the companies studied is waiting for the development of appropriate standards. While recognizing the benefits for enterprise integration of widely accepted standards, all are proceeding with enterprise integration using available products and technology, developing company-unique solutions where needed. Companies that are infrastructure buyers expressed a widespread desire for appropriate standards. In most cases, infrastructure vendors would prefer having widely accepted standards.

Lack of scientific knowledge and accepted engineering practice. While increasingly complex integrated systems are being implemented, the understanding of scientific and engineering issues inherent in such systems is generally weak. This understanding can be increased through continued industrial efforts such as those reported in this study, through demonstrations of new approaches in realistic settings, through academic, government and industrial research, and through development of new integration technology.

Principal Conclusions

Organizational limitations of current approaches. The commonly used incremental "continents of integration" approach does not provide for evolvability, thereby incurring higher costs to take the next steps in integration. Mechanisms for sharing integration experience and for identifying common successes and failures are lacking. Methods for overcoming cultural barriers to integration that are successful for intra-organization integration, the dominant mode to date, do not transfer easily to inter-organization integration.

Technical limitations of current approaches. Lack of standards represented in available products leads to locally unique solutions to integration problems, which later become obstacles to further integration, to be worked around or converted at additional cost. Formal standards will become more important as inter-organization integration becomes the dominant mode. Lack of an accepted framework or reference model for information infrastructures makes identifying holes and overlaps in standards coverage extremely difficult.

Enterprise integration and the DoD. In many senses the DoD is the prototypical enterprise, with multiple suppliers, numerous customer programs, highly technical and information-flow dependent products and processes, people and operations physically located throughout the world, and a complex internal organization. The DoD has much more difficult hurdles to overcome in achieving successful integration than most enterprises, and has commensurate potential for realizing benefits in quality, cost reduction, and responsiveness.

Recommendations - Strategy

Some Defense contractors have begun to re-engineer business processes and the information systems that support them. The key ingredients exist: technologies to start the process, approaches to eliminate barriers, and a favorable government climate for infrastructure investment. DoD and the Services can accelerate industrial implementation of the required processes and systems through four strategies: (1) exerting leadership through the use of the National Information Infrastructure (NII) initiative and joint rapid-response task forces from government and industry; (2) acting as an informed customer of informed suppliers; (3) forming partnerships with industry to support and accelerate *de facto* and emerging formal standards for information systems interfaces and elements; and (4) demonstrating and advancing technologies, thereby mitigating the risk in developing high-risk elements needed for large-scale, dynamic, and rapid integration. The results of the fourth strategy would be to advance the state of the art, provide performance results as benchmarks for industry, and accelerate technology transition into the information management marketplace.

In response to these strategies, two types of implementations should be applied, usually simultaneously, to projects started in response to any specific recommendation:

- With *incremental implementations*, the DoD and each industrial enterprise should focus first on part of the process that the enterprise executes and then expand. Incremental implementations are feasible and desirable if long-term *evolvability* is kept as a critical requirement. For example, focusing on integrated product/process development (IPPD) would be appropriate if planned for future expansion into other enterprise processes such as logistics, manufacturing operations, and strategic planning.
- With *application-driven implementations*, the DoD should focus on product-type-specific processes first and then generalize. Implementation strategies should be application driven. Past efforts have shown that generic approaches to concepts such as IPPD are seen as too abstract and having limited success.

Specific Recommendations

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1. Defense Leadership

1.1 The Advanced Research Projects Agency (ARPA) should establish a focus area for industrial information integration within the National Information Infrastructure (NII) initiative.

The NII initiative can enable ARPA to prototype and demonstrate the capabilities required to address the compelling national issue of industrial efficiency and effectiveness. Instead of using application areas simply to motivate underlying technologies, ARPA should pay considerable attention to the exploitation of the infrastructure by industrial users interested in leading to new ways of doing business. These new industrial uses of the NII will simultaneously stress the underlying assumptions of the prototype networking services and help U.S. industry understand how to use the new capabilities to maximum advantage for international competitiveness. The result will be a better and more immediately useful NII and a more efficient U.S. industrial base for both Defense and civil purposes.

1.2 DoD and the Services, working with industry, should establish a consensus vision of enterprise integration and set an example of integration within their own acquisition processes.

DoD and Service acquisition and technology organizations should stress the priority of integrated enterprises and integrated information systems to both government and industry. To make this credible, DoD and the Services should work with industry to set goals, objectives, and characteristics of integrated enterprises, and then establish a phased program to both re-engineer government acquisition processes and integrate supporting information systems. This would create a model for industry and provide processes and systems to which industry can link. Repeated evidence from leading companies indicates that sustained commitment by the Office of the Secretary of Defense and Service acquisition and technology executives will be required for these efforts. Current efforts being initiated within the Office of the Undersecretary of Defense for Acquisition can provide a basis for responding to this recommendation.

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2. Informed Customers and Suppliers

2.1 DoD and the Services should integrate deliverables within both acquisition and technology programs, creating incentives to motivate industrial process and information system integration.

The separate functional or "stovepipe" requirements currently typical for contractual deliverables act as inhibitors to industry information system and process integration, and would inhibit Defense use of well-integrated civilian industrial capabilities. In support of process integration efforts, the efforts started by the DoD Computer-Aided Acquisition and Logistics Support (CALS) program to define integrated weapons system data bases and Contractor Integrated Technical Information Services should be accelerated to replace current separate CDRLs (Contract Data Requirements Lists) for separate functional areas. Furthermore, the development of industrial integrated information systems should be an evaluation factor in source selections and an explicitly allowable cost for internal research and development (R&D) and implementation phases.

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3. Partnerships

3.1 DoD technology organizations, cooperating with other interested federal agencies, together with leading industrial firms, should establish partnerships to develop information infrastructures to support integrated industrial activities.

Here the objectives would be to share experience on implementation approaches, metrics, test and validation, and, where appropriate, to share the risk in technology developments. The government appears willing to support pre-competitive industrial cooperation to implement industrial information infrastructures. These partnerships should be as free as possible of federal acquisition constraints so as to enable the participation of firms that do not normally contract with the government. The partnerships should be built within Advanced Technology Demonstrations (ATDs) and the Manufacturing Science and Technology (MS&T) pilot programs, or similar programs, executed in settings grounded by real applications. DoD should evaluate leading company-specific infrastructure implementations for potential DoD-wide application and should then support generic information infrastructure technology developments by vendors so as to accelerate availability of vendor-supported products. The goal would be to shorten lead times, from feasibility demonstration to commercial availability of infrastructure-enabling products, based on *de facto* and appropriate formal standards, from an estimated 8 to 15 years at present to 2 to 3 years.

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4. Technology Demonstrations and Development

4.1 DoD acquisition and technology organizations should implement programs that demonstrate innovative concepts and information systems for enterprise integration.

DoD should plan for ATDs and pilot programs in the following areas: (1) metrics and benchmarks (measures of effectiveness for enterprise processes); (2) single and multiple company integration (for example, demonstrations of single firms and teams of firms in IPPD environments); (3) small business integration (addressing infrastructure and integration issues at the small business level); (4) network services and distributed products (assessing the potential effectiveness of network services in accelerating multi-enterprise integration); and (5) NII manufacturing services and interfaces (developing and demonstrating a family of services and interfaces to support manufacturing applications of the proposed NII).

4.2 The Director, Defense Research and Engineering (DDR&E), ARPA, and Service technology organizations should implement an aggressive technology strategy to develop DoD industrial information infrastructures and to accelerate emerging threshold technologies.

DoD, in concert with leading companies, should formulate an R&D strategy, incremental and evolutionary, to create a new generation of enterprise architectures, models, tools, and software systems, and to determine the potential for new business operations, engineering practices, and manufacturing concepts. Efforts should be focused on the following: (1) operational frameworks, demonstrating multi-layer operational frameworks for tool and information integration; (2) product/process representations, implemented in product-specific, multi-phase programs with a coordinating mechanism established by ARPA to derive and feed back generic technical and architectural approaches for use in later phases; (3) advanced services, where some integration applications might best be executed as services on an easily accessible network; (4) legacy database integration, developing near-term solutions such as semi-automatic wrapper generation as well as exploratory demonstrations of mid- and long-term solutions such as mediation and easy-to-tailor artificially intelligent agents; and (5) persistent object brokerage, extending to wide-area applications so that wide-area enterprises can be more easily integrated.

4.3 DoD technology organizations should take advantage of existing programs and industry cooperative efforts where appropriate.

Several programs exist with potential to evolve industrial information infrastructures for integration. The topic of information infrastructures is expected to be a significant part of the Technology Reinvestment Project (TRP). Selection and management of TRP programs should follow the overall strategy outlined here. Because of the high leverage of infrastructure to U.S. design and manufacturing, the follow-on to the current TRP should include a focused dual-use infrastructure program supported jointly by ARPA, Departments of Commerce and Energy, the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF). The Thrust 7 infrastructure program (along with the Agile Manufacturing Program) could provide the national technology lead.

Where applicable, planners, developers, and demonstrators should use forward-thinking, existing and emerging industry cooperative efforts to accomplish required industry liaison. This implies an understanding of the mechanisms and interests of various types of groups such as technology cooperatives (e.g., the CAD Framework Initiative (CFI)), industry-government cooperatives (e.g,. the CALS Industry Steering Group), and formal standardization mechanisms (e.g., ESPRIT AMICE consortium, the Object Management Group, the ISO STEP committees, and the sector-specific Automotive Industry Action Group).

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GUIDE TO THE REPORT

Section 1 introduces enterprise integration and industrial information infrastructure. It summarizes the DoD task directing this study, with pointers to particular issue discussions. It highlights progress being reported in enterprise integration. The section ends with a discussion of DoD interests in the subject.

Section 2 discusses the current state of industrial enterprise integration as captured in visits to 22 leading companies in the electronics, automotive, and aerospace sectors. It begins by presenting the enterprise integration context of information infrastructures, including definitions, objectives, and critical factors, followed by a synthesized case study reflecting current best practice. It discusses reported benefits and pitfalls of integration. It next discusses the DoD's role in enterprise integration and related issues. It surveys issues in the engineering of integrated information systems. The section ends with a brief discussion of how enterprise integration and information infrastructures are related to concurrent engineering, computer-integrated manufacturing, integrated computer-aided design, and flexible manufacturing.

Section 3 presents a vision of future industrial enterprise integration suggested by the findings of this study. The vision is presented from two perspectives: first, in terms of the effect of information infrastructures in the year 2001, and second, in terms of the technological developments that have permitted that effect.

Section 4 is a summary of IDA Document D-1386, *Current Standardization and Cooperative Efforts Related to Industrial Information Infrastructures*, which contains an extensive baseline analysis of standards, technologies, cooperative efforts, and related organizations. The standards and technologies are grouped into technical categories, and are related to the organizations and programs in terms of deployment activities required for successful technology development and market building. A quality function deployment analysis is used to identify which standards and technologies are most critical to successful implementation of information infrastructures, and to assess the maturity of these efforts. The objectives of the baseline report are to identify, organize, and present available technology components from which a U.S. information integration strategy can be coalesced and to identify specific opportunities to accelerate the development and adoption of components and/or to increase their likelihood of success.

Section 5 presents the principal findings and conclusions of the study. General findings are given in more detail in Appendix A.

Section 6 puts forth recommendations for the DoD.

Appendix A contains general findings and issues. Appendices B, C, and D contain sector-specific business rationales for integration for electronics, automotive, and aerospace, respectively. Appendix E contains individual company reports.

1. INTRODUCTION

1.1 BACKGROUND

Recent events have caused a reevaluation of defense acquisition strategies. New strategies will be based on the need to merge the defense and civil industrial bases, the requirement for rapid insertion of new technologies into weapons systems, and the need to form teams rapidly to design and produce affordable defense systems that can be transitioned quickly into production. This study provides evidence of the efficacy of supporting integrated industrial activities by the application of integrated information management systems. The industrial results are presented mostly in terms of cost, quality, and schedule benefits reported on specific product or product line developments and manufacturing.

Because infrastructure for integration is insufficient, current applications are found largely in *ad hoc*, closed, or common systems approaches that are designed individually by each company or defense contracting team. While such approaches are driven by the business requirements for efficient, effective, fast product development and delivery within each given company, they do not fulfill the need for a rapid response to new developments requiring dynamic, multi-company, multi-tier efforts on various scales. To meet the goal of rapid, dynamic integrated product team formation, whenever, wherever, and on whatever scale needed, the Department of Defense (DoD) must help create enough infrastructure on a national scale to allow rapid integration of information management systems and the processes they support.

It turns out that some of what civilian industry needs for international competitiveness is similar to DoD requirements. Civilian industry also needs to react quickly to customer demands, to insert technology as soon as it is applicable, and to field products rapidly. Leading companies recognize that to reach these objectives, they must be able to form multi-company integrated product teams rapidly and enable them to share information and processes quickly and dynamically.

Previous arguments that the DoD should base its infrastructure developments on commercial efforts have been based entirely on efficiency considerations. Now civil-military integration requires that the DoD cooperate with commercial industry to create industrial information infrastructures that will support both post-Cold War defense acquisition requirements and U.S. industrial competitiveness goals. This study, based on cases from commercial and defense industries, provides evidence that integrated infrastructures yield significant benefits, identifies key issues, and makes recommendations on how to start implementation. The report does not deal with details of acquisition policy and practice even though changes to these might be desirable in order to accelerate integration.

Enterprise Integration

Leading U.S. commercial and defense industries have recognized enterprise integration as a key ingredient in their efforts to be more responsive to the marketplace for engineered and manufactured products. In their aggressive pursuit of quality, cost, and schedule goals, companies are striving to deliver more effective products in a more efficient way, into an even more sophisticated marketplace. New organizational patterns are being explored, new engineering and manufacturing methods are being implemented, new relationships with vendors are being established. All of these changes are happening within an environment of dramatic economic, geopolitical, and technological change. These changes in turn have made the DoD rethink its defense acquisition goals and strategies as well as to take advantage of opportunities created by new technologies.[1]

Enterprise integration is a critical strategy companies have been adopting to reach their quality, cost, and schedule goals. Although the details vary from company to company, the basic idea is to increase the interaction among the various actors (people and machines) in previously separate engineering or manufacturing processes. Previously separate product and process engineering activities, characterized by sequential execution and batched, "over the wall" information flow, are being increasingly integrated. The result yields significant quality, cost, and schedule improvements.[2] Other examples of integration include the integration of

- Supplier people and information into the design process
- Production scheduling with the customer ordering process

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1 *The NCAT Strategy—Key Technologies for the Year 2000*, National Center for Advanced Technologies, Washington, D.C., 1991.

2 Winner, R., et al., *The Role of Concurrent Engineering in Weapons System Acquisition*, IDA Report R-338, Institute for Defense Analyses, Alexandria, VA, 1988; "A Smarter Way to Manufacture," *Business Week*, April 30, 1990, pp. 110-117.

- Management information systems with engineering and manufacturing systems
- Defense maintenance and logistics systems with contractor technical information bases
- Defense customer requirements definition with contractor conceptual engineering[3]

In all the companies studied for this report, information flow is recognized as an important factor in achieving integrated activities. Expert opinion points to the company of the near future as an information-based enterprise. Drucker, for example, writes:

> In the factory of 1999, sectors and departments will have to think through what information they owe to whom and what information they need from whom. A good deal of this information will flow sideways and across department lines, not upstairs. The factory of 1999 will be an information network.[4]

All the companies studied for this report are attempting to create or use information infrastructures to support integration in various ways and to various degrees. They view the integration of information flows as an enabler of more integrated processes throughout the enterprise. This being the case, the question arises as to how the government, the DoD in particular as a buyer of complex manufactured goods, can benefit by getting involved.

DoD Interests

The DoD buys over $150 billion in goods and services each year. Many of the products bought and developed are among the most complex in the world. The development of a complex product can involve thousands of companies. Such products have long, complicated development processes involving a widely distributed population.

Complexity of Teaming Process

Drawing people together in a DoD program is more complicated than in a typical commercial situation. The teams that produce DoD systems and subsystems are not static across programs. Each contractor must be prepared to link to other companies in almost arbitrary combinations. Competitors in one program may be teammates in another. The requirement that one company adopt another's systems in order to integrate activities can-

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[3] The integration of requirements definition with conceptual engineering would be included in concurrent engineering as defined by IDA Report R-338 and most other sources.

[4] Drucker, P., "The Emerging Theory of Manufacturing," *Harvard Business Review*, May-June 1990, p. 99

es expense and delay for the DoD customer. But the rationale for integration is compelling. From the DoD point of view, the best solution would be common and conventional interfaces, allowing all systems to interoperate when required.

Complexity of Products

Besides the complexity of the teaming process, there is the complexity of the products. One reason the products are difficult to design and build is that they are required to push the state of technology.[5] To absorb new technologies faster, the DoD systems developments need a more flexible and adaptable design and manufacturing base than exists today. Integrating activities and information allows both the products being designed and the systems and processes used to design and manufacture the products to evolve.

DoD products are not only technically complex, they also require unusually high robustness. In the past, industry and government have depended on test and inspection to discard items that will not be robust enough in the field. Now we know that robustness can be achieved through the strategy of *problem avoiding*, implemented through integrated approaches such as concurrent engineering. To help resolve the complexity problem, every company visited in this study and in previous Institute for Defense Analyses (IDA) studies on concurrent engineering has concluded that computers can be used in a highly cost-effective manner to help implement a generalized integration strategy.

Adapting to New Environments

Another part of the robustness issue is the problem of adapting defense systems to new environments quickly. The speed in which making and inserting design changes into defense products has been shown to be critically important—such adaptations could completely determine the usefulness of systems within a future conflict. Such changes may have to be accomplished in days rather than months or years. Commercial industry has shown that integrated activities, based on integrated information infrastructures, provide the kind of leverage necessary to accomplish the required adaptability.

The DoD has a unique problem in planning the capacity required to manufacture the goods it buys. The vastness of the defense enterprise could lead to a situation where DoD is paying for a great deal of excess capacity while, at the same time, being unable to effect

5 The need to push technology is inherent in the defense doctrine of qualitative superiority. It is also a consequence of the current approval process for new systems which tends to emphasize dramatic improvement.

the required surge efficiently. Being able to develop, store, and deliver integrated product and process designs into a well-integrated, flexible manufacturing operation could have far-reaching implications for DoD capacity and surge strategies.

Intertwined with the capacity issue is the problem of affordability. As the government has to make hard political and economical decisions on which systems to continue, it will become more important that systems be developed in an environment that maximizes efficiency of development and production. Each system program will be required to address the internal efficiency of its processes. The overhead structure attributable to the fragmentation of effort[6] in government and industry can be addressed in terms of enterprise integration and the information infrastructure that supports it. (There are many other issues inside the affordability problem beyond the scope of this study.)

Beyond the issue of development and unit production costs, there is the life-cycle cost issue. DoD systems have unusual but not unique life spans. Costs that are magnified by a system's longer life span include, for example, the maintaining of the very large amounts of data required to repair, replace, reproduce, and evolve parts of the system. The DoD organizations, suppliers, and contractors involved in the sustaining the effectiveness of such a system form, in effect, a very large enterprise with many information linkages required. The efficiency of this kind of enterprise can be no greater than the efficiency of its information flow. With the existence of the CALS (Computer-Aided Acquisition and Logistic Support) initiative, the DoD recognizes that there are intra-government and government-industry linkages that require extensive, more integrated computer support. An important point is that this internal (to the DoD) information infrastructure must be connected to the industrial information infrastructures for maximum effectiveness. At the same time, government practices must be adopted to ensure that government access to industry data does not become intrusive and counter-productive.

1.2 OBJECTIVES OF THIS STUDY

IDA was tasked by the DoD to study information infrastructures for enterprise integration, focusing on several questions:

- Why companies are investing in integration?
- What progress leading companies are making?

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6 Fragmentation of effort leads not only to duplication of effort developing similar infrastructure elements, but also to duplication of effort among different enterprises to integrate the same processes using these infrastructure elements.

- What the key issues are and their implications for DoD?
- What progress relevant cooperative and standardization efforts are making?
- What is the vision of the future in the year 2001?

This report provides a non-technical description of the current state of information infrastructures for industrial enterprise integration and a vision of integration infrastructures in the year 2001. The focus of the study is the relationship between information infrastructure and the integration of industrial enterprises. This report concentrates on best practices within leading companies, the rationale for attempting integration, and open issues. The intent is to create focused discussion around the important issues and to help build a common understanding of the subject, thereby creating the groundwork on which an effective DoD strategy for enterprise integration can be based.

The information presented here is based on company visits, and provides the starting point for an industry-government dialogue. The end objective is to reach a consensus among interested governmental, industrial, and academic parties as to the nature of industrial information infrastructure issues and the potential for government and cooperative action. Comments on the document should be communicated directly to the authors.[7]

1.3 APPROACH AND SCOPE

The basic strategy of the IDA study team was twofold:

- To analyze, from the points of view of both industry and government, the support that well-integrated information infrastructures can give to achieving legitimate business goals.
- To relate this support to the major issues surrounding the creation of such infrastructures.

The IDA study team identified 22 leading U.S. companies in 3 industry sectors: electronics, automotive, and aerospace (see Table 1), concentrating on companies that have targeted integration as an important objective. The team visited these companies to find out what has been accomplished in integrating activities,[8] why the efforts were undertaken, and what is the potential utility of industrial information infrastructures. Two additional com-

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[7] Comments should be sent to Industrial Information Infrastructures Study, Institute for Defense Analyses/CSED, 1801 N. Beauregard Street, Alexandria, VA 22311.

[8] The focus of the study was on demonstrated integrated activities at leading-edge companies, rather than industry-wide practices.

panies interested in integration *per se* were also interviewed.[9] For the automotive sector, a panel of experts was convened to discuss trends and rationale. The results and issues discussed in this report are derived from assessments of those visits and review of the related literature.

The topic of information infrastructures for enterprise integration is new enough that its scope was open to discussion. Therefore, the study team had the opportunity to define the scope of the study as it explored current states of practice and trends in industry, government, and, to a lesser extent, the research world.

Industrial managers are beginning to understand the need for increasingly integrated activities. However, the relationship between business goals and technical information strategies has not been articulated in a widely accepted way. An early objective of the study has been to articulate the connection between goal and strategy, based on results and trends in leading industrial examples. Other objectives have been to identify the best of what has been accomplished and to understand why the efforts were undertaken.

The report is shaped by DoD interest in securing the full benefits of enterprise integration for the weapons acquisition process. The findings, conclusions, and recommendations are directed toward that interest.

1.4 INDUSTRIAL EXPERIENCE

The companies visited were selected for study in order to discover the best practices of industrial integration. The electronics, aerospace and automotive companies visited are listed in Table 1. These companies reported having made substantial commitments, both financial and cultural, to using information infrastructures, and they reported achieving significant results. The study team's assumption is that the applicability, of both the commitment found in these companies and the results they are getting, to broader DoD and U.S. industrial practices can be assessed by the reader.

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[9] The integration companies were Electronic Data Systems and Enterprise Integration Technologies. Several discussions with representatives of the Microelectronics and Computer Technologies Corporation (MCC) consortium were also held but are not explicitly reported in this document.

Table 1. Companies Studied

ELECTRONIC		
Digital Equipment Corporation	Motorola	Texas Instruments
Hughes	National Semiconductor	Westinghouse
IBM	NeXT Computers	
Intel	Tektronix	
AEROSPACE		
Allison	Lockheed	Northrop
GE Aircraft Engines	Martin Marietta	Pratt and Whitney
AUTOMOTIVE		
Cross and Trecker	General Motors	Ryobi
Ford	Modern Engineering	SATURN

Common Themes and Issues

The study found numerous common threads throughout industry and government discussions of enterprise integration and information infrastructure. These can be grouped into seven categories:

1. Scope of enterprise integration
   (example issue: using integrated information infrastructures to manage change)
2. Relationships among companies
   (example issue: integration with multiple customers in the absence of generic representation or product standards)
3. Relationships within companies
   (example issue: relationship between information infrastructure and achieving a dynamic and relatively lean management structure)
4. Roles and objectives of information infrastructures
   (example issue: approaches to dealing with legacy systems)
5. Architecture of integrated information infrastructures
   (example issue: benefits and pitfalls of the "continents of integration" strategy)

6. Role of standards in integrated information infrastructures
   (example issue: incorporating "evolvability" into standards)[10]

7. State of technical understanding of how to engineer integrated information systems
   (example issue: absence of widely accepted measures of progress).

Progress Reported

Companies visited in the study reported savings from information-system supported integration of activities in the form of cost reductions, cycle time reductions, and quality improvements. Some reported results are very broad: they refer to whole enterprises and are measured in very large units. Others are focused on small parts of the product realization process, with correspondingly smaller measures of success. In all cases, the companies reported that savings came from integration projects and initiatives in the sense described in this report. Some representative results are summarized in Table 2.

Table 2. Improvements by Business Function

	COST	CYCLE	QUALITY
Enterprise Integration and Streamlining (Overall)	SATURN: 20% across the board savings (est.). DEC: 30% ROI from CIM. CROSS AND TRECKER: 30% return on new integrated system. PRATT AND WHITNEY: reduction in bid savings $10M in one area and $20M in another. MARTIN MARIETTA: reduction of work force by over 40% while business increased by 3%.	NEXT: product shipped in 11 months, 5 months before competitors. MOTOROLA: cellular product cycle reduced 50%. NATIONAL SEMICONDUCTOR: time to market reduced from 2 years to 9 months in some cases.	
Engineering and Design	DEC: 90% reduction in design data admin staff; 83% reduction in design data coordinators.	MOTOROLA: 50% reduction in design cycle for products using ASICs. MARTIN MARIETTA: reduced board development iterations from 2.5 to 1.5.	DEC: reduced release version errors to zero. MARTIN MARIETTA: reduced from 4 changes per drawing to 2.2. TI: reduced mask version release errors from 6 to 0 ($600,000 savings/yr.).
Test and Mock-ups	MARTIN MARIETTA: reduction from 2,100 hours to 900 hours engineering time for mock-up.	FORD: on track with reduction of physical models by 90%.	NORTHROP: integrated CAD led to error-free mock-up of many B-2 sections.

[10] See IDA Document D-1386, *Current Standardization and Cooperative Efforts Related to Industrial Information Infrastructures.*

Table 2. Improvements by Business Function

	COST	CYCLE	QUALITY
Manufacturing Engineering, process planning, tool design	TI: 90% reduction in order entry labor for mask. MARTIN MARIETTA: reduction of 10 tool designers to 4	MOTOROLA: time to bring up complex pager manufacturing line reduced by order of magnitude based on integrated, reusable software.	
Operations including materials management	FORD: 10-15% reduction in sheet metal operations. SATURN: work in process reduced from 5 days to 30 minutes. DEC: reduced assembly line work force from 250 to 70 workers. GM: increase of fraction of inventory in use to 95%.	MOTOROLA: 5-week to 1-week reduction in PCB supply and assembly cycle. FORD: reduction of sheet metal manufacturing time by 19% with improved quality.	
Business Operations		MOTOROLA: purchasing delinquencies reduced from 25% to 0.1%. NATIONAL SEMICONDUCTOR: on-schedule deliveries, increased from 88% to 98%. DEC: 60-day savings in part ordering due to on-line data base.	
Information Systems Design, Implementation	DEC: $675,000 from moving from fiche to on-line access.		
Data Generation and Delivery		NORTHROP: reduction of provisioning list release from 6 months to 60 minutes.	

ASIC - Application-Specific Integrated Circuit
CAD - Computer-Aided Design
CIM - Computer Integrated Manufacturing
DEC - Digital Equipment Corporation
GM - General Motors
PCB - Printed Circuit Board
ROI - Return on Investment
TI - Texas Instruments

2. THE CURRENT STATE OF INDUSTRIAL ENTERPRISE INTEGRATION

This section discusses the current state of industrial enterprise integration as captured in visits to 22 leading companies in the electronics, automotive, and aerospace sectors. Topics covered include objectives and results of integration activities, critical management and technical factors in information infrastructures, current best practice, the DoD's role in achieving information infrastructures for enterprise integration, and related efforts.

Supporting data for the material presented here is in Appendix A, and is based on the industry rationales found in Appendix B, Appendix C, and Appendix D, as well as the company reports found in Appendix E.

The following definitions are assumed throughout this document. These definitions are commonly used by the companies and individuals involved in this study.

An **enterprise** is a collection of organizations and people formed to create and deliver a product or products to customers. An enterprise may span more than one company, and may be envisioned as a value chain[13] of producers and consumers. As determiners of the need for and characteristics of the product, end consumers are a part of the value chain and so of the enterprise. This study concerns enterprises whose products are designed by engineers and are manufactured.

An **activity** is a set of actions, contiguous in the value chain, that are executed by a sub-part of an enterprise. Activities may be viewed at different levels of granularity (e.g., design engineering as an activity or, at a finer granularity, circuit board layout as an activity). Activities may occur solely within a closely coupled set of organizations (e.g., product testing) or all over the enterprise (e.g., accounting).

[13] A "value chain" is a set of linked activities that process materials and information to produce a usable product. An activity "adds value" when the increase in the product's market price resulting from that activity exceeds the additional cost of the materials.

Activities may be more or less **integrated** to the extent that the agents (people and machines) executing them can work together as a unified process. Agents within integrated activities can negotiate trade-offs in order to reach a common objective. Integrated activities are generally characterized by intense, integrated, and often interactive information flows. As an example, concurrent engineering is more integrated than sequential engineering.[14]

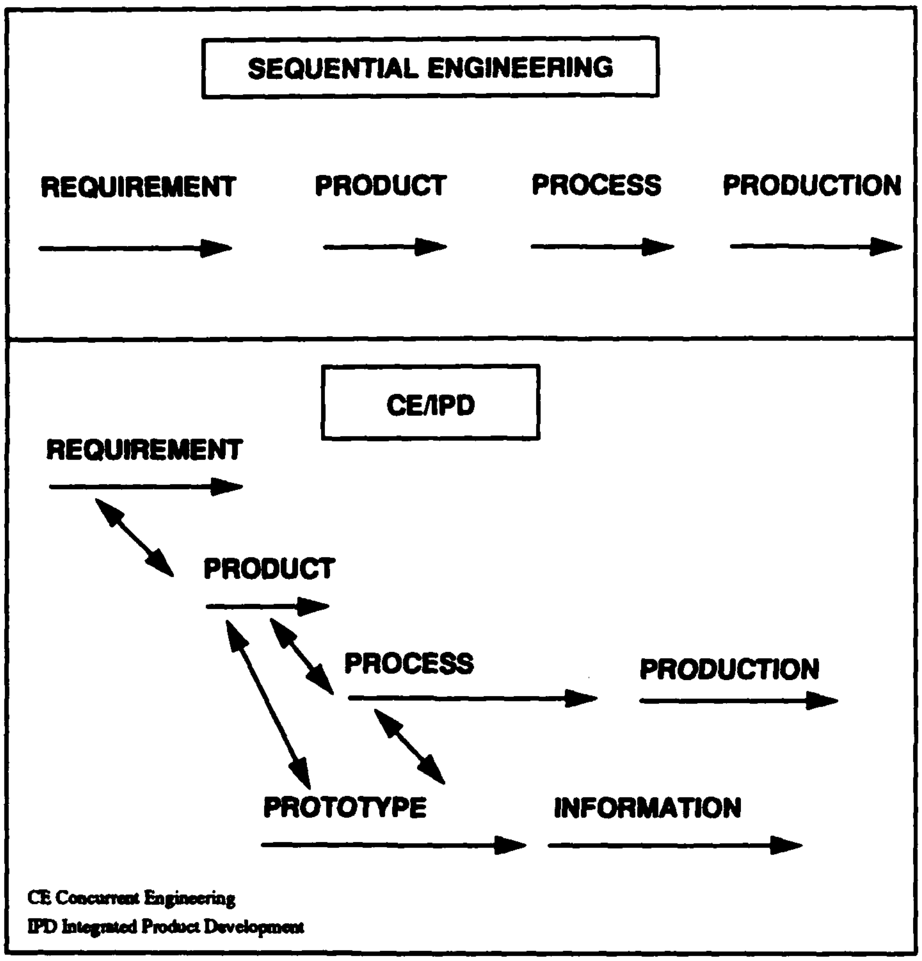

Figure 1. A Comparison of Sequential Engineering and Concurrent Engineering

Enterprise integration is the process of achieving the smooth and effective flow of material and product between the activities of an enterprise, often through the removal of organizational, process, and informational barriers. Possible barriers include changes to

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[14] From the *Concurrent Engineering (CE) Integrated Product Development (IPD): Guide to Understanding and Implementation*, Draft, May 28, 1993.

product requirements or process characteristics, breaks in process flow, organizational boundaries, and blockage of access to needed information.

Information is *data* with *meaning*. Information has form, syntax (rules of grammar), semantic content (meaning), and pragmatic content (usage attributes).

An **information infrastructure** is a structured collection of information system components and organization processes that enable the flow of necessary information within the enterprise. These components and processes may include various computer platforms, networks and communications systems, application programs, product representations, data management systems, policies and practices, shared user skills and expertise, process models, and interfaces among these elements.

An enterprise's information infrastructure may be more or less **integrated** to the extent that it easily supports intense, interactive information flows with minimal transformation of the information. The more integrated the information infrastructure, the more efficiently enterprise-wide policies can be deployed. An information infrastructure is more or less **modular** to the extent that changes local to a sub-part of the infrastructure can be made without enterprise-wide side effects.

2.1 OBJECTIVES AND RESULTS OF INTEGRATION ACTIVITIES

2.1.1 Objectives

U.S. companies are integrating activities because they perceive integration as necessary to competitiveness in the world marketplace of the 1990s and beyond. Commercial companies are compelled by time-to-market considerations which, in turn, result in better technology tracking and lower costs. Defense companies are driven by the decrease in defense business opportunities to demonstrate that they can design and delivery military systems at higher quality and lower cost than the competition. In both sectors, having more efficient product cycles—producing products demanded by the market in less time or at lower cost—requires attention to many factors, notably the quality of intermediate products (for example, designs and production plans). Critical large-scale implementation targets include integrating the activities of marketing and design, design and manufacturing, design and purchasing, manufacturing and purchasing, design and maintenance, and finance with everything. Having an integrated information infrastructure is key to achieving these targets.

Companies visited in this study want more integrated infrastructures both because current infrastructure is viewed as a barrier to integrated activities and because a more integrated infrastructure would facilitate the information sharing on which integrated activities depend. Typically, they reported spending more (whether in design, manufacturing, finance, or marketing) to get information systems to work together in support of integrated activities than was spent on the systems themselves. The related effort expended to maintain systems, to train administrators and users, and to support translators, all due to a fragmented infrastructure, is widely viewed as a waste which can be correctable system-wide.

Further, the information infrastructure is viewed by many as mainly a mechanism for the support of change management.[15] The message received during the study was that change is inevitable, that it is sometimes quite rapid, and that the information infrastructure of the future must be able to change with the surrounding environment. It must support both large grain and fine grain change. At any given time, the information system products bought to implement the infrastructures must be tailorable to each enterprise and part thereof, a means of achieving change over time.

The information infrastructure can support change only if the infrastructure itself is smoothly evolvable. This requirement of evolvability applies to all aspects of infrastructure: information system components to network protocols to product representations to organizational policies and practices to process models and so forth. As an example, a new step in the engineering process using a new analytic tool would result in a change in the process model and methodology enforcement part of the operational environment, and the new tool would be set up to use certain existing information classes, possibly outputting a new type of information. This requirement for evolvability and tailorability is a recognized issue, and one on which some of the companies visited have made progress.

2.1.2 Benefits

The companies reported significant benefits realized from information-system supported integration of activities. Most of these benefits fall into the categories of quality improvements, cycle time reductions, and cost reductions. The division of the effects of integration into these categories is somewhat artificial since they are interrelated and most integration activities yield improvements in more than one category.

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[15] Various notions of change about which people are concerned are described in Section 2.2.1.4 on page 24.

As an example, it is a simple but fundamental observation that improvement in quality reduces the need for rework and allows increased lot sizes, leading to improvements in schedule and cost. Texas Instruments reported a decrease from six per year to zero in released mask version errors. This quality improvement results in a cost savings of $600,000 per year. Another example is captured in the following chart (2). Here the reduction in engineering change orders from using a logically centralized computer-aided design (CAD) model is quite clear.

An example of an integration effort that yielded benefits in all three categories is Westinghouse's Electronic Assembly Plant (EAP). The EAP assembles printed wire assemblies (PWA) using integrated systems to automate workstation activities. EAP uses both robotic and manual workstations to achieve flexibility. The PWA Computer-Integrated Manufacturing (CIM) system transforms engineering design data into machine control data. The Material Accountability-Robotic Kitting system automates preparation and kitting of electronic components for assembly. The Standard Electronic Assembly System

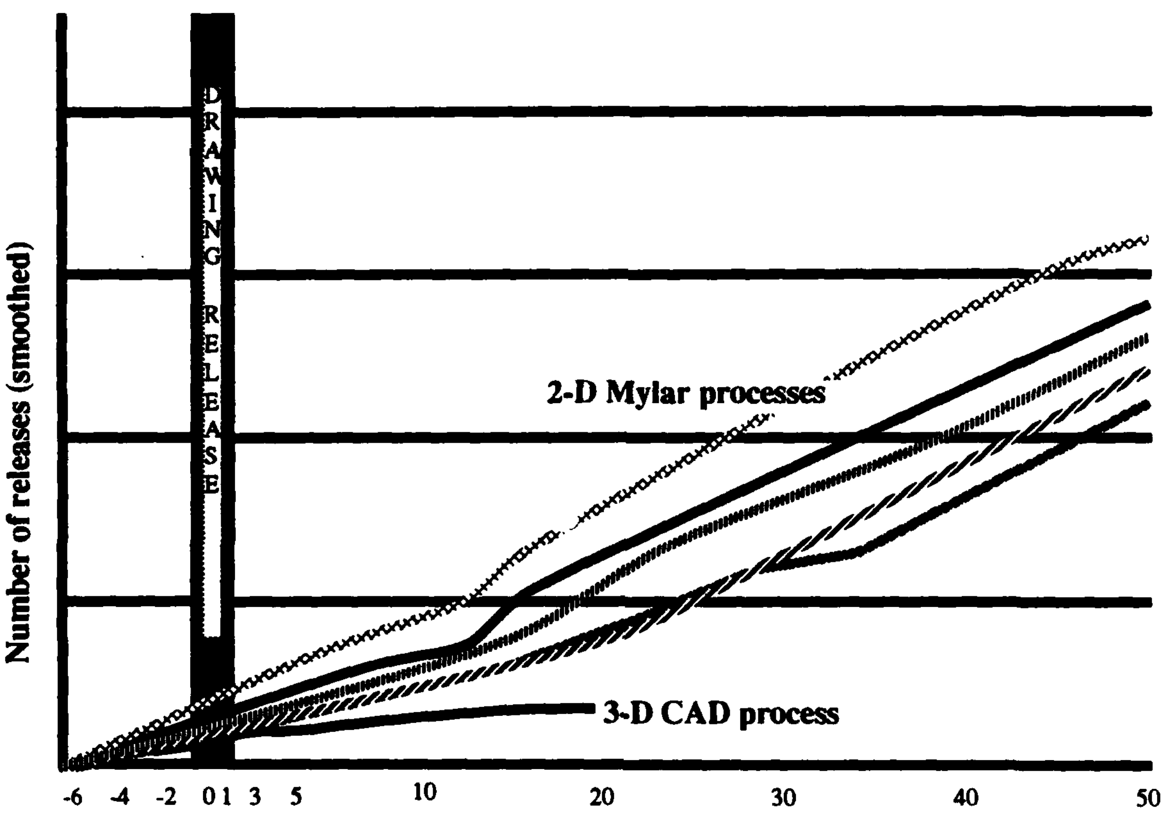

Figure 2. Six Recent Aerospace Projects: Sustaining Releases

(SEAS) consists of insertion robot, Computer-Aided Miscellaneous Operations (CAMO), and Inspection Data Entry (IDE) workstations. At the CAMO station, SEAS provides computer-directed operator assembly when manual work is needed, and at the IDE station SEAS directs consistent PWA inspection and captures non-conformance data. The improvements achieved and projected by integration in the EAP are shown in Table 3.

Table 3. Westinghouse Electronic Assembly Plant

	1981	1983	1985	1987	1989
Yields (first time through)	33%	45%	65%	85%	90%
Cycle Time (weeks)	12	8	5	3	2
Relative Cost	100%	92%	56%	45%	30%

An *integrated information infrastructure* enables extending integration practices up and down the value chain. Several companies stated that they were working with suppliers to extend the company's integrated systems to the suppliers' facilities. For example, automotive sector companies typically require their suppliers to use the same CAD system. Representatives of several companies reported best success with suppliers for whom their company was the primary customer. A side benefit of being integrated with one's suppliers is that outsourcing decisions become mostly an economic and capacity decision, as integration will have removed many of the technological barriers that might otherwise have to be considered.

An *effective information infrastructure* enhances information sharing and flow, which are critical ingredients of *enterprise integration.* It allows prompt dissemination of information, subject to appropriate access control, on a need-to-know basis. For example, Digital Equipment Corporation reported reducing design distribution time from three weeks to two hours. Further, electronic access to design data enhances the timeliness of the information. A manager can probe for the needed information rather than have to wait for a report to circulate. At SATURN, Martin-Marietta's LANTIRN facility, and NeXT Computers, there are capabilities to monitor and probe the status of manufacturing lines, in real time, from remote facilities.

2.1.3 Reported Results

Some of the reported results are very broad; they refer to whole enterprises and are measured in very large units. Other results are focused on small parts of the product realization process with correspondingly smaller measures of success.[16] In all cases, the companies reported that savings came from integration projects and initiatives in the sense described in this report. Some results, described in the next section, are categorized by function in Table 2.

2.1.3.1 Cost Savings

- SATURN: an independent expert estimated 20% across-the-board savings due to integration. work-in-progress inventory on power train line reduced from 5 days to 30 minutes.
- Texas Instruments: 90% labor reduction in order entry process for masks.
- Digital Equipment: 38% return on investment (ROI) from CIM DecShop on a project; 3-5% total product cost reduction on a major product line; 90% reduction in design data administration staff; 83% reduction in design data coordinators; reduced assembly line work force from 250 to 70; $675,000 per year savings in moving from microfiche to on-line, electronic archives.
- Pratt and Whitney: $10 million in bid savings in one area and $20 million in another.
- Martin-Marietta: reduction from 2,100 hours to 900 hours engineering time for mock-up; reduction from 10 tool designers to 4.
- Cross and Trecker: 30% internal rate of return (IRR) on new integrated system with legacies scrapped.
- Ford: 10-15% cost reduction in sheet metal production, with better quality.

2.1.3.2 Cycle Time Reductions

- NeXT Computers: went from concept to shipping product in 11 months, 5 months before the next-best competitor shipped.
- Motorola: 50% reduction in design cycle time for end products using ASICs (Application-Specific Integrated Circuits); 5-week to 1-week reduction in PCB supply and assembly cycle; cellular product cycle reduced 50% with target to reduce 50% again; one cellular product cycle was 3 weeks; time to bring up complex pager manufacturing line reduced by an order of magnitude due to

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[16] Appendix E contains reports on all companies visited. All of the reported results were taken at face value. Virtually all of them are estimates.

software reuse allowed by integration; purchasing delinquencies reduced from 25% to about 0.1%; achieved best order release-to-ship time of 4.5 hours.

- National Semiconductor: in selected cases, time to market reduced from two years to nine months; on-schedule deliveries increased from 88% to 98%, with target accounts increased from 95% to 100%.
- Digital Equipment: 60-day savings in part ordering via on-line database; design distribution time reduced from 3 weeks to 2 hours; achieved best-time 20 minute cycle from filing of ECO (Engineering Change Order) to installed change in mask information (average, 2 hours).
- Northrop: reduction of provisioning list release from 6 months to 60 minutes.
- Martin Marietta: reduced board development iterations from 2.5 to 1.5.
- Ford: 14% reduction in time for sheet metal production with better quality; on track toward goal of reducing physical model builds by 90%.

2.1.3.3 Quality Improvements

- Texas Instruments: reduced released mask version errors from six per year to zero (worth $100,000 per error).
- Digital Equipment: reduced released version errors to zero.
- Northrop: integrated CAD led to first-time, error-free physical mock-up of many B-2 sections (projecting zero physical mock-ups in future); same result for physical design of electronic missile subsystems; achieved first-time correct tube bend connections.
- Martin Marietta: reduced from 4 changes per drawing to 2.2, with target this year of 1.9 (each decrease of 0.1 is worth about $6 million per year)

2.1.3.4 Capacity, Productivity, and Other Improvements

- NeXT Computers: project factor of 15 to 20 improvement in direct manufacturing labor productivity versus benchmark of "typical" workstation manufacturer (in sales per manufacturing touch laborer).
- Northrop: increased customer interest due to electronically delivered CDRLs.
- Martin Marietta: increase in total business from $0.75 billion to $2.5 billion with reduction in work force of 15,000 to 8,600 over last 20 years.

- General Motors: increase in fraction of inventory actually in use from 5% to 95%.[17]

2.1.4 Pitfalls

In addition to the benefits discussed above, a number of the companies reported on pitfalls encountered in their progress toward creating integrated Information Infrastructures. These pitfalls included the following:

- Effects of cultural and organizational barriers to the acceptance of enterprise integration.
- Perceived threats of integration practices to individuals.
- Failure to match integration efforts to organizational goals.
- Development of enterprise-unique, non-standard integration solutions.

Even when integration goals are technically achievable, integration is not easy to implement, largely for cultural-organizational reasons. As noted above, an information infrastructure can enable a manager to probe the status of manufacturing lines, or to gather other metrics such as the number of engineering change releases. Some middle managers are concerned that increased upper management visibility into day-to-day activities will be counterproductive, tempting higher-level managers to "interfere" and react to details out of context. On the other hand, some high-level managers see integration information infrastructures as enabling a decrease in management structure. And others see the downsizing of management as enabling enterprise integration through the elimination of empires.

At the technical staff level, personal productivity metrics are seen as intrusive or threatening. And several companies voiced concerns about the willingness of workers, particularly engineers, to follow integrated process models.

Existing systems present both a technical and a cultural issue that must be dealt with in integrating an enterprise. Frequently these systems belong to an organization and tend to reinforce organizational structure. Some managers see enterprise integration as a threat to their organization, and the organizational culture will strongly oppose any integration project that eliminates or phases out their system. One enterprise integration director observed that the only way to replace some systems is by retirement.

[17] Source: Electronic Data Systems interview.

Enterprise integration is not to be pursued for its own sake in the absence of strategic goals. A well-integrated company can still make wrong decisions. An enterprise must attend to the effectiveness as well as the efficiency of integration. It is possible to become trapped into viewing individual integration activities as ends in themselves. Also, integration and automation are not coextensive. All companies recognized that the automation of a faulty process is dangerous. Digital Equipment Corporation representatives observed that most automation failures were ones that addressed automation without integration.

A more subtle pitfall arises from the need to proceed with integration even in the absence of clearly desirable standards and standard practices. Enterprise integration leads to consistent practices across the enterprise. To do so requires an integrated information infrastructure which must include common information exchange facilities. These information exchange facilities could be based on official standards (or *ad hoc* standards), such as product data representation standards. In the absence of such a standard, certain information exchange usage must be adopted by local convention. No company visited in this study was waiting for a standard to emerge before starting to integrate activities. As standards are developed and vendors offer tools that are based on those emerging standards, companies then plan to adopt them within their infrastructures. Adopting emerging standards is one manner in which an information infrastructure must be evolvable. In the meantime, companies implement local "standards" whose presence is embedded in the systems created by a successful integration effort. Evolutionary adoption of emerging standards must deal with these legacies as well as those from "pre-integration" times.

In summary, the reported benefits from integrated information systems emphasize improvements in quality, cycle time, and cost, achieved through more timely and more complete sharing of both operational data and successful integration practices. The reported obstacles and pitfalls reflect resistance to integration efforts, misdirected automation, and the new "status quo" that results from successful but limited integration.

2.2 CRITICAL FACTORS IN INFORMATION INFRASTRUCTURES

The following sections focus on those attributes of information infrastructures and of the process of creating infrastructures that were identified in this study as critical factors in achieving integration.

2.2.1 Management Factors

Critical management factors discussed in this section include the following:

- Start-Up and Sponsorship
- Transfer Strategies and Mechanisms
- Inter-Company Integration
- Make or Buy
- Metrics
- Larger Islands of Integration
- Managing Change - Flexible Integration
- Role of Cooperative Efforts
- Use of Formal Models
- Automation and Integration

2.2.1.1 Start-up and Sponsorship

All large firms studied in this effort started their integration activities internally as a means of both exploiting what was seen to be a competitive advantage and reducing overhead, time in a project, staffing — in other words, cost. Cost was particularly evident as a driver in the aerospace firms although time-to-market was also a factor in the commercial airplane business. In the commercial electronics firms, time-to-market was seen as an overwhelming driver because of the rapid pace of change in the underlying technologies. In defense electronics firms, cost and problem avoidance are the major drivers.[18] In the automotive firms, the competitive advantage was to some extent viewed as arising from internally developed product design systems, and integration was seen as a way to use those systems as leverage to achieve quality, cost and cycle-time improvements.

In most firms, decisions to pursue integration were based on intuition and competitive benchmarking, the companies deciding to integrate to avoid being left behind. In firms with extremely strong quality programs, Motorola for example, integration was seen as a way of reducing errors and this has proven out in practice. In most electronic firms, integration was initiated from the middle ranks in response to cost and schedule objectives deployed from the top. A group of peers would recognize the need to cooperate and share data, and would propose a project to effect their integration. However, for success a high-level sponsor was critical to the task. The sponsor, typically a president or vice-president, needed to be in the common chain of command to resolve impasses between the groups and smooth management delays occurring between the project management level and the spon-

[18] Some people have expressed the need to insert new electronic technologies into weapons systems more quickly, but the defense acquisition system has not yet been adjusted to focus on cycle time. Thus, time-to-market is a secondary consideration.

sor's level. This sponsor tended to be the Least Common Manager above the groups to be integrated.

2.2.1.2 Larger Islands of Integration

While it is possible to abstractly define information infrastructures that span enterprises, what is actually happening is driven more by culture and the nature of localized knowledge than by abstract technological feasibility.

Most of the companies studied are implementing a "continents of integration and automation" strategy to support integration goals. They were moving from very large numbers of loosely coupled activities and disconnected information systems ("islands of automation") to a small number of large islands ("continents"). This implementation strategy exists even where there is strong support for enterprise integration from the top. There are technological and cultural reasons for this approach, but it may have drawbacks that the companies using it have not yet encountered.

The technological reason for this approach has to do with the availability of solutions from information system vendors. For example, an enterprise may desire an integrated approach to CAD, but there are no systems in the open marketplace that integrate electrical and mechanical CAD. Available systems that help integrate one domain are seen as tremendous improvements over current practice, and so are used. This inherently creates continents of automation.

The cultural reasons for adopting the continents approach include the fact that in most companies the organizations best suited to understand the processes being integrated are within the organizations themselves. The people in these local organizations, fairly or not, view corporate or other cross-cutting information systems groups as too far from the local problems and too focused on short-term objectives.

Potential drawbacks to "continents of integration" approaches reported to the study team have three bases: investment, consistency, and evolvability. The first concern is that, having invested in integration within several large entities, it will be very difficult to justify the cost of changing the resulting systems to integrate those continents. The second concern is that a hierarchy of coordinating committees may not be able to arrive at consistent approaches across large companies.[19] The third concern is that these continent-oriented

[19] Extreme examples can be found in the DoD where some negotiations over common approaches to similar activities and information among the military services have spanned decades.

information systems are not being implemented with consistent evolution mechanisms, so that marrying two systems will require greater initial investment, on-going changes will have to be implemented in different ways, or both.

Many company representatives felt that even if technological solutions that support tailorable, evolvable integration were available in the marketplace, the cultural issues would still make enterprise-wide integration difficult. These representatives feel that, even when the potential drawbacks are well understood, only very strong, constant, and visible top leadership can overcome cultural barriers of the sort they encounter.

In defense contractors, integration projects are often project oriented. Contract-specific activity is normal in defense contractors due to the inconsistent nature of the demand for defense products, but it does have its problems. One problem with the contract-by-contract approach is that there is no continuous infrastructure. The infrastructure resides in the knowledge of the people who implemented the last project. A great deal of start-up investment must be supported by the government program with each new contract. On the other hand, it is in the government's interest to have integrated activities and support systems used on its projects. Indeed, some defense projects are among the most advanced implementations of integration over physically distributed, multi-company engineering and manufacturing teams. The Northrop-led, multi-company integrated approach on the B-2 strategic bomber, for example, is credited by some as making the project feasible.

2.2.1.3 Transfer Strategies and Mechanisms

For companies integrating within divisions or functions rather than across enterprises, there are issues of knowledge, culture, and technology transfer strategies. One common transfer approach is the multi-organization committee. These committees can work both as idea exchanges and policy originators. As idea exchanges, best practices from one organization are brought into another. As policy originators, best practices are reformulated and proposed as policies to top management for adoption and deployment. Both modes of operation are widespread in large U.S. companies.

Another transfer mechanism is based on employee rotation. There is increasing use of this mechanism in U.S. companies, but the companies visited for this study did not report widespread use.

In some companies, transfer of best practices is left entirely to chance. There are instances where coordinated visits from outside parties, such as during this study, effected a transfer of knowledge between divisions of a company. This absence of planned transfer may be evidence that top management, while wanting integration within divisions, favors total divisional independence, or it may be evidence of insufficient attention to deploying policies for company-wide integration.

Use of information technology as a knowledge, culture, or technology transfer mechanism is being considered in research organizations, but is not widespread except in the increasing industrial use of "expert" or "knowledge-based" systems.

2.2.1.4 Managing Change and Flexible Integration

Change management is a theme that appears in most discussions of enterprise integration and information infrastructure. The sorts of change that concern people range from very large (e.g., reorganizing the company) to highly focused (e.g., adding a new engineering tool). The future will bring the formation of *ad hoc* inter-organizational teams more frequently. Information and control flows will change in both the human and mechanical sides of the enterprise. And the nature of the information will change.

For example, the advent of new ways of synthesizing and analyzing designs have already changed engineering processes. Yet, in typical practice, organizations are slow to adapt to the changes, and the related information infrastructures that have developed are chaotic.

For the integrated enterprise to adapt to change efficiently, the integration approaches must be planned with change management as a fundamental objective. The information infrastructure itself must be designed for change.

There is also a potential role for standards in change management. If there were a standard, neutral representation for a particular sort of information, three-dimensional CAD models for example, then a new tool from a new vendor could be substituted for an old one without having to translate the existing data. Also, the change inherent in working with a new parts supplier or new teaming partner might be eased by the existence of standard representations and information frameworks.

Conversely, increasingly rapid change must be factored into the approach to standards themselves. Appropriate representations for mechanical, structural objects today are not the same as ten years ago, and these were not the same as ten years before that. These changes are very rapid in some fields and product data standards are not keeping up. According to companies visited, an evolution mechanism must be devised as part of the structure of standards and not just as part of the bureaucratic process that develops the standards. The companies express concern that such structural evolution mechanisms are not being developed in current efforts.

2.2.1.5 Inter-Company Integration

Outsourcing is increasing in almost all companies visited during this study. For some products, commercial and military aircraft for example, thousands of suppliers are involved. In the automotive industry, development and supply of tooling are primary contributors to product development cycle time. In all the studied industry sectors, electronics are being used to replace mechanical devices. In the electronics industry, increased use of integrated circuits from outside suppliers, especially ASICs, is at once an imperative for competitiveness and a source of schedule risk.

All this would indicate that integration initiatives should include careful consideration of how to include suppliers. While such consideration was reported by the studied companies, it is clearly a secondary issue to most of them. It is reasonable to conclude that this is a consequence of the middle-out and bottom-up approaches to integration that predominate in these companies as described in Section 2.2.1.2.

Three kinds of exceptions found in military aircraft development, automotive supplier relationships, and exchange of electronic simulation models reveal interesting points. In recent cases of military aircraft development, teams of prime contractors have joined to execute the programs. The systems being developed are so complex and so integrated in concept that integrated design activities are necessary for success. In these cases, common systems have been adopted and acquired as platforms for information infrastructures. Significant investments have been made to implement these infrastructures both out of contract funds and from company capital. Issues that have been dealt with in these efforts include such matters as establishing common bills of materials, establishing common product data representations, and inter-company security. One key issue is how best to use concurrent engineering where manufacturing or other downstream issues in one company affect and are affected by design decisions in another company. This is still an issue being addressed in complex military development programs.

Military aircraft development. The study team asked an electronics executive whose company was beginning to establish more integrated relationships with its suppliers whether his company was leading the suppliers or the other way around. He replied that his company was leading its suppliers except for those suppliers who also sold to the automotive industry. This evidences the effects of 10 years of automotive industry effort in the direction of working to integrate better with its suppliers. Use of electronic data interchange (EDI) for purchasing is commonplace. The large automotive companies have been bringing suppliers into the engineering process in a concurrent engineering sense for about 8 years. Some have included supplier engineers in Quality Function Deployment (QFD) exercises early in the development process, and there are reports of benefits gained by including outside manufacturing engineers in car design teams.

Automotive supplier relationships. The use of common information infrastructure has progressed in the automotive industry to the point where suppliers are using CAD systems that are common with each supplier. There is some controversy about whether it would be advantageous for these CAD systems to be based on publicly available, common interfaces. These interfaces could include common data representations, procedural interfaces, frameworks, or modeling methodologies. From the point of view of some automotive companies, notably Ford, sustainable strategic advantage can be gained by using their own proprietary systems and requiring that suppliers license and use such systems on projects for that company. These companies feel that open standards are too slow in appearing and may compromise system performance. The cost of maintaining such a system can run upwards of $10 million per year and forfeits the benefits of open-market competition to some extent.[20] From the suppliers' point of view, this approach is also very expensive. One supplier estimated it sustains a 20% user-engineer inefficiency cost due to the requirement to use sixteen different systems for its various customers. That is in addition to the cost of actually having to support the systems with additional staff, capital investment, and licensing costs. Some automotive companies recognize that they are paying part of the cost of that inefficiency, but the cost-advantage balance is not very well understood. Thus, the automotive companies are of divided minds on the issue of common solutions, but their suppliers are in favor of them.

Exchange of electronic simulation models. The third illustrative exception to the general finding that companies are concentrating on internal integration comes from model sharing in the electronics industry. When a company buys an integrated circuit from a supplier, it is advantageous to have access to a simulation model of that circuit as well. This amounts to design information sharing because the simulation model contains enough information to be able to recreate the design. The model must also have well-defined, or

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[20] Outside engineering tools are sometimes brought into the proprietary systems either by interfacing them with the company data using a translator (typical) or by paying the tool vendors to port the tools to the proprietary system (uncommon due to lack of programmers).

preferably standard, interfaces so that it can be used in simulation and analysis of the circuit in which it is incorporated. All this raises many issues of information infrastructure in microcosm. For example, there are security concerns associated with the design information included in the model. How can the supplier enforce a security policy on the user in a different company?

Another way in which this industry provides an interesting exception is in the development of ASICs. Here it is common for design to be the result of intense cooperation between supplier and customer. Otherwise, a working end-product would be very unlikely. The situation is unlike, for example, the relationship between an aircraft builder and its engine supplier. The behavior of an ASIC is much harder to capture in a limited number of measurable, analyzable, continuous variables such as engine thrust, vibration, moments, and weight. Thus, the industry has had to think through the supplier-customer relationship in terms of an integrated approach, including support tooling, and contracting vehicles.

2.2.1.6 Role of Cooperative Efforts

There are dozens of efforts to create common approaches, data representations, and system and application interfaces related to enterprise integration and industrial information infrastructures.[21]

To understand the role of these efforts in current integration activities, it is useful to differentiate between several kinds of efforts: potential standards, official standard developments, existing and maintained official standards, product-based but unofficial standards, and *ad hoc* support groups.

Many of the companies visited take potential and developing standards efforts quite seriously but do not depend on them. Representatives from user companies often monitor and sometimes participate in the development of standards, but most of the effort is supplied by vendors of systems that might incorporate the standards once developed. Examples of these include the unofficial CAD Framework Initiative and the official ISO Open Distributed Processing efforts. User companies will begin using standards as they become widely available in products, either as partial results or more complete ones. No company visited in this study was waiting for a standard in order to start integrating activities.

[21] For discussion of specific efforts, see the companion publication, IDA Document D-1386, *Current Standardization and Cooperative Efforts Related to Industrial Information Infrastructures.*

Several companies, particularly in aerospace, put product data exchange (PDE) standardization as a top priority item for recommended government support. Those companies all felt that an organizing structure or macro-architecture was lacking in current efforts, and that the absence of such an organizing structure would inhibit integration.

Use of existing standards is variable, ranging, for example, from partial use of the International Graphics Exchange Specification (IGES) for drawing exchange in parts of all three industries studied to virtually universal attempts to use the SQL standard for relational databases.

One factor in the success of a standard is whether its implementations are validated. The user community always says it wants validation, but it is often unclear who is willing to pay for the development and execution of validation processes. There is a potential government role, but the criteria for government investment in validation must be formulated.

Product-based unofficial standards are, by definition, widely accepted within the domain in which they are considered standards. That domain may be a single functional organization within a company or it may be a national user group. This sort of standardization does not really depend on cooperative efforts except in the sense that the system vendor and its more influential users determine cooperatively the evolution of the system. Nevertheless, proprietary solutions should not be ignored. There is the possibility that official standards could be developed based on them if there is enough community support, particularly from users. For such an effort to produce results quickly, a deliberate plan must be executed to converge on a result that will be seen as in the interests of the competitors of the original product as well as its originator.

The last kind of cooperative effort is the *ad hoc* support group. Such groups are generally composed of representatives of user companies pushing for convergence on a profile of standards to be implemented in a broad array of products. It is beyond the scope of this study to determine what is required to make such a group successful.

2.2.1.7 Make or Buy

Every large company seeking to create integrated information systems faces a make (build) or buy decision. Most companies want to use a collection of licensed software consisting of database management systems, tools for computer-assisted design (CAD), engineering (CAE), software engineering (CASE), production planning (CAPP), manufacturing (CAM), and so forth. The companies must decide whether to make or buy the integrating environment in which these tools operate and interoperate. A useful, static set of tools and databases can be interfaced and integrated for a few million dollars. An industrial-strength framework that accommodates the integration and evolution of a dynamic set of tools appears to cost upwards of a $100 million to develop. On-going maintenance can cost $10 million per year.

The choice to make offers a greater possibility to integrate the tools very tightly, particularly if the tools themselves are developed in house as well. Even with licensed tools, it is possible to negotiate access to their data structures in order to integrate them into a coherent system. The choice to buy offers the advantages of selection in a competitive market, with the vendor responsible for finding and making productive those rare people capable of successfully implementing an evolvable, open, integrating environment. Buying increases the probability of reasonably easy integration with a teammate or subcontractor. And it shares costs with other buyers of the system. Most companies indicated that buying is cheaper. Among the companies studied, buying is the usual approach.

2.2.1.8 Use of Formal Models

Process and information modeling efforts were reported at several companies visited in this and previous related studies.[22] Many people involved in activity and information integration efforts regard modeling as a central integration tactic. These kinds of modeling are not widely understood outside the information science community. Yet several companies reported significant process and information modeling efforts with various objectives, approaches, and levels of success.

Process models (descriptions of a collection of interrelated activities) have been used to establish a formalized picture of what goes on in various activities in a company. They can be used to redesign and streamline processes, to define mandated or preferred procedures for both operational and training uses, and to plan for support activities and systems including information systems. Process models are commonly used to design computer programs. In a sense, all computer-based simulations contain process models as well.

Process modeling efforts can be used to create large, centrally controlled models, or the efforts can be very distributed and localized. Models reported in this study as used for integration and training purposes tended to be centralized. Models used purely for process improvement were often very local.

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[22] Linn, J. and Winner, R. *The Department of Defense Requirements for Engineering Information Systems (EIS) Volume I: Operational Concepts* (NTIS AD-A176 153) and *Volume II: Requirements* (NTIS AD-A176 154). IDA Paper P-1953, Institute for Defense Analyses, Alexandria, VA, 1986.

Models used to help define new support systems, especially information systems, tend to be very formal. The people responsible for development of new software hope that a formal model of the encompassing processes will drive the definition of accurate software requirements. While such modeling does help, there is a school of thought that anything that claims to develop accurate, dependable software requirements is an illusion, and therefore dangerous.

Some companies report another potential pitfall: viewing the modeling process as an end unto itself. Arbitrarily, large efforts can be expended trying to make models even more accurate, particularly when the processes being modeled are not static or are too complex for anyone to grasp. It is imperative to keep the purpose of the modeling exercise clearly in sight of the modelers and to ensure that the modeling approach is suited to the objective.

Information models (descriptions of the form, categories, and meanings of a collection of interrelated information) are typically used in the development of information systems. These models describe the kinds of information used in company activities. The information model often includes information that is not and never will be in a computer. Most of the models include information flow in the enterprise and thus may be tied to a process model.

The set of definitions of the meaning of information that is included in an information model can be used as kind of data dictionary for various activities. The extent to which a model should and can capture meaning in order to be useful to human users is not well defined. Nevertheless, some successes have been reported.

2.2.1.9 Metrics

Process metrics are increasingly used in industry for more than their traditional application on the factory floor. The most extensive use encountered in this study is the Motorola Six Sigma program, a corporate program to reduce the error rate in all corporate processes to fewer than four errors per million opportunities.

Other process measures that could be applied to enterprise activities include transaction throughput, response time, and transaction cost. Although the results listed in Section 2.1.3 are not reported within a commonly accepted framework of process metrics, most could be regard as either throughput, response, or transaction cost.

Another measure considered indicative of process quality is the change history of process products. Cumulative releases of a product over time (e.g., Figure 2.) is an example.

Given the locality of most metrics, an important issue is how the measure becomes usefully visible to higher levels of management or to peers in an integrated enterprise. Today's hierarchical management structure makes relatively straightforward roll-ups of data if handled by humans. Automated data capture, filtering, reduction, and presentation is a promising field. Some have noted its similarity to military C^3I data fusion, and there could very well be dual-use technology developed to help solve this problem. Current examples of capabilities to monitor and probe the status of manufacturing lines from remote facilities can be found in all three sectors in this study. The application of this idea to other activities besides manufacturing is viewed by some as enabling a leaner organization. This appears to be an important potential focus for industrial information infrastructure.

2.2.1.10 Automation and Integration

Although much of this report concentrates on automation, integration and automation are not coextensive. All companies recognized that automation of faulty processes is dangerous. It is dangerous because it can make the process worse, because it diverts resources that could be used to make the process better, and because it can create an investment that is then difficult to discard, making the faulty process permanent.

Integration can occur in some instances without automated support. It used to be commonplace to say that the new process must be designed first and then automation considered. This is usually no longer true, first, because of the scale of integration being considered at leading companies and foreign competitors, second, because of the increased effectiveness per dollar of automation platforms, and third, because it violates the principles of integrated solutions. Given the state of technology, one should plan integrated process concurrently considering the potential automated support. This does not say that everything should be automated. It does say that the evidence from leading firms visited indicates that automation is an inherent part of most successful integration solutions.

2.2.2 Technical Factors

Critical technical factors discussed in this section include the following:

- Heterogeneous Environments
- Open Systems
- Integration vs. Interfacing
- Legacy Systems

- Frameworks
- Formal Models
- CASE Frameworks
- Security and Protection

2.2.2.1 Heterogeneous Environments

Most companies currently have many different kinds of computers running many kinds of software with different communications networks. This is true in many companies even for systems of like applications. Such heterogeneity effectively blocks direct integration of information, requiring significant additional expense to make information in one system available to another. At the companies visited for this study, this problem is being addressed largely by adoption of common platforms and software environments for each "continent of automation."[23] The problem of heterogeneous systems is to a large extent being avoided by switching to homogeneous systems where possible. Users are pressuring system vendors to extend the scope of their systems where possible, and it is often in the vendors' interests to respond favorably.

Four approaches have been proposed to dealing with heterogeneous systems:

- a standard middle layer of interface software
- a set of information exchange standards
- a standard set of platform interfaces
- a standard metamodelling technology for heterogeneous systems.

The approach of installing a middle layer of software that provides a common interface to applications software was not in evidence at any company visited for this study.[24] Most of those supporting efforts to create a widely adopted set of information exchange standards have come to recognize that such standards, to be effective, must be developed in concert with solutions to operational environment issues. A few of the companies visited expressed strong support for such efforts and appear to be including them in long-range planning. The idea of creating standards for platform interfaces assumes that applications will see the same operating system services and interfaces regardless of what machine is in use underneath. While user companies wish that this were the case, not many are planning

[23] Further discussion of "continents of automation" is found in Section 2.2.1.2.

[24] There are examples of places using a "middleware" approach to integration, but the evidence of this study is that the notion has not penetrated industry very well. One example is the Smithsonian Observatory, Cambridge, Massachusetts, which uses the ANSAware product developed within the European ESPRIT program. The Observatory is reported to use the product to integrate a system with over 3000. users on several different kinds of computers.

on it. The metamodel approach, in which high level models of heterogeneous systems would drive interfacing software enabling unlike systems to interact, is a very advanced approach not visible on the planning horizons of the companies visited.

2.2.2.2 Integration vs. Interfacing

Systems are integrated to the extent they can interact without translation of procedural interfaces or data. Systems can be interfaced by using extensive translation. Several companies reported that their integrated "continents of automation" contained a great deal of interfacing. Others are making a serious effort to build integrated systems from the database out, establishing fixed information representations and reprogramming tools to use those representations. Yet others depend on the commercial strength of their common system vendors to cause applications vendors to integrate with the large common systems.

Even those considering middle-layer approaches to integration of heterogeneous systems state that, for the foreseeable future, some systems will have to be interfaced to the logically central infrastructure rather than integrated into it. This conclusion is based on the existence of legacy systems and databases, performance issues, and market forces.

2.2.2.3 Open Systems

In an open system, definitions of the architecture and interfaces are widely published and stable, so that new software and hardware can be integrated with the system by many people, for example tool vendors. In contrast, a closed system is one in which the architecture and interfaces are controlled by, and so understood and changeable by, a small group.

At first view, open systems seem most desirable for integration. However, openness itself does not guarantee applicability. Microsoft MS/DOS, arguably the most successful open system in the history of information systems, is inadequate for many engineering and manufacturing applications.

Other issues are cost, performance, and timeliness. With an open system, costs of changes in platform are paid by the user community. When a user chooses a closed system, porting costs are paid by that user. Standardized approaches to evolvable, tailorable infrastructure components have not yet achieved the levels of performance required for maximal integration. It should always be possible to design a custom system that integrates needed applications and outperforms an open system.

Over time this advantage may be obviated by the ability of the marketplace to respond to performance demands on open systems. If the time for the marketplace to respond becomes less than that required to develop and maintain custom, closed systems, then there will no longer be a performance vs. openness trade-off. However, the start-up time for establishing open systems (other than those based on *de facto*, market-based standards) is currently too long. Open systems appear only in the long-range plans of companies visited for this study.

2.2.2.4 Legacy Systems

Legacy information systems are existing collections of activities, machines, computer programs, and databases that may not fit well with an organization's new plans and initiatives. Legacy systems have some continuing value to people or operations within an organization, and they exist in all but new-start organizations (which, if successful, develop their own legacies).

Companies report three ways they are dealing with legacy information systems (other than doing nothing): interfacing via translators, system duplication, and replacement. The extent of the problem can be considerable. One large, but not huge, company reported having six hundred incompatible databases. Such databases are difficult to integrate because they have many transaction routines coded into the database management system. These routines run very fast and are hard to replace with systems where transaction routines are more visible.

One approach to integrating legacy systems is to encapsulate the database system with a translator that makes the system more amenable to integration. This is expensive because the translators are often very large, error-prone, difficult to maintain, and carry a possibly unacceptable performance penalty.

Another approach is to duplicate the functions of the system in a new technology more amenable to integration. This can make sense where old programs are too expensive to replace and where they already satisfy the needs of the organization very well. New applications are implemented on the duplicate (shadow) database and old applications continue to run on the original. In some cases, the plan is to keep both systems forever. This approach is reasonable unless the maintenance cost of the older system is too high for its value to the company.

A third approach, relatively unusual in companies that have large legacy systems, is to replace old systems with easier-to-integrate new systems. Key issues are availability of capital and people to implement the new systems. The cost of software and data conversion can be very high.

In any case, dealing with legacy systems is expensive. Any approach should be based on a plan for evolution that decreases the risk of being in the same situation again in a few years.

2.2.2.5 Frameworks

The word framework is widely used in describing information systems, but refers to differing concepts and components. For purposes of this discussion, the term *operational integration framework* (OIF) will be used.

An OIF is a collection of executable software. The OIF is a skeletal part of an operational information and process management system. The OIF is a set of services and data types commonly available to all information systems based on the OIF. The OIF is used by human users and software (tools and agents) to structure and manage information, collections of software tools, and collections of external process in an integrated fashion. The actual information being managed may be inserted into the OIF, but is not part of the actual framework. The framework manages both information and metadata about the information; that is, it manages the information model that the user organization defines.

Thus, the information and process management system an organization uses will be made up of an OIF filled in with tools, information and process models, information bases, and policies. Two systems based on the same OIF might contain different kinds of tools and information, different tools and information of the same kinds, or some common tools and information. Having the same OIF, the organizations owning these systems would have an identical notion of "kind" and so would be able to exchange information of the same kind. Communities of interest would have a base, the OIF, in which to implement conventions on information representation, service interfaces, and kinds of policies (e.g., configuration management), and would know that these conventions were enforceable on their systems through the mechanisms of their common OIF.

The utility for integrated information infrastructures of systems based on a common OIF is in terms of interactions within the user community. This community might be made up of organizations within a company, or of organizations from several companies teaming to design and build a product. In either case, there may be an economic payoff in a standard OIF. Currently there is a reasonable level of understanding of the OIF concept within the community of potential suppliers of OIF products and of tool vendors who would build to

OIF-specified interfaces. There is reasonable understanding of how to deal with legacy systems. Finally, there are some demonstration products. These products have had some but not overwhelming market penetration, so that the interface specification situation has not yet gotten out of control. The opportunity exists now to begin the process of OIF standardization in earnest. Continuing demonstrations of various approaches will be needed both to settle some issues and to demonstrate utility in real projects. These will also educate the community on the necessary support structures. Nevertheless, the standardization process, focused on an OIF approach to integrated information and process management, is now feasible.

2.2.2.6 CASE Frameworks

The software engineering community is developing sophisticated operating frameworks for the integration of software engineering. For CASE environments, "framework" is generally accepted to refer to a set of common services, found in all environments and callable by an *ad hoc* tool that is introduced to the environment. The National Institute of Science and Technology Reference Model[25] has been widely accepted throughout the CASE community. The NIST Reference Model defines several categories of framework services: object management, task management, communication, user interface, tool integration, security, and framework administration and configuration.

Most frameworks are described as integrating agents, providing data integration, control integration, and presentation integration. In the NIST model, the data and control integration are categorized as object management services and presentation integration as a user interface service. Differing strategies for object management services are a partial reason for the current lack of uniformity among CASE frameworks. In particular, disagreement on an object-oriented approach to information management continues to be a barrier to widespread agreement on framework standards.

2.2.2.7 Formal Models

Process models (see Section 2.2.1.8) could be used to a greater extent than currently within an integrated information infrastructure. Companies visited in this and previous studies[26] reported a desire to use the information infrastructure to establish work procedures. A process model can be the basic data structure for establishing a set of operational

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[25] *A Reference Model for Computer-Assisted Software Engineering Environment Frameworks.* National Institute of Standards and Technology Working Draft, prepared by the NIST Integrated Software Engineering Environment (ISEE) Working Group, May 29, 1991.

procedures guided or enforced by the information infrastructure. The infrastructure itself would have standards for process modeling languages, representations, and, perhaps, methods. Version control, approvals, and configuration management could all be automated based on such models and their use within the infrastructure. Currently, some companies have thought about such uses and a few vendors are marketing products that allow this kind of modeling and enforcement. Several companies voiced concern about the willingness of workers, particularly engineers, to use such a system.

The use of information models (see Section 2.2.1.8) is in its infancy. Use as a basic driver is beginning to appear. If all information managed by the infrastructure were contained in a machine-sensible information model, there would be a greater possibility that the meaning of the information could be conveyed via the infrastructure over space and time. As with process models, this assumes that standards for information modeling languages, representations, services and methods would be part of the operational framework for the infrastructure.

The capture of meaning for use by computers is both an available technology and a research issue. Object-oriented information management, organizing information into classes, gives an ability for efficiently inferring attributes of an item of data from its class memberships. No companies reported use of object-oriented information management in this study, but a few reported use of object-oriented programming and several said they were monitoring the marketplace to determine how and when to incorporate this technology in their information infrastructures.

2.2.2.8 Security and Protection

Several of the companies visited, especially but not exclusively defense contractors, mentioned that information protection and security were important issues to be considered in integrating the information infrastructure.

Integration of enterprise information is taking place within many companies along functional lines and will provide "large islands" of processing in logically centralized, possibly widely distributed functional centers. For many companies, the next step is integration across function lines, beginning with key functions such as engineering and manufacturing, for example. Further integration to include suppliers and customers is envi-

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[26] Linn, J. and Winner, R. *The Department of Defense Requirements for Engineering Information Systems (EIS) Volume I: Operational Concepts* (NTIS AD-A176 153) and *Volume II: Requirements* (NTIS AD-A176 154). IDA Paper P-1953, Institute for Defense Analyses, Alexandria, VA, 1986.

sioned by most companies, and may occur before cross-functional integration. These integration steps should be assessed in terms of security risk and information protection. Specific risk management approaches need to be negotiated and defined so that they are suitable to the environment each participant brings to integration planning.

There are three major approaches available to address and manage risk to information assets or to assets represented by information in automated information systems: legal redress, insurance, and the incorporation of self-protection through security measures. All three must be considered in assessing the trade-off issues of managing both unique company-oriented risks and general inherent risks in the integration of enterprise information. In particular, the information infrastructure must support requirements needed for legal redress and insurance coverage, and must provide for incorporating appropriate security measures. These approaches are discussed in more detail in Appendix A.

2.3 CURRENT STATE OF INTEGRATION

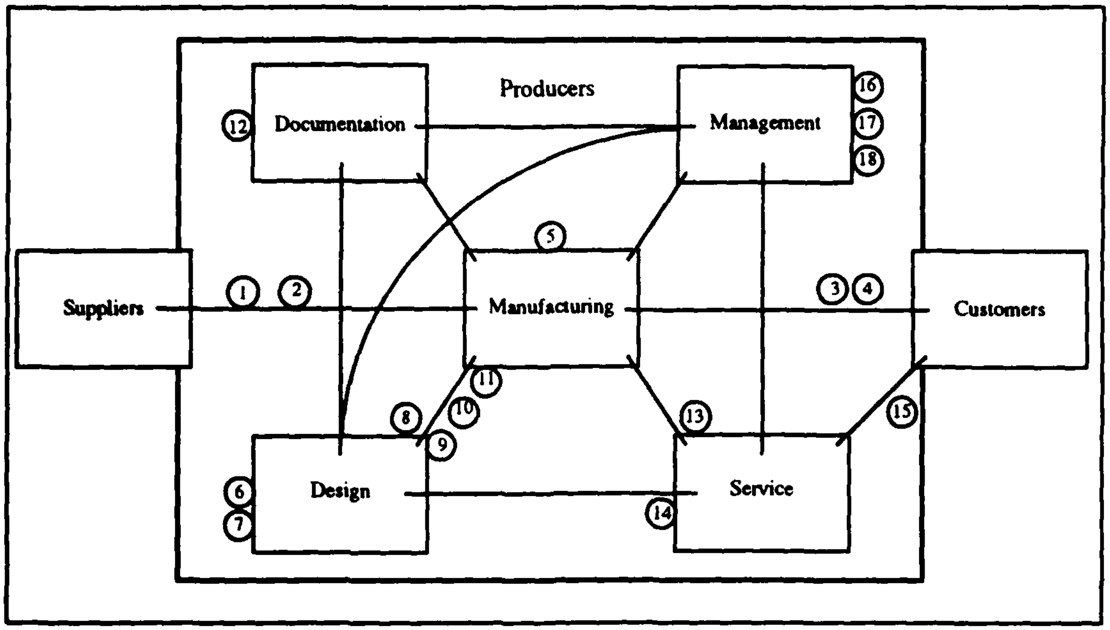
2.3.1 A Synthesized High Water Mark

The integration technology and infrastructure elements available today, in 1993, would enable an enterprise to develop a significant integration infrastructure. However, integration projects are constrained by cultural inertia, financial and resource limitations, and, significantly, risk management. Thus, Enterprise Integration projects and their supporting integration infrastructures tend to be deployed in an incremental and evolutionary manner. Since each enterprise chooses its integration path based on particular business needs, the corporations visited in this study each presented a different road map of integration efforts to date and a unique snapshot of current integration infrastructure.

The following scenario presents the profile of a hypothetical integrated enterprise. This profile synthesizes the high-water practices of 10 electronics sector corporations visited.[27] All the integration infrastructure elements and integration practices described in the scenario are based on current technology and have been validated by deployment in at least one company visited. Figure 3 depicts this profile of an integrated electronics enterprise.

The seven boxes in Figure 3 represent seven key actors (functional groups) within an enterprise. The main horizontal axis corresponds to the product value chain of suppliers-producer-consumers. The suppliers provide materials and component assemblies to the

[27] Although this scenario is geared to the electronics industry, the best practices in the other two sectors are comparable.



Enterprise Integration Activities:

1. Transmit purchase orders to suppliers electronically using EDI.
2. Deliver drawings and schematics to suppliers electronically.
3. Receive product orders from customers electronically using EDI.
4. Schedule deliveries electronically using factory capacity, inventory, and work-in-progress databases.
5. Compute manufacturing schedules based on inventory, capacity, orders and delivery commitment databases.
6. Apply downstream rules in design process.
7. Approve design using automated design approval process.
8. Release approved design to manufacturing via an electronic vault.
9. Develop parts database, parts approved by design and manufacturing.
10. Compile manufacturing control programs for PCBs from design database.
11. Plan and optimize manufacturing control programs based on manufacturing schedules.
12. Print manuals and documentation on demand, custom configured to product options.
13. Use repair history database feedback to improve precision of service diagnostics.
14. Use repair history database to drive ECO/MCO for reliability.
15. Respond to customers request repair or warranty services.
16. Manage quality programs for products, using design, manufacturing and repair data.
17. Select "corporate standards," common platforms, tools, and other technology elements for use on a corporate-wide basis.
18. Have senior management sponsor successful integration projects.

EDI Electronic Data Interchange
PCB Printed Circuit Board
ECO/MCO Engineering Change Order/Manufacturing Change Order

Figure 3. Functional Groups and Processes in an Integrated Electronics Enterprise

producer, and the consumers purchase the products manufactured by the producer. The producer is partitioned into five actors in the research, development and production process: managers (Management), design engineers (Design), manufacturing engineers (Service), technical writers (Documentation), and field and factory service engineers. A line between a pair of groups indicates an information flow in support of integration of their activities.

Eighteen integrating actions or integrated processes are also shown, each represented by a circled number. Where a number is placed next to a box representing a functional group, the corresponding action is undertaken by that group. Where a number is placed next to an information flow line, the action is performed to the mutual benefit of both functional groups, and brings about some of the information flow between them. A brief description of each activity is given in the figure, and each is described more fully in the following paragraphs.

2.3.1.1 Suppliers, Producers, and Customers

EDI is used to exchange business information, including purchase orders, invoices, and advice of payment. EDI is used between the manufacturing organization and its suppliers, and between customers and the order entry organization (activities 1 and 3). EDI may also be used within the company, between divisions that have a supplier-consumer relationship. The EDI transmissions to suppliers may be issued by manufacturing's MRP (manufacturing resource planning) and JIT (just in time) systems.

For electronic components, a purchase order must have an attached schematic or technical drawing. Since EDI supports only the transfer of business forms, drawings must be transmitted via a supplementary mechanism (activity 2), such as an interchange format for the CAD system in which the drawing was created, an industry standard interchange format (e.g., IGES, a neutral document exchange format (e.g., Standard Generalized Markup Language, SGML), or a proprietary format used by the enterprise. Frequently a supplier will not have the necessary equipment or software required to receive drawings and, for smaller suppliers, the purchaser will install a system for electronically viewing drawings in the supplier's facility. For security reasons, drawings being transferred to a supplier are either downloaded to the supplier's workstation or copied to an isolated workstation in the producer's plant that the supplier can access as needed. In neither case is the outside supplier given access to the engineering network of the purchaser, and normally the purchaser is not given access to the network of the supplier.

During the process of ordering an electronic component, particularly components available from multiple sources, the customer will seek a committed price quote and delivery schedule. Data involved in responding include finished inventory data, work-in-process data, and manufacturing capacity data. The order entry system accesses these data from their various sources within the company in responding to the customer (activity 4).

2.3.1.2 Design and Manufacturing

A flexible CIM facility can, in principle, manufacture product in lot sizes of one unit, although there are many factors that favor larger manufacturing runs. Schedules for each manufacturing line are computed periodically, the frequency depending largely on lot sizes and setup overhead. (Shorter setup times allow more frequent scheduling.) The scheduling activity (activity 5) uses order and delivery commitment data, finished product, work-in-progress and materials inventories, and manufacturing capacity information.

Practicing concurrent engineering, a design engineer obtains feedback about the suitability of the emerging design for downstream processes, in order to efficiently produce a high quality design. The feedback may be provided through tools run by the design engineer (e.g., an expert system) or it may be provided by a formal or informal review. For example, by running an ASIC design through a design rule checker using appropriate design rules amid parameters (activity 6), the design engineer verifies that the design conforms to the ASIC foundry's process rules.

When a design engineer completes a design or an engineering change and the design is ready for release, it goes through an approval process. An approval form giving the name and version of the design is routed by electronic mail (activity 7) for the required approvals, which may include the designer, a quality engineer, the project lead, and one or more additional managers. A password-verified signature is entered electronically for each signer. After the electronic design approval has been completed, the design proceeds in the release process while a paper approval form is circulated in parallel for formal signature. The paper approval form is required because electronic signatures have not been established as legally binding, should they be required for contractual purposes.

In the release process (activity 8), the approved configuration of the design (the correct version of the design and the correct versions of the components used in the design) is checked into an electronic vault. There it is available on a "read-only" basis to both design engineering for reuse in future design activities and to manufacturing engineering for developing the CIM programs used in the manufacture of that design.

When designing, an engineer specifies some purchased components. These components are selected from the shared corporate approved-parts database. Frequently there is a choice among several optional parts that provide the required functionality; perhaps a choice among options with identical functionality, but from different suppliers. In this case the choice may be based on manufacturing issues. (For example, choosing a chip already in use on the manufacturing line avoids additional setup time to custom load an alternative chip into a "pick-and-place" machine.) Manufacturability information, such as reliability, maintainability and usage, is collected and used by the manufacturing engineers, and the approved-parts database is selected (activity 9) either by manufacturing or jointly by design and manufacturing, with the latter having veto power.

To manufacture a PCB, a numerical control (NC) program for control of the fabrication, drilling, stuffing, and soldering processes must be developed. The approved design, as placed in the electronic vault, is the specification for the NC program. Manufacturing acquires the PCB design from the vault and compiles the NC program (activity 10).

Some optimization of an NC program is done during its development (i.e., in activity 10). Much of the optimality of the CIM operation of a facility depends on interactions among the various NC programs for the parts and products being manufactured in that facility. Therefore, after the manufacturing schedule for the facility is established for the day (week, etc.), further CIM optimization is performed (activity 11). This optimization is based on the CIM NC programs, the schedule (from activity 5), and the materials inventory and outstanding JIT purchases (activity 1).

2.3.1.3 Documentation and Service

Documentation in support of products is produced by many group[illegible]s all collected into a documentation database, and *no* inventory of printed manuals is maintained (other than a supply of blank paper for the printing process). When a unit of product is prepared for shipping to the customer, a manual customized to describe exactly and only the features in that product unit is printed on demand (activity 12) just in time for inclusion in the shipment.

As a side benefit, service documentation reflecting the requirements and idiosyncracies of the exact product configuration of a unit under repair can be read electronically by a service engineer. This allows the engineer to focus on the failure modes and repair steps relevant to the repair task at hand. The same diagnostic results for two different configurations of a product might be correlated with two different types of failure. By capturing a reliability and repair history database (activity 13), manufacturing and service can detect such patterns and guide the service engineer to a precise diagnosis and an efficient repair process.

Using the reliability and repair history database, service engineers can detect (activity 14) a recurring pattern of poor reliability or failures. Service can describe to design and manufacturing groups this pattern and together they can arrive at an ECO or a MCO that addresses the problem.

After an order is delivered and installed, most interaction with the customer is performed by the field service engineers. By establishing electronic mail or EDI communications between the customer and the service engineer, customer requests for service (activity 15) are received with greater timeliness and accuracy than manually, and electronic communications provide the opportunity to capture this input for the reliability database.

2.3.1.4 Management

Quality programs such as continuous product improvement (CPI), "Six Sigma," or total quality management (TQM) require accurate and timely data on all products. All functions in the enterprise (e.g., design, manufacturing, service, management) must collect accurate data appropriate to quality measurement. To manage the quality of an enterprise (activity 16) requires electronic access to the appropriate data from these disparate sources, coupled with the ability to integrate the data into a model that enables correlation of the overall quality of a product with the data elements from the various functions.

Selection of common tools and platforms (activity 17) has two positive effects. First, it minimizes the cost of training and support. Second, it enables the tool users to focus on fewer tools and to spend more time on using them well; this indirectly increases the quality of the products produced using these tools.

Successful integration projects are characterized by bottom-up opportunities and top-down sponsorship. Opportunities to integrate two related activities, or a common activity in two separate but related organizations, are first visible to the two groups whose activities would benefit from their integration. Management, particularly a manager whose domain of control spans both groups, must embrace such an opportunity and provide enabling sponsorship (activity 18) to the individuals who will execute the integration project.

2.3.2 Summary of Current Practice

The high water mark scenario presented in Section 2.3.1 is based upon the best practices of organizations visited in this study. In actual practice, the introduction of these integration activities is more widespread than might be implied from the scenario. Most organizations currently practice several of these integration activities to some degree. Current practice as surveyed by the study team is summarized in Figure 4.

2.4 DOD ROLE

The DoD is a buyer, creator, and maintainer of vast amounts of product and process-related information. When the DoD buys a weapons system, for example, it is involved in the definition of requirements and specifications, the receipt of technical and business data, the maintenance of technical data about each system (as built and as specified), and other operational, logistical, and business information. The DoD produces spare parts and replacement software and, as such, is a collection of manufacturing enterprises. Its systems are built by teams of contractors and subcontractors, each team often containing thousands of entities. The ability of the DoD, as a government agency, to maintain strategic partnerships with its suppliers is very limited by competition regulations and law. These limits apply to DoD prime contractors as well.

All this argues for the development and use of a dynamically linkable information infrastructure on which DoD can layer its business operations, especially those involving outside parties such as contractors. In the past, the DoD has paid (directly or indirectly) for the creation of infrastructures to support each system it buys. The technology and understanding of infrastructure issues is now at the point that DoD can consider reducing the inherent inefficiency of repeated infrastructure creation. Further, the continuing cost of maintaining numerous incompatible infrastructures, one for each kind of weapons system, for example, is increasingly burdensome.

Finally, the DoD has a strong military interest in being able to bring new technology to field operation as quickly as possible. This timing interest is not unique; the commercial electronics industry is similarly driven. The DoD, though, pushes the states of many product and process technologies at once and undertakes unusual technological risk. Military superiority depends on success. The time-to-market rationale for integration and information infrastructures used in commercial industry takes on this additional weight in the DoD environment.

COMPANIES		CANDIDATE INTEGRATION ACTIVITIES																	
		1. EDI with suppliers	2. Electronically transfer drawings	3. EDI with customers	4. Automatic scheduled deliveries	5. Automatic manufacturing schedules	6. Automate design approval	7. Electronic vault release process	8. Shared approved parts database	9. Compile CIM Program from design	10. Optimize CIM programs	11. Print-on-demand documentation	12. Diagnostics use repair feedback	13. Repair feedback to ECO for reliability	14. Customer service feedback	15. Integrated quality programs	16. Common tools corporate-wide	17. Management sponsors integration	18. Peer-to-Peer Electronic Mail
AEROSPACE	Company A		●	●				●									◗	●	●
AEROSPACE	Company B	◗	●	●			●	◗	X			◗	●	●	●		◗	●	●
AEROSPACE	Company C		●				●										◗	●	
AEROSPACE	Company D	●	●	●		●			●	X				X		●	◗	●	●
AEROSPACE	Company E	◗	●	●	◗	◗										●			◗
ELECTRONIC	Company F			●			●	●									◗		○
ELECTRONIC	Company G	●	●			◗	◗	●	●	◗			●					●	●
ELECTRONIC	Company H	●	●	●	◗	●	X		●	●	●	●		●		●	◗	◗	●
ELECTRONIC	Company I					●			●	●	●					●	●	●	●
ELECTRONIC	Company J	●	●					●	●	●						●		◗	
ELECTRONIC	Company K			◗	●	◗										◗		●	
ELECTRONIC	Company L	●		●	X	X										◗	◗	○	○
ELECTRONIC	Company M	●		◗		X		X	X							◗	◗	◗	X
ELECTRONIC	Company N	●	●	◗		X		◗			X	X						◗	●
ELECTRONIC	Company O							X	◗	◗	◗	●		○	◗		◗	◗	

X = Planned ○ - Fair ◗ = Very Good ● - Excellent

Figure 4. Current Industrial Integration Practices

The scope of DoD Enterprise Integration requirements is the same as those of commercial industry. Therefore it makes sense for the DoD to team with industry in developing an integration infrastructure meeting those needs.

While not differing in scope, DoD requirements do differ substantially in degree. Whereas most companies visited are focused on intra-company integration, DoD inherently operates in an inter-organization mode. Some DoD product[illegible] the F-22) are more complex and have more rigorous performance requirements [illegible] commercial products. Furthermore, the DoD acquisition process tends to incur fresh-start, contract specific elements of integration infrastructure on each program. The DoD accumulates heterogeneous systems, contract-unique legacy systems, and many islands of integration that often are truly incompatible. In the DoD environment, a homogeneous systems approach is generally not legal.

Thus, DoD has a stronger interest than industry in general in solutions such as standard middle layers, standard operational frameworks, and standard information exchange representations. The government tends to prefer a vigorous marketplace in open information system tools and technologies to closed or proprietary solutions. The DoD has recognized in several programs that open-system solutions to information infrastructure issues will depend on operational integration frameworks. DoD's interest will be best served if framework standards span the domains of product design, production, and maintenance.

The DoD has a special interest in the evolvability of the infrastructure for several reasons: it has tens of thousands of legacy systems to absorb over time, it has very long-lived products and associated information, and it has products that evolve. Inter-organizational factors introduce an additional element of change, which may be a threat to evolvability. Having a slowly evolving framework in which to house relatively more quickly evolving information and models and residing on very rapidly evolving platforms is a requirement for rationalizing DoD information management.

Software makes up a very large and growing fraction of the DoD acquisition budget. The DoD therefore has an unusually strong interest in the engineering process that surrounds the software it buys, uses, and maintains. The cost of buying and operating a unique software engineering environment for every piece of mission-critical software has gotten very large. The DoD seeks a solution through framework, language, and interface standards. Furthermore, the DoD is beginning to recognize that it is possible for a framework to span more than one domain, for example both software and computer hardware development. The DoD work on CASE frameworks may prove to be useful in this larger setting.

The security issue for DoD is older but not technically very different from the issues relating to trade secrets and competitive information faced by industry. Again, the differences are largely a matter of scale. Compartmentalized and extremely sensitive information must be managed. Development of classified systems using a geographically distributed infrastructure, as was done in the B-2 program, for example, is very difficult at the current state of the art.

The DoD's needs for Enterprise Integration can best be met by working with commercial industry to develop the required information infrastructure. While the government will support projects and activities that develop and standardize this infrastructure, the DoD needs to ensure that adequate attention is paid to its specific needs including, for example, legacy systems, evolvability of operational integration frameworks, and management of security information.

2.5 ENGINEERING OF INTEGRATED INFORMATION SYSTEMS

Section 2.2.2, Technical Factors, contains numerous examples of difficult trade-offs that must be made in designing integrated information systems and mating them with continuously evolving organizations and processes. The company visits made during this study show that progress is being made in implementing increasingly complex integrated systems. Yet the engineering of these systems is based more on intuition and experiential rules-of-thumb than on a sound science or analytic technology. As pilot and demonstration systems are implemented and new approaches explored, community experience will increase. Unfortunately, very little of this learning is being disseminated at present. There are active research areas within information infrastructures, but transfer of results to the industrial community appears inadequate.

As examples of issues that would benefit from concerted attention, and where benefits seem achievable, consider the following.

- Representing the semantics of mechanical design entities. The electronic CAD world has dealt with the functional behavior of design elements for a long time, but mechanical CAD (MCAD) is still practiced at the geometry level. "Feature-based design" is the term most commonly associated with bringing mechanical CAD to a level where the purpose of each item is known to the CAD system and, therefore, can be kept as part of the design history and rationale. Bringing the MCAD world to the semantic level would allow information modeling for electromechanical systems to admit more consistent solutions than exist today.

- Representation of management policies for use in process-model-driven information systems. Policies (expressed as rules) could be represented as entities in process and information models. A mechanism for executing policies could then be applied by the information infrastructure to such activities as version control, configuration management, and methodology enforcement. Given metrics to measure the effectiveness and efficiency of these activities, enterprise simulations would allow testing the effects of policies prior to deployment.
- Evolvability (implementation for change) of infrastructure architecture and components. Mechanisms for evolvability are beginning to emerge in products, and leading users are beginning to plan for evolvable systems. Among the many open questions in planning for evolvability are, for example, how detailed should the information model be? At what levels of granularity should semantics be formal and machine sensible, as opposed to informal (and, therefore, not interpretable by machine)? What are the maintenance requirements for an object base? How can an enterprise control the growth and proliferation of information classes within its infrastructure?
- Open system vs. closed system trade-offs. In Section 2.2.2.3, there is an argument that the performance shortcomings of open systems may be eliminated over time by the response of the marketplace. Among the many open questions are, for example, what are the trade-offs involved? What methods should be used for measuring openness and integration, and their effects? How does information system performance relate to the performance of surrounding processes? The tendency toward local optimization is not just based on cultural biases and reward structures, but in part reflects the contention that openness and integration together yield low performance. Among the measures to be developed are process measures to apply to human processes. These involve social as well as technical considerations. For example, does high-level-management visibility into measurable low-level processes help or hinder process and enterprise efficiency?

In summary, there are many opportunities to develop a greater scientific and engineering understanding on which to base integration decisions. Some issues are information system specific; others have to do with the measurement and management of the enterprise in general. All would benefit from a greater basis of understanding.

2.6 RELATIONSHIP TO OTHER CONCEPTS

Several industry representatives interviewed in this study felt that the relationship of enterprise integration and information infrastructure to certain other topics should be discussed. In particular, concurrent engineering, CIM, CAD integration, and flexible manufacturing were most often mentioned.

Concurrent engineering seeks to integrate the engineering of products and their related processes. It also seeks to integrate the different engineering domains within product design. As such it is a subset of enterprise integration because it integrates the design aspects of the whole product life cycle from recognition of need through design, production, operation, and maintenance to disposal. In large projects concurrent engineering necessitates inter-company integration of activities and information flows. Thus, concurrent engineering requires the information infrastructure and demands that the infrastructure be controllable and evolvable. Concurrent engineering expects the infrastructure to enable CAD integration because of its requirement to integrate engineering domains. Concurrent engineering receives constraints from flexible manufacturing and the degree of flexibility should affect the resulting product designs. Concurrent engineering outputs product and process designs to CIM via the information infrastructure.

CIM is both an integrated activity and an integrated information system. It is an integrated activity in that all manufacturing activities are considered as a system. It is an integrated information system because computers and their related communications systems are used as the mechanisms for creating a unified system out of the many manufacturing entities. As such it is a subset of both enterprise integration and information infrastructure. It can receive information from integrated CAD via the information infrastructure. It is of particular utility because it can dynamically define and organize the activities of flexible manufacturing entities.

CAD integration is to information infrastructure as concurrent engineering is to enterprise integration. That is, CAD integration is a subset of integrated information infrastructure as particularly applied to CAD and CAE. It receives inputs from the requirements and specification process and produces outputs to CIM both via the information infrastructure. It supports concurrent engineering by allowing broad information sharing among engineering activities.

Flexible manufacturing is the use of manufacturing equipment [illegible] produce more than one product in an economic mix. It is used within CIM to bring abou[illegible]e (but, perhaps, not all) of the production activities on a manufacturing line. It takes advantage of the information infrastructure as part of CIM. It places its own kind of manufacturing constraints on the concurrent engineering activities.

3. INDUSTRIAL ENTERPRISE INTEGRATION VISION—2001

3.1 INTRODUCTION

This section presents a vision, one possible scenario, of future industrial enterprise integration suggested by the findings of this study. The vision is meant to describe a possible, desirable state of enterprise integration in the future. It is not a forecast, but rather a goal state. The technologies required to achieve this state are available now, thus the goal is feasible. However, it could still pose a challenge to industry in reaching it by the stated date, or ever. The vision is presented from two perspectives: first, in terms of the effect of information infrastructures on enterprise integration as they have developed by the year 2001, and second, in terms of the technological developments that have permitted that effect. The purpose of the vision is to provide focus for planning and implementing these infrastructures.

The vision reported here has been developed by synthesizing appropriate ideas from a variety of planning exercises, books, and reports.[28] In addition, we asked a panel of individuals with experience in relevant areas for comments. They recommended eliminating specific quantitative predictions in favor of descriptive terms. As the process of refining the

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[28] Barber, Norman F., *Enterprise Architecture: Organizing for Integrated Manufacturing*, Cutter Information Corp., Arlington, MA, 1990. Clark, K. and T. Fujimoto, *Produce Development Performance: Strategy, Organization and Management in the World Auto Industry*, Harvard Business School Press, 1991. *CIM/OSA Reference Architecture Specification*, ESPRIT Project Report No. 688, 1989. Drucker, P., "The Emerging Theory of Manufacturing," *Harvard Business Review*, May-June 1990. Kaplan, Robert S., "Accounting Lag: The Obsolescence of Cost Accounting Systems," in Clark et al., *The Uneasy Alliance*, Harvard Business School Press, 1985. McGlone, Stephen, "Integrated Flexible Manufacturing Systems" (briefing materials), U.S. Army Industrial Engineering Activity, Rock Island, IL, 1991. National Research Council, *Improving Engineering Design: Designing for Competitive Advantage*, National Academy Press, Washington, D.C., 1991. *Reports on Integrated Information Support System Enterprise Integration Framework*, Manufacturing Technology Directorate, U.S. Air Force Wright Research and Development Center, Wright-Patterson AFB, OH, 1990. Rosenbloom, Robert S., "Managing Technology for the Longer Term," in Clark et al., *The Uneasy Alliance*, Harvard Business School Press, 1985. *U.S. Navy RAMP Program, Rapid Acquisition of Manufactured Parts*, 1991. Under Secretary of Defense (Acquisition), *Bolstering Defense Industrial Competitiveness: Report to the Secretary of Defense*, 1988. (Several other documents are not cited because of their draft status.)

vision moves forward, an early step would be to consider how much of it can be realized by 1996, and in that context, if specific figures can then be given.

3.2 THE EFFECT OF INFORMATION INFRASTRUCTURES ON ENTERPRISE INTEGRATION—2001

By 2001 many changes have influenced the state of enterprise integration. The global economy is more advanced, with greater requirements for rapid, timely exchange of information between distant locations. The impact of multi-national (or global) companies is better recognized, and significant capital investments have been made in the information infrastructures required to support an integrated enterprise.

There are parallel changes in business cultures. Success stories of enterprise integration have helped to remove barriers that impede sharing control of information. Companies more readily assimilate integrated systems into their way of doing business.

Government agencies, facing increased pressures to achieve significant cost reductions without sacrificing effectiveness, have also responded to these technological advances and industrial sector successes. DoD, in particular, has demonstrated a leadership role in implementing key aspects of enterprise integration.

3.2.1 State of the Infrastructure

By coordinated efforts, a national high-capacity information network, the backbone of a national Enterprise Integration Infrastructure, has been put in place in the United States and is considered essential to U.S. competitiveness. Similar efforts have developed varying infrastructures in the European Community and in other parts of the world, with some common features, shared standards, and abilities to share certain information. In the United States, some economy-wide data is in standard form and shared through the Infrastructure. Some industries have adopted standardized product data representations using forms beyond merely text, and are routinely sharing data.

Enterprise Integration has been stimulated by the following:

- The need to increase productivity and decrease time-to-market or time-to-delivery in manufacturing.
- Horizontal and vertical partnering relationships.
- Intra-company integration to promote competitiveness.

It has also allowed improved management practices through information availability and better quality control through awareness and prevention of errors.

The infrastructure has enabled widespread and growing enterprise integration by allowing both large and small firms to participate in integration more easily, reducing the cost of the necessary transitions. It has opened opportunities for new products and services, and has provided new ways to compete for those innovators who have adapted to it.

3.2.2 Evolving the Infrastructure

National mechanisms are in place to facilitate cooperation among standards bodies and to assure the orderly evolution of the Enterprise Integration Infrastructure for the future. Relevant standards developed by established professional and standards organizations provide for necessary evolution, and stress flexibility for innovation and interchangeability through voluntary adherence. The value to organizations and vendors of the Infrastructure is so widely recognized that reliance on voluntary adherence is successful.

The Infrastructure is based on an Operational Information Framework[29] that supports evolution of information types and allows continual improvement of the underlying platforms and communication technologies. The national information highway provides an example of managing the evolution of Infrastructure components.

Communication interfaces and filters exist among enterprise integration infrastructures world wide, and cooperative endeavors are underway to move to a common framework over the next two decades. In some information-intensive industries (e.g., financial) there is substantial progress towards (what appears to the user as) a single global information infrastructure. Many large world-wide manufacturing enterprises are developing their own global infrastructures for internal use, and are providing valuable input to the standards development process.

3.2.3 Facilitating the Transition to Enterprise Integration

The importance of participation in enterprise integration to small business has been widely recognized. Experience with the transition to enterprise integration is being gathered, studied, and made available. Mechanisms have been developed and are constantly being refined to enable organizations not yet operating in an integrated fashion to move in that direction. Federal and state agencies supporting small business development now

[29] See Frameworks, section 2.2.2.5, and OIFs, section 3.3.8.

advocate and fund integration activities. Academic study of the mechanisms and effects of integration continues to grow.

3.2.4 Effect on Competition

Existence of the national Enterprise Integration Infrastructure has had a mixed effect on competition.

- On one hand, it has facilitated joint ventures and other horizontal and vertical integration relationships, supporting a continuing trend toward fewer, more closely coupled suppliers.
- On the other hand, it has enabled relatively inexpensive routes to the marketplace. Ideas and innovations have assumed more value, and location and ownership of capital, the means of production, and information are no longer as formidable obstacles.

Within this context, large organizations are forced to compete nationally and internationally, and they, in turn, require their component divisions and their suppliers to compete.

The trend toward outsourcing for goods and services is supported by the Infrastructure, helping to create an economy in which large organizations reduce their employment and many small ones arise to provide services formerly carried out within the larger one. The role of firms as assemblers of outside components has expanded to include assembly of outside services also.

3.2.5 Customizing Products

Customizing products is possible at much lower dollar and time cost than was previously the case. This is highly beneficial in military markets, where the need for specialized equipment and supplies had led to very high costs, and in space and research settings, where similar custom or small lot needs are found. Customizing products is also providing more options for consumers, aiding in sales of U.S. products.

Within the military logistics structure, the infusion of CIM technology has led to reduced cost and lead times in the procurement of small quantities of high quality parts by manufacturing on demand, thus reducing the costs of warehousing and overproduction.

3.2.6 Savings in Time and Cost

In manufacturing industries, time to prototype new product versions has been regularly cut to a fraction of what it had been a decade earlier. This has led to new product development times which are correspondingly lower. Similar reductions have been realized in development-to-deployment time.

The transition time for innovative ideas to development has become half or less of what was traditional in the twentieth century. These innovative ideas in many cases come into an organization from the outside, through teaming relationships with small businesses.

Real costs for engineering design have been cut substantially. Enormous gains in engineering productivity has been noted by various manufacturers and design organizations.

Overall manufacturing personnel costs have been cut substantially due to automation and productivity gains within activities that had previously been labor intensive. There have been drastic reductions in manufacturing lead time and in work-in-progress, and large gains in overall production.

Capital equipment is replaced less frequently because of the flexibility and evolvability provided by integration. This has led to gains of hundreds of percentage points in operational productivity. These gains have been achieved simultaneously with large improvements in production quality, with little need to stop production to deal with defects.

3.2.7 Managing the Flow of Information

Sophisticated standards for product data exchange are widely used in most major manufacturing areas. These standards extend beyond American enterprises to others around the world.

Product data information is routinely used with generic tools in automated process planning, generative numerical control programming, automated inspection, and computer-aided inventory control.

The DoD CALS program has resulted in the widespread use of computerized technical information on weapons systems and has moved beyond weapons systems into other DoD systems. It is being used by other government agencies as well. It has reduced costs of documentation while adding flexibility for both the government and business.

Within the civilian sector, the results of CALS and related activities have had valuable ramifications for a variety of organizations, leading to systems that rely primarily on paperless data. The result has been cost savings and flexibility.

New forms of accounting have been developed and continue to develop to account for the value and value added of informational entities and operations. Activity-based accounting has had a major influence in this development. Tools to use these new methods of accounting, and related tools for financial control, have been incorporated in the Infrastructure as they are developed.

As part of the information network that Drucker envisioned as constituting the "factory of the future," and that has in fact become the backbone of the modern business, the Enterprise Integration Infrastructure has accommodated traditional data processing and information systems. The Infrastructure has allowed different trade-offs in data access and distribution within the organization. It has made possible the notion of integrated information management for the entire enterprise, not just separate information managements for the components organizations. It has provided additional services and filters that have allowed further automation of traditional data processing. Information management principles continue to evolve with experience, and the Infrastructure's continuing evolution takes full account of them.

3.2.8 Management in Integrated Enterprises

Management methods emphasizing enterprise integration are considered important or essential over a broad spectrum of companies, both inside and outside of manufacturing. Professional practices routinely employ the methods of enterprise integration in their interactions with corporations utilizing the Infrastructure.

Custom-tailoring of reports and other information products is now commonplace in integrated enterprises, enabled by the use of integrated data representations. Data-access tools, based on dual-use technology developed for military command and control, are being introduced into commercial use. These tools enable executives to develop data "probes" that fit their own styles of taking the pulse of the organization, pulling information when needed rather than waiting for scheduled reports. Such tools are made possible by and accommodated within the Infrastructure.

It is becoming widely recognized that every manager in a manufacturing enterprise should learn and practice a discipline that integrates engineering, business economics, management of people, and management of information into the manufacturing process. Such a discipline is being systematized and beginning to be taught in engineering and business schools. Just as all managers learned to live with and use computers, so all managers are beginning to learn to live with and use integrated systems concepts and techniques. Tools to aid these managers are steadily improving as the demand grows. Management evaluation and compensation practices are beginning to reflect the value of this knowledge. A rudimentary general understanding of the enterprise integration infrastructure is now considered a basic part of good management.

3.2.9 Personnel in Integrated Enterprises

People in integrated organizations typically are utilized more effectively and are more productive. They tend to be comfortable with the information systems that are essential to their jobs, feeling that they have a better idea of the "big picture" in their organization and that they are able to communicate and contribute better within the new environment. The systems themselves are increasingly engineered to provide human interfaces that accommodate to the work practices of individual users.

Tools accommodated by the Infrastructure facilitate training of new personnel and flexibility of existing personnel in moving among jobs. The tools capture standard practice aspects of the "corporate culture," enabling it to be reinforced widely.

3.2.10 The Effect on the DoD

DoD is ideally suited to benefit from enterprise integration. It is an enterprise with *geographically dispersed organizations* and suppliers, characterized by changing programs and combinations of work teams, and the need to respond to developing technology. As such, DoD has always been involved in enterprise integration and is experiencing many of the quality improvements and cost reductions cited above.

Several leadership efforts undertaken over the last decade have contributed significantly to the benefits DoD is now realizing. These activities have included (1) systematic efforts to identify and disseminate learnings from early DoD-sponsored integration efforts, such as the B-2 development; (2) specific endeavors to develop needed technologies and standard practices for such key (to DoD) issues as dealing with legacy systems, smoothly integrating heterogeneous systems, and providing secure electronic signatures and automated sign-offs; and (3) working with suppliers to identify and, where possible, modify the policies, rules, regulations, directives, procedures, and practices that are seen as barriers or inhibitors to industry's use of Enterprise Integration Infrastructure within DoD programs.

3.3 TECHNOLOGICAL DEVELOPMENTS IN INFORMATION INFRASTRUCTURES

Improvements in the Enterprise Integration Infrastructure in 2001 have been made possible by interacting changes in the vision of the future and organizational structures, and improvements in technological capabilities. The follow sections discuss these technological developments contributing to integrated information infrastructures.

Continued, predictable advances in the cost and capability of semiconductors and electronic components over the past decade have resulted in highly cost-effective hardware systems.

Continued development and more widespread adoption of object-oriented software technology have helped to expand the size and range of possible applications, particularly in dealing with data structured in diverse ways, such as formatted documents, sound, graphics with identifiable parts, textured surfaces, movement in three-dimensional space, and so forth.

Selective use of software and hardware technologies incorporating learning, such as rule-based expertise, fuzzy logic, and neural networks, has extended information processing capabilities in some applications where precise algorithms are not available or where system *self-modification* based on experience is more cost effective than human analysis and programming.

The availability of high-speed, high-capacity data transfer, together with the capability to provide access to massive data stores, has led to greater awareness of the importance of standards for information representation and for software interfaces. Software innovators throughout the network see value in being able to "hook up" with the data and software components of other innovators, often developed and housed on quite different platforms. What was formerly an issue within a few specialized communities, such as the electronic CAD community, is becoming a generally recognized need.

3.3.1 Data Accessibility and Usability

CALS for the DoD and similar smaller initiatives in a few industries have made data widely accessible, and many organizations have reached their limits in the ability to interpret available data. The distinction between accessible data and usable information is more widely recognized, and efforts have begun to increase the usability of accessible data. NIST and the DoD are sponsoring activities to extend IRDS (Information Resource Dictionary System) standards so as to capture semantics about how to use data, as well as developing more procedurally oriented standards such as those pioneered by the Object Management Group (OMG), the CAD Framework Initiative, and PDES in their API (Application Program Interface) work.

3.3.2 System Hardware

Significant advances in technology have occurred during the last decade, enabling better support of integration infrastructures. All of the following are improved by a factor of 8 in the last 10 years: processor speed and cost, memory, storage capacity and cost, and network capacity and reliability. Workstations are multiprocessor systems with multiple multimedia displays.

3.3.3 Database Technology

Database technology has evolved to enhance information usability and to provide adaptive interfaces. Relational and object-oriented data models are understood as two views of the same data services. Tables or spreadsheets are a conventional mechanism for accessing and manipulating enterprise data. The semantics associated with data objects are supported by the cell objects in the tables or spreadsheets. Hybrid databases have developed as a mechanism to evolve "legacy" databases, such as those in older hierarchical or relational database management systems, into the newer database servers.

3.3.4 Networks, Archives, and Development Information

Although network capacities and data storage capacities have increased dramatically, the complexity of the enterprises that they support has increased their utilization commensurately. Networks continue to have a backbone and hub architecture, with local networks attached at the hubs. These hubs are the loci of common and application framework services. Mainframe computers have evolved to data servers functioning as the network hubs. They provide electronic vault and archive facilities for data that will have historical significance, such as released versions of engineering data, documentation, and safety and maintenance data as required by law. Data for work in progress is stored in local, project-team (workspace) databases at workstations or local hubs that serve development teams. These network hubs also provide enterprise-wide peer-to-peer communication services (e.g., electronic mail).

3.3.5 Legacy Systems

The cost of acquiring data is generally recognized as greater than the cost of storing the data. Strategies for hybrid database systems allow use of "legacy" systems in a static mode, coexisting with successor systems that are serving updates and other dynamic requirements. Hybrid combinations of database systems enable an evolutionary migration of already acquired data into newer integrated systems.

3.3.6 Process Models

Process models have extended beyond the input-control-output characterization of a process to include formal description of the actions taken to effect the process. Process modeling is a common practice in designing or validating an integrated system, but there are as yet no standards for formal, on-line characterization of a process model. Leading edge organizations have developed proprietary formats to represent their process models and are using the models to manage the automated portions of their integrated enterprise.

3.3.7 Adaptive Interface Technology

Adaptive interface technology provides an object-oriented mechanism enabling data servers and clients to exchange data, requests, and responses. Adaptive interface technology is required because users have realized that the value of information depends on proper use of data in context. Data is owned by a server that acts as the steward of that data and of the information that it represents. The steward provides access to the data, or transfers the data to a user's system. In addition, the steward responds to queries about how to interpret the data, and the steward performs services on the data in response to client requests. Available services are published by the steward as a standard set of interfaces that can be used to request services and other descriptive information.

3.3.8 Operational Integration Frameworks

Operational integration frameworks provide the architecture within which a server publishes the services it provides. These frameworks may be acquired in the open marketplace and are built to standards. Framework standards specify common services that must be offered by all servers, generic services such as *open*, *close*, *print*, and *describe*. These frameworks are network resource managers for the enterprise and are provided as a network layer of the operating system (much as network file systems are today). Application frameworks contains extensions that are services applicable within a specific application domain. An example would be an electronic CAD Framework, with services for various design views. There may be cross-cutting, application-oriented frameworks as well. An example would be a framework for simulations, design of experiments, and their analysis.

3.3.9 Autonomous Systems

Autonomous systems are composed of many actors, each carrying out a process in the value chain of the enterprise, and stewards, each managing one view of a part of the enterprise. Adaptive interfaces enable these independent computations to collaborate in achieving the common integration of the enterprise. But each computation is in some sense autonomous. One sense in which a computation is autonomous is that a steward process owns the data that it serves and will prevent inappropriate manipulation of that data by taking unilateral actions if necessary. Another sense in which a computation is autonomous is that it is shielded from activities in the integrated system that are irrelevant to its own role.

3.3.10 Software Development Environments for Autonomous Systems

Programming an autonomous system requires software development environments that provide framework fixtures to emulate the environment of the computation under development, including monitoring its behavior against formal specifications. Different computations in an integrated system can run on different processors in a multiprocessor workstation or on different processors across the network. In this environment, compilers produce executable code that is linked dynamically with the service communication interface provided by the run-time framework. Software developers use network-oriented, communications-oriented parallel debuggers.

4. CURRENT STANDARDIZATION AND COOPERATIVE EFFORTS

Standards are important to information integration. The study team has developed a baseline of current standards and cooperative efforts to support the achievement of industrial information infrastructures for enterprise integration. During the study the team set out to:

- Identify, organize, and present available technology components from which a U.S. information integration strategy can be coalesced; these technology components are derived from current standards and from standardization and pre-standardization efforts.
- Identify specific opportunities to accelerate the development and adoption of components and/or to increase the likelihood of their success.

4.1 BASELINE REPORT

A companion study, IDA Document D-1386, *Current Standardization and Cooperative Efforts Related to Industrial Information Infrastructures*, provides an assessment of key standards and technologies that will be required over the next 10 years to build the necessary components of an information infrastructure. It establishes a baseline of 85 standards and technologies. Both public and proprietary standards are reviewed since important contributions to an information infrastructure will come from both sources. A brief description of each standard and technology is provided and its importance to information integration is assessed along with its current status. This assessment provides insight in developing strategies for the most critical standards and technologies that will be required for establishing a successful information infrastructure.[30]

The baseline report also profiles 27 organizations and programs that develop or support the standards and technologies identified. The organizations and programs are

[30] For another view of an overlapping set of standards, see Sarah H. Nash and Robert P. Walker, *A Survey of Technical Standards for Command and Control Information Systems*, December 1992, Alexandria, VA, Institute for Defense Analyses, IDA Paper P-2805, Draft.

described in terms of who is involved, what they are doing and how they link to other organizations and programs. Understanding the key players and their roles is important in developing an appropriate strategy.

The report relates organizations and programs to standards and technologies by summarizing their standards deployment (technology development and market building) activities. For this purpose and others in the report, standards and technologies are grouped into 10 technical categories based on the Advanced Manufacturing Technology (AMT) Standards Reference Model.

a. Integration Frameworks[31] and Architectures: Overall integrating representations, models, and schemata of the enterprise and its component parts.

b. Operating Systems and Distributed Environments: Components used to provide system services to applications.

c. Communications: Components used to connect applications, allowing applications to transfer data and control among themselves.

d. Data Management Systems: Components used to store, manage, and retrieve data.

e. User Interface: Components that allow users to interact with applications making up the integrated enterprise.

f. Information Modeling Tools and Methods: Tools and methods used to construct models of the enterprise and its components.

g. Application Development Tools and Methods: Tools and methods used to model and build applications.

h. Security Tools and Methods: Tools and methods used to control access to applications and data.

i. Data Representations: High-level data representation standards.

j. Programming Languages: High-level languages used to represent algorithms

Using the baseline data, a number of useful questions concerning the status of standards, technologies, organizations, and programs relevant to information infrastructures for enterprise integration can be answered directly. Examples of such questions include the following:

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[31] Note that this is the usage from the AMT category list. It is substantially more general than the notion of *Operational Integration Frameworks* as described in Section 3.3.8.

- What organizations and programs are concerned with information modeling?
- What standards and technologies are proposed or in place concerning user interfaces?
- What organizations and programs are involved with POSIX (Portable Operating System Interface for Computer Environments), and what are their interests?

Other questions, such as which of the standards and technologies are most critical to success in implementing a National Information Infrastructure, and what are their current status, require further analysis and often additional data. The specific analytic techniques needed, of course, depend on the question being asked. This report presents an example analysis of this last question, in the next section, to demonstrate the types of analyses possible with the baseline data.

4.2 EXAMPLE ANALYSIS OF CRITICAL STANDARDS AND TECHNOLOGIES

The approach is to relate the baseline standards and technologies to business needs. This relationship is established in a two-step process, first relating business needs to activities that an integrated enterprise may undertake to satisfy those needs, and then relating the activities to supporting technical categories and standards and technologies within categories. The analysis presented here is based upon work done by the Enterprise Integration Program (EIP) Needs Analysis team and makes use of the Quality Function Deployment (QFD) methodology.

The concept of QFD is to relate "what the customer wants" (needs and requirements) to "how product features meet those wants" (solutions). A chart is used to record the evaluation of how each solution contributes to each need or requirement. QFD supports decomposition, in that a solution at a higher level can, in turn, be considered a need at a lower level of analysis.

In this study, "what the customer wants" related to "how product features meet those wants" translates at the first level into "business needs" related to "activities," and at the second level into "required activities" related to "standards and technologies," using material from the Enterprise Integration Program Needs Analysis team (see Figure 5). The baseline standards and technologies relate to aspects of successful standards development and deployment, using criteria from the NIST APP (Application Portability Profile) and the POSIX OSE (Open Systems Environment), with some additional criteria by the study team.

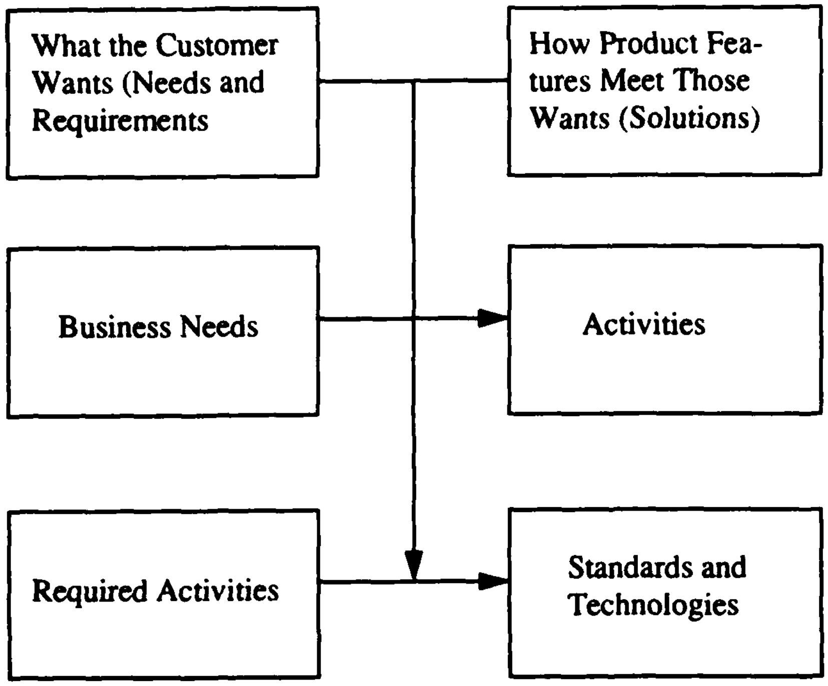

Figure 5. Relating Business Needs to Standards and Technologies

The results of the QFD analysis are presented in Figures 1, 2, and 3 of IDA Document D-1386, *Current Standardization and Cooperative Efforts Related to Industrial Information Infrastructures*, and are summarized in Table 4. For most technical categories, a small number of standards and technologies dominate. The standards and technologies are divided into two major groupings: Proprietary and Open. The following paragraphs summarize the analysis of the key standards and technologies for each category.

Integration Frameworks and Architectures. This category is characterized by a relative absence of standards activity. The CAD Framework Initiative (CFI) is one of the few open systems efforts, but it is currently limited to a particular application area. An open, non-proprietary framework, similar to SAA (Systems Application Architecture), NAS (Network Application Support), GM-C4, or NewWave, is yet to be developed. The NIST APP is a start, though it tends to be a *collecting* framework rather than an *integrating* one. Proprietary solutions are beginning to appear and there are related research efforts.

Operating Systems and Distributed Environments. Three different types of functional subareas require attention: traditional operating systems, distributed environments, and distributed object management systems. Assuming that current micro-kernel

Table 4. Important Standards and Technologies by Category

Category	Importance	Proprietary			Open		
		Name	Importance within category	Status	Name	Importance within category	Status
Information Frameworks and Architectures	10.0	NAS GM-C4 NewWave SAA	10.0 9.2 8.9 5.6	5.8 5.2 4.5 5.6	APP CFI	9.0 5.4	3.9 5.2
Operating Systems and Distributed Environments	9.5	OO-CORE DCE NetWare	7.7 6.1 3.3	3.5 5.8 6.2	OMG OSF/1 SVR4	6.8 5.0 4.6	3.7 4.7 6.2
Communications	6.6				MAP/TOP GOSIP TCP/IP X.500	7.3 6.4 3.9 3.9	6.0 6.2 6.8 7.4
Data Management Systems	6.5	OOSQL	7.8	3.9	SQL IRDS2 RDA SQL IRDS1	7.8 4.0 3.7 2.8 2.1	3.9 3.7 2.7 8.8 4.3
Application Development Tools and Methods	5.5	PlantWorks KBS (Application Development) Application Generators	3.1 2.9 2.6		IDS X/Open + POSIX APIs	2.6 2.3	2.7 6.2
Data Representation	5.4				STEP SGML EDI	6.5 3.6 3.5	3.3 6.0 7.4
Information Modeling Tools and Methods	4.8	KBS (Information Tools) Yourdon	4.4 2.1	4.5 6.8	SUMM IDEF0 IDEF1x	3.2 2.1 2.1	2.5 5.4 5.4
User Interfaces	2.3				POSIX 1201 (XVT) Motif Open Look X-Windows	3.2 2.9 2.9 2.4	2.7 6.4 5.6 7.2
Programming Languages	2.3				Ada C++ C Fortran	2.7 1.6 0.9 0.7	6.8 5.4 8.8 8.8
Security Tools and Methods	1.8				POSIX 1003.6 DES	1.8 1.4	2.5 6.6

efforts like the Mach operating system project are viewed as implementations rather than standards, Unix derivatives are the primary contenders for the traditional operating system. SVR4 from Unix International and OSF/1 from the Open Software Foundation, both of which reference the POSIX standard, scored highly in this evaluation. The many Unix derivatives being developed emphasize the importance of moving the POSIX efforts forward so that a common standard exists. Both SVR4 and OSF/1 are beginning to develop capabilities to support distributed environments as well. A key contributor in this area is the ISO in its Open Distributed Processing (ODP) effort to develop a reference model for future distributed processing standards. Distributed object management is also emerging as a critical technology for the future. IBM has developed OO-CORE to support object management. The Object Management Group (OMG) is also heavily involved in promoting object standards (such as the Common Object Request Broker Architecture, or CORBA).

Communications. The need for standards in the area of communication has long been recognized. The Open System Interconnection (OSI) family of standards (e.g., MAP/TOP, GOSIP—the Government OSI Profile) dominates this category. TCP/IP (which was often the third member of the list) must also be considered both because of its large installed base and open nature. The OSI standards define more functionality than TCP/IP, but TCP/IP is on a trajectory where it is continuing to adopt OSI functionality. It is still seen by many as an interim step to full OSI compatibility.

Data Management Systems. The first ANSI IRDS standard (IRDS1) is based on the relational model. It defines the information captured by an Information Resource Dictionary as well as the services provided by enterprise processing facilities. Future object-oriented systems are focusing on the second IRDS standard under consideration. The high level of interest in this work indicates the importance of this relatively young effort. The Remote Database Access (RDA) protocol is seen as an important standard to enable the operation of distributed databases. Object-Oriented SQL (OO-SQL), an object-oriented extension to SQL, is used as the data manipulation language developed by IBM as part of its OO-CORE project. The importance assigned to OO-SQL and OO-CORE indicates the need to bring these technologies into the public arena where an open evolution process can take place.

Application Development Tools and Methods. The X/Open APIs define a tool kit of program interface calls across a number of functional areas. This effort stands out in its effect on architectural and business needs. However, other useful tools and methods are proprietary in nature, such as application generators and knowledge-based systems.

Although seen as important, there are no visible standards activities associated with these areas.

Data Representation. This area has also experienced intense standards activities. There are many different domain-specific data representation standards. Combining scores across a spectrum of requirements emphasizes those standards that have the broadest intended scope such as STEP (the Standard for the Exchange of Product Data). STEP is an important ISO effort bringing together several national efforts to build an engineering data exchange specification. Much work remains in the development of Application Protocols and test tools. Other important representation standards include the ANSI EDI standards for exchanging business documents, SGML for document markup, the Programmer's Hierarchical Interactive Graphics System (PHIGS) which is a three-dimensional graphics standard, and the Computer Graphics Metafile standard (CGM) which defines a graphics file format.

Information Modeling Tools and Methods. IDEF0 and IDEF1x are important standards for process and data modeling for large organizations. There are, however, many different modeling tools available. SUMM is an effort to define the mechanisms that will allow integration of data models and schema defined by various modeling languages. Knowledge-based systems are also being used for information modeling, but no significant standards activity could be found on this.

User Interfaces. X-Windows is a key standard and is also found integrated with higher-level functions in Motif and Open Look. Motif (OSF) and Open Look (Unix International) provide extensive libraries for building graphical user interfaces. The IEEE POSIX 1201 effort is important because it is attempting to build a single common application interface (using the Extensible Virtual Tool kit, XVT) that sits above Motif and Open Look.

Programming Languages. This area already has a number of well-developed standards and technologies (Ada, C, Cobol, Fortran, Lisp), and primarily needs only maintenance. Extensions for objects (e.g., C++) or APIs (e.g., X/Open) are the key development activities.

Security Tools and Methods. IEEE POSIX 1003.6 is a key standard under development. It is intended to provide comprehensive security access and control for applications.[32] Data Encryption Standard (DES) is an encryption standard that is now part of GOSIP.

An artifact of using a broad (business or technical) requirements-driven method is that the results emphasize those standards and technologies that are more broadly based. However, any strategic plan must consider the difficulty of integrating these standards and technologies with the legacy of existing and future proprietary solutions. Systems based on today's operating systems (MS-DOS, VMS, Unix), windowing environments (MS-Windows, Macintosh, X-Windows), and networks (Novell and TCP/IP) must be able to fit within the information integration infrastructure. In fact, there has been some success mixing these principal components to construct usable information infrastructures. A U.S. industrial information infrastructure must support these and other very popular technologies.

4.3 CONCLUSIONS AND ISSUES

The analysis of critical standards and technologies and their current status presented here is heavily dependent on the choice of framework or reference model for expressing "what the customer wants." The use of requirements derived from business needs, as in the EIP Needs Analysis task, can be defended as reflecting the wants and perceptions of those who must ultimately pay the bill for enterprise integration. It also includes the organizational, procedural, and personnel aspects of enterprise integration, as well as the technical ones.

Also, this analysis takes a broad view of the importance of standards and technologies in meeting the general needs of an information infrastructure. It does not differentiate between standards and technologies with a broad scope and those addressing a narrow set of requirements. With those caveats, some general conclusions can be reached:

a. Operating systems, distributed environments, integration frameworks, and architectures are critical foundation technologies that must be established. These categories scored the highest across all evaluation frameworks. Several potentially important standards and technologies were identified. Since much of the work in this area is proprietary or consortial, there is still a need to promote standards in these areas. The lack of unifying standards may lead to market fragmentation that will slow the development of an information integration infrastructure.

b. Data management, communications, and data representation standards and technologies are next in importance. The information infrastructure requires standards that support highly integrated information management systems

[32] But see the discussion in Section A.3, SECURITY RISK MANAGEMENT AND INTEGRATED ENTERPRISE INFORMATION PROTECTION, in Appendix A, for a broader view of this issue.

across the entire enterprise. The need for standards in these areas has long been recognized as evidenced by the preponderance of standards available. There is still a need to organize these standards into a consistent framework and to ensure that they are compatible.

c. Other categories such as application development tools and methods, security tools and methods, user interfaces, information modeling tools and methods, and programming languages are also important. Standards and technologies in some of these categories are more important in the development of applications. Since this report focused on an information infrastructure, they did not score very high.

The importance of integration frameworks supports the necessity of identifying a reference model that can be used to guide the selection of standards and technologies for an integrated information infrastructure. A detailed reference model identifies the major architectural elements of the information system and their interrelationships. It also provides a framework for identifying needed interface, representation, or other standards. It provides an organizing structure that helps to characterize the standards and technologies and their relationships.

The need for a reference model is widely recognized. As a result several activities are developing reference models in this area, including proprietary models (GM C4), vendor models (EIS Working Group (EISWG)), and standards efforts (CIM/OSA). Consensus is needed around a single reference model (or group of related models) from which a coherent set of standards can be developed. These models must be driven from clearly articulated and prioritized business needs. The information in this report and its companion report, IDA Document D-1386, *Current Standardization and Cooperative Efforts Related to Industrial Information Infrastructures*, lays the foundation for capturing some of these critical business drivers. Future tasks should look at how well these business needs are captured in current and emerging reference models.

A single reference model, with its benefits for analysis and decision-making, does not imply a single view of information integration. Business needs vary with the corporation, its market sectors, and its strategies. It is unlikely that a single set of standards will emerge to fit all these varying needs. Still a well-designed reference model can support profiles of standards suited for different needs (such as the use of the OSI reference model for communications standards). Future analysis should look at this question in greater detail. Business needs should be captured for different segments of the industry in order to identify the major profiles that may be required to meet those needs.

Further, at least in the context of a national information infrastructure, other demands besides those of industrial enterprise integration will help shape the infrastructure. A national information infrastructure is viewed by many as doing "... for the flow of information—words, music, movies, medical images, manufacturing blueprints, and much more—what the transcontinental railroad did for the flow of goods a century ago and the interstate highway system did in this century...[It can be] a national resource that would improve education, health care, scientific research, and the ability of corporations to compete in the world economy, among many other things."[33] To the extent that analogies with, for example, the interstate highway system can be accurate, then unanticipated uses of the infrastructure and resulting major changes in the way the nation lives and works will occur. Some of these uses and changes will come from the industrial sector, and be adopted by others. But others, equally attractive, will come from outside of industry and be adopted by that sector. It is important that any reference model be flexible enough to incorporate this pattern of infrastructure development.

From a standardization point of view, three areas for future work emerge from this study:

- Redo analysis with common reference model.
- Assess compatibility of standards.
- Determine missing standards and technologies.

As critical standards and technologies are identified, effective deployment strategies must be put in place. It is never sufficient to simply bring a standard to approved international standard status or to prototype the technology. The Deployment Forces Tables and the Standards and Technology Status Matrix in IDA Document D-1386, *Current Standardization and Cooperative Efforts Related to Industrial Information Infrastructures*, identify some of the activities and issues which determine the success or failure of a standard or technology. A strategy to deploy critical information technologies must take these issues into consideration.

It is important to maintain a sense of timing and evolution about infrastructure development. The U.S. Air Force's Enterprise Integration program is an effort focused on identifying appropriate responses to near-term demands for information integration. Likely,

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33 "Building the Electronic Superhighway," *New York Times*, January 24, 1993. Much has been written since this article presenting various visions of the NII. Nevertheless, the goals stated in this article are widely accepted among those directly interested in the effort to create a new national information infrastructure.

these responses will take the form of finding ways to use existing and near-term standards and technologies more effectively. The anticipated needs 10 years or more in the future appear to require the development of new technologies and architectures leading to systems of autonomous modules. The development of strategies and methods for aiding the transition towards these forms of information integration must be planned and pursued.

5. PRINCIPAL FINDINGS AND CONCLUSIONS

During the study many facts emerged that reflect the state and trends of current industry efforts to integrate. From these facts the study team derived 42 general findings.[34] Eight principal findings stand out as summarizing the experiences reported by a number of companies. These principal findings are presented in Section 5.1.

Based on review and analysis of this material, the study team developed several conclusions summarizing progress in enterprise integration and limitations of current approaches, the relationship of these efforts to a National Information Infrastructure and to national economic goals, and DoD's position and potential in enterprise integration. These conclusions are presented in Section 5.2.

5.1 PRINCIPAL FINDINGS

Extent of Enterprise Integration

Companies are making significant commitments and executing large efforts in the direction of enterprise integration. Significant results are being achieved, and companies now realize that achieving significantly more is feasible.

Justification for Enterprise Integration

The justifications reported for investing in enterprise integration tended to be intuitive, expressed in terms of competitive necessity and a sense of potential quality improvement and cost reduction, rather than the traditional cost-benefit analysis.

Incremental Approach

Most of the companies studied are implementing an incremental "continents of integration" strategy to support integration goals. They are moving from large numbers of loosely coupled activities and disconnected information systems ("islands of automation") to a small number of large islands ("continents"). Factors dictating this strategy include a

[34] The complete general findings are presented in Appendix A.

general lack of experience and scientific knowledge relevant to integration, the need to include legacy systems, and the existing organizational environment.

Current Culture, Infrastructure as Barriers

Corporate culture and current infrastructure are widely viewed as the dominant barriers to progress in enterprise integration. Current infrastructures are not constrained by the state of technology, except possibly for integration frameworks and architectures. The companies visited want more integrated infrastructures both because the current infrastructure is viewed as a barrier to integrated activities and because an integrated infrastructure would facilitate the information sharing on which integrated activities depend.

Role of Management Sponsor

Several companies reported that a high-level sponsor is critical for moving forward successfully with enterprise integration. The sponsor, typically a president or a vice-president, needs to be in the common chain of command in order to resolve impasses between groups, and to smooth management delays between the project management level and the sponsor's level. This sponsor tended to be the Least Common Manager above the groups to be integrated. Only very strong, constant, and visible top leadership can overcome cultural barriers of the sort commonly encountered.

Change Management a Critical Problem

Management of change and the required evolvability of information infrastructures are critical problems for all companies studied. Changes range from very large to highly focused, and may be *ad hoc* or permanent. Changes affect the structure and content of both information and control flows, in both the human and the automated sides of the enterprise. Most implementers regard assistance with change management as a key goal of information integration. They require system solutions that are designed and implemented to facilitate change in the infrastructure itself.

Role of Standards

While recognizing the benefits of widely accepted standards for enterprise integration, none of the companies studied are waiting for the development of appropriate standards. All are proceeding with enterprise integration using available products and technology, developing company-unique solutions where needed. Nevertheless, companies expressed a widespread desire for appropriate standards.

If the demand for standards were articulated with sufficient focus, strength, and indication of priorities, a focused response from the vendors would be elicited. Only a few of the studied companies prefer to rely on internally created systems with company-specific data representations, usually in search of a strategic advantage. In most cases vendors have an interest in widely accepted standards and would prefer their existence.

Lack of Scientific Knowledge and Accepted Engineering Practice

While increasingly complex integrated systems are being implemented, the understanding of scientific and engineering issues inherent in such systems is generally weak. Suggested ways to increase understanding include continued industrial efforts such as those reported in this study, demonstrations of new approaches in realistic settings, academic, government and industrial research, and development of new integration technology.

5.2 PRINCIPAL CONCLUSIONS

Achievements of Current Approaches to Enterprise Integration

The achievements of U.S. industry in implementing enterprise integration should be applauded. Many projects have been undertaken, by many firms, with promising results. There have been real, significant benefits in terms of quality improvements, cost reductions, and cycle time reductions. These achievements should be acknowledged. At the same time, they should be reviewed in terms of identifying and understanding the problems and limitations revealed, as well as the successes.

Technical Limitations of Current Approaches

The incremental "continents of integration" approach used by most companies studied has enabled successful integration in uncertain situations. However, it has several potential drawbacks. A large investment in an "island" may create an inertial barrier against future integration, since required change can be seen as devaluing the original investment. Coordination of integration efforts across "islands" within large companies, necessary to ensure a consistent evolvable approach to integration, is typically very difficult. Without providing for evolvability, separate "islands" may adopt incompatible infrastructure mechanisms, thereby incurring either re-implementation costs or increased system maintenance costs. Thus, the "continents of integration" approach, while allowing early progress, may be, in the longer term, self-limiting.

The absence of relevant standards, represented in products obtainable in the market, means that most firms are achieving integration results by inventing in part their own solutions to particular problems. While this approach allows progress now rather than delay in waiting for the market, it also means that future integration, intra-firm and inter-firm, may have to deal with the results of successful earlier integration efforts as legacy systems, to be worked around or converted at additional cost.

Formal standards are more important for inter-organization enterprise integration than for intra-organization integration, as they provide an accepted alternative to negotiating unique solutions to integration problems. As time passes and more firms integrate internally, inter-organization considerations will become dominant.

Undoubtedly, holes and overlaps exist in the current coverage of standards for various aspects of information infrastructures. The lack of an accepted framework or reference model for information infrastructures makes it extremely difficult, if not impossible, to identify these holes and overlaps. The absence of a framework, and inconsistent standards coverage, will become increasingly relevant limitations on enterprise integration as it expands beyond the boundaries of individual organizations.[35]

Organizational Limitations of Current Approaches

Companies engaged in enterprise integration are forming an internal base of experience, but this learning is not being disseminated widely. Mechanisms for sharing experience and identifying common successes and failures are lacking. In the longer term, systematic sharing of experiences about how to integrate effectively should provide a real economic benefit.

With some notable exceptions, successful inter-organization enterprise integration has been much less common than intra-organization integration. Why is this so? (Exceptions include automotive industry supplier-manufacturer integration and prime contractor teams for military aircraft development, and have tended to depend on use of homogeneous tools or platforms.)

- The consensus among those engaged in enterprise integration is that current cultural and organizational arrangements present the most significant barriers to

[35] These issues are discussed in detail in IDA Document D-1386, *Current Standardization and Cooperative Efforts Related to Industrial Information Infrastructures.*

progress. In most cases, *present* technology is seen as meeting *present* integration needs.

- However, overcoming the barriers arising from organizational culture is much more manageable within a single organization than across organizations.
- Within hierarchical organizations, the presence of a high-level management sponsor can work to resolve issues.
- Within project-oriented organizations, the culture typically facilitates cooperation and negotiation as the preferred method for solving common problems.
- Between disparate organizations, mechanisms for dealing with conflict are not as developed.
- As enterprise integration expands beyond the boundaries of any single organization, problems of conflict-resolution in the context of disparate organizational cultures will come to the foreground, and resolution techniques beyond mandating a common integration platform will be needed.

Relation to Business Objectives

Successful integration activities are generally those that follow from agreed-upon business objectives and that do not go (to far) beyond the knowledge basis and understanding of integration available to the enterprise.

Relation to National Information Infrastructure

Enterprises using the National Information Infrastructure will often be using that infrastructure to integrate different organizations. Standards coverage is thus highly relevant to successful use of that infrastructure. There is a strong need to start working now toward the specification and adoption of one or more *integration frameworks* and architectures, and the identification of weaknesses in standards coverage.

Relation to National Economic Goals

Enterprise integration holds promise for enhancing the competitiveness, both locally and globally, of U.S. firms. The improvements previously depicted in Table 2 already realized from first steps toward integration have demonstrated that promise. Effective participation in the global economy requires enterprise integration almost by definition. This means both that existing multi-national companies are a source of experience with integration and that successfully integrating firms are likely to become, if not multi-national themselves, partners of multi-nationals.

The effect of enterprise integration on employment is problematic. Enterprise integration viewed as automating information and control processes seems likely to result in the same job reduction result as is being experienced in other areas of automation. At the same time, achieving enterprise integration requires the development and deployment of many new hardware and software products, involving a great deal of skilled problem solving. Efforts to deal with job displacement and retraining need to be sensitive to these effects, both of potential job loss and the need for new skills.

DoD's Position and Role

In many senses DoD is the prototypical enterprise, with multiple suppliers, numerous customer programs, highly technical and information-flow dependent products and processes, people and operations physically located throughout the world, and a complex internal organization. As such, DoD stands to benefit greatly from enterprise integration. And DoD can expect the same problems in achieving success with integration as other organizations. For example, technology will not be the problem; culture clashes within the organization and overcoming the existing information infrastructures will.

Today, with a few exceptions, industry is well ahead of the DoD in successful integration. The DoD has much more difficult hurdles to overcome in achieving successful automation than most enterprises. The DoD must place relatively more emphasis, early-on, on inter-organization integration, which can be significantly harder to achieve than intra-organization integration. This difficulty is further aggravated by the framework of legal and procedural limitations within which the DoD must operate. Successful integration will demand that some of these barriers perceived by contractors and DoD personnel alike be removed. The DoD's potential for quality improvement, cost reduction, and responsiveness improvement are commensurate with these problems.

6. RECOMMENDATIONS

Enterprise integration makes company processes such as design, manufacturing, and business operations (including overhead processes) work in concert to become more effective and efficient. The basis of enterprise integration is the interaction of integrated activities (such as IPPD, concurrent engineering, integrated manufacturing) and integrated information systems. Applied on a large scale, benefits of this interaction result in large cost savings and shorter times to field systems with the latest technologies; products can be developed and built by integrated teams formed rapidly to meet the needs of defense or civilian customers. As shown in this report, the benefits can be dramatic even when circumstances challenge progress.

DoD efficiency objectives—lower costs, shorter schedules, and higher quality of DoD products—can be achieved by enabling industrial implementation of re-engineered and integrated processes with intense, interactive use of supporting information systems. While there are high-level dialogues on implementation of integrated and re-engineered processes (for example, recent Defense Science Board studies on IPPD), there is inadequate high-level dialogue on acceleration of integrated information systems to support the proposed new processes.

DoD executives, managers, and planners should recognize that improving the efficiency of industrial processes on a scale to benefit DoD and the national economy is a large but approachable issue. Leading practitioners of integration point out that tenacious, multifaceted attacks are necessary even within individual companies. The DoD should, therefore, create multiple angles of approach, in the Services and Agencies, from advanced technology developments and demonstrations through pilot implementations and various styles of insertions into acquisition programs. The achievable target of widespread and very significant efficiency improvements in industry and DoD acquisitions is important and should not be compromised for short-term and relatively minor investment savings. Coordination will have to be dynamic and flexible in order to identify winning approaches and propagate them. In this way, near-term returns on investment, such as those experienced in the cases reported here, can be achieved and expanded.

Strategies

DoD and the Services can encourage and enable industrial implementation of the required processes and systems by implementing the following strategies:

- Exert leadership: Use the National Information Infrastructure initiative to create an environment for industrial information integration; create rapid-response task forces for government and industry development of a shared vision for re-engineering DoD acquisition processes, information requirements, and information systems that are traditionally mirrored by the defense industry; and then implement the vision.
- Act as informed customers of informed suppliers: Modify acquisition interfaces, information deliverables, and incentives to create a "pull" on appropriate industry actions
- Form partnerships: Participate in coalitions with industry to accelerate *de facto* standards and to support selected emerging formal standards for information system interfaces and elements (for example, design representations and common network services) which will enable information system integration and accelerate change
- Demonstrate and advance technologies: Mitigate the risk in developing high-risk elements needed for large-scale, dynamic, and rapid integration; these demonstrations and developments will advance the state of the art, provide process performance results to act as a basis for industrial adoption, establish directions for vendor products and network services, and accelerate technology transition into the information management marketplace.

The specific recommendations are organized to implement these strategies through industry and DoD actions. The findings and conclusions of this study show that the reported benefits derive from a close coupling of information system integration with process re-engineering to address cultural, organizational, and policy issues. Although the study focused on information systems and technologies, findings related to management and culture led the team to recommend leadership and management actions to move forward in this critical area.

Implementations

Two implementation approaches should be applied, usually simultaneously, to projects started in response to the specific recommendations:

- Incremental implementations: Focus on part of the process first and then expand.
- Application-driven implementations: Focus on product-type-specific processes first and then generalize.

Incremental implementations are feasible and desirable if long-term *evolvability* is kept as a critical requirement. For example, several enterprises have started their implementations by focusing on the product realization process from the engineering process point of view. Rapid IPPD, with support from integrated, distributed product/process engineering frameworks, tools, and information bases, can be implemented based on existing methods and technologies and can be scaled up using emerging concepts and tools. Another starting point is in integrated, flexible manufacturing operations with incremental, interactive resource planning, intensive information linkages with suppliers, and real-time integrated factory control. Any serious effort at either of these should be designed for integration with the other so that efficient design/manufacturing trade-off, feedback, and change management would be possible. Building onto these foundations, business systems could be integrated allowing rapid enterprise resource planning (rather than just manufacturing), strategic trade-off decisions, and fully flexible electronic commerce.

Second, implementation strategies should be *application driven*. Past efforts have shown that generic approaches to concepts such as IPPD are seen as too abstract and having limited success. Basing the implementation of information technologies for enterprise integration on specific product types or sectors will yield the knowledge required for generic solutions. It is important, however, that the intent to generalize be represented by specific requirements in every application-driven program and that mechanisms be established to harvest the results of the specialized programs and to develop generic approaches. These mechanisms should be planned to be available from the open market and then fed back into specific product developments.

The time to act is now. The technologies to start the process are available, the approaches to be explored for mid- and long-term progress have been identified by the technology community, the past approaches that form barriers to integration are still reversible, the need for integration has been widely recognized in industry, and the climate for infrastructure investment by government is favorable.

Specific Recommendations

The following specific recommendations are derived from the findings and conclusions of the study and organized according to the above listed strategies. They are directed not only to the immediate sponsors of the study (ARPA, USAF ManTech, and OSD CALS) but also to high-level DoD and Service management and industry planners.

* * * * *

1. Defense Leadership

1.1 ARPA should establish a focus area for industrial information integration within the National Information Infrastructure initiative.

The DoD, through ARPA's participation in the National Information Infrastructure (NII) effort, has the opportunity to seed the technologies, standards, and services required for wide-area, scalable, and widely used industrial information integration. In addition to the traditional focus on underlying technologies, such as high-speed networks and communications protocols, this initiative can enable ARPA to prototype and demonstrate the capabilities required to address the compelling national issue of industrial efficiency and effectiveness. Instead of using application areas simply to motivate underlying technologies, ARPA should pay considerable attention to the exploitation of the infrastructure by industrial users interested in leading to new ways of doing business. There is technology available now to begin, and there are open technological issues to be explored by partnerships of industry, government, and research organizations. A basis for beginning is described in Recommendation 4.1. These new industrial uses of the NII will simultaneously stress the underlying assumptions of the prototype networking services and help U.S. industry understand how to use the new capabilities to maximum advantage for international competitiveness. The result will be a better and more immediately useful NII and a more efficient U.S. industrial base.

1.2 DoD and the Services, working with industry, should establish a consensus vision of enterprise integration and set an example of integration within their own acquisition processes.

DoD and Service acquisition and technology organizations should stress the priority of integrated enterprises and integrated information systems to both government and industry. To make this credible, DoD and the Services should work with industry to set goals, objectives, and characteristics of integrated enterprises, and then establish a phased program to both re-engineer government acquisition processes and integrate supporting information systems. This would create a model for industry and provide processes and systems to which industry can link. Repeated evidence from leading companies indicates that sustained commitment by the OSD and Service acquisition and technology executives will be required for these efforts.

Scalable integration and re-engineering of activities and integration of the information infrastructure are intertwined. To achieve maximum benefits, top-level industry and government executives should integrate the planning and execution of process re-engineering, streamlined business practices, and information management improvements. Within DoD, current actions related to implementation of IPPD by the Office of the Secretary of Defense (OSD) and the Services can serve as a focus for actions to develop and implement integrated information systems. These actions should also focus on integrating the information requirements from contractors (see Recommendation 2). This approach will help contractors drive toward the use of integrated enterprises on DoD projects. The systems would initially be implemented to support the newly integrated processes associated with IPPD implementation. OSD, USD(A), and the Services should each establish appropriate task forces and executive-level directions to initiate planning for streamlined processes and their integrated information systems. Process owners should be engaged by OSD and Service managers so as to encourage process change.

While the goal of the above is across-the-board redesign of acquisition processes and their associated information management, the focus on IPPD points to two kinds of focused DoD opportunities. First, the front end of acquisition, as executed by the Science and Technology (S&T) program, can be reoriented to more integrated approaches through the use of new advanced technology demonstrators in the lead programs in each of Thrusts 1 through 5 and 7. Then the MS&T program could be used as a link with the acquisition phases beyond S&T through a set of pilot programs providing high-visibility examples of integrated processes in demonstration/validation (DEM/VAL), engineering and manufacturing development (EMD), and modification and upgrade programs.

Industrial liaison to support these activities can be established through existing organizations that have demonstrated concern for and understanding of the issues. They should be used to identify inhibitors to integration in fundamental DoD and Service policies and to suggest different approaches that can realistically be expected to be adopted by industry. Example organizations that could be used include the Defense Industry Affordability task force of the National Center for Advanced Technologies (NCAT), the CALS Industry Steering Group, and the Industry Forum for Agile Manufacturing.

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2. Informed Customers and Suppliers

DoD and the Services should integrate deliverables within both acquisition and technology programs, creating incentives to motivate industrial process and information system integration.

As part of their enterprise integration efforts, DoD and the Services should charter process re-engineering task forces to develop new interfaces and deliverables for Defense acquisition and technology programs. The new interfaces and deliverables should specifically motivate industry integration of its processes and supporting information systems. Past experience in government and industry has shown that these efforts must be led by the line managers who control and are responsible for the processes in question. The re-engineering efforts can be facilitated by such organizations as CALS and the OSD Functional Process Improvement Office (under the auspices of the Assistant Secretary of Defense (C^3I) and the Deputy Assistant Secretary of Defense (Information Management)), and they must be visibly supported and demanded by top management, but the line-management process owners must actually be responsible and authorized to execute the re-engineering.

The separate functional or "stovepipe" requirements currently typical for contractual deliverables act as inhibitors to industry information system and process integration and would inhibit Defense use of well-integrated civilian industrial capabilities. In support of the process integration efforts described above, the efforts started by the DoD CALS program to define integrated weapons system data bases and Contractor Integrated Technical Information Services should be accelerated to replace current separate CDRLs for separate functional areas.

The development of industrial integrated information systems should be an evaluation factor in source selections and an explicitly allowable cost for internal R&D and implementation phases.

The Principal Deputy Undersecretary of Defense for Acquisition (PDUSD(A)), with the visible support of the Deputy Secretary as needed, should oversee the implementation of this recommendation by line managers in the Service acquisition and technology organizations and by the OSD and Service owners of source selection and allowable-cost policies.

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3. Partnerships

DoD technology organizations, cooperating with other interested federal agencies, together with leading industrial firms, should establish partnerships to develop information infrastructures to support integrated industrial activities.

DoD organizations such as ARPA and the MS&T offices should enter into strategic partnerships with the U.S. firms, both commercial and military, most advanced in implementing information systems for enterprise integration, and with other interested government organizations such as NIST, Department of Transportation, and Department of Energy. The objectives would be to share experience on implementation approaches, metrics, test and validation, and, where appropriate, to share the risk in technology developments. These partnerships should be as free as possible of federal acquisition constraints so as to enable the participation of firms that do not normally contract with the government. The partnerships should be built within Advanced Technology Demonstrations (ATDs) and MS&T pilot programs executed in settings grounded by real applications. DoD should evaluate leading company-specific implementations for potential DoD-wide application and should then support generic information technology developments by vendors so as to accelerate availability of vendor-supported products. The goal would be to shorten lead times, from feasibility demonstration to commercial availability of products based on *de facto* and appropriate formal standards, from an estimated 8 to 15 years at present to 2 to 3 years. The FY94 Technology Reinvestment Project (TRP) should be focused on support for high-leverage design and manufacturing technology efforts. The ARPA Shared Infrastructure Program could be used to support and coordinate the activities described in this recommendation.

Commercial firms rarely consider the opportunity to gain leverage by cooperating with government in the development, demonstration, and deployment of technologies that would improve industrial processes and for which the government could provide an appropriately neutral planning environment. DoD and other technology development agencies, however, are increasingly open to civilian and military industrial cooperation in planning and developing the required technologies. Since government appears willing to support pre-competitive industrial cooperation to implement industrial information infrastructures, industry, particularly those organizations that do not normally engage in government contracting, should participate in government activities (such as the TRP and its successors) that can help develop and deploy broadly applicable and desirable technologies. Industry should also advise government agencies seeking to cooperate with industry on how best to structure government activities to allow commercial participation, eliminating the undue burdens of the government acquisition system.

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4. Technology Demonstrations and Development

4.1 DoD acquisition and technology organizations should implement programs that demonstrate innovative concepts and information systems for enterprise integration.

Metrics and Benchmarks: DoD should plan for ATDs and pilot programs to develop measures of effectiveness for enterprise processes (for example, design, manufacturing, purchasing, partnering) and evaluate these as part of the demonstration phases of the programs. This may be the highest leverage area for accelerating implementation on a broad scale if the demonstrations are done on real products in real development and production facilities and if schedules are reasonably short or well phased. To support this, the DoD should sponsor a series of efforts by contractors, the Services, and industrial cooperative organizations to establish enterprise metrics such as cycle time, cost, and quality; enterprise information metrics such as information cost, response time, latency, and quality; and benchmarks with respect to these. The Agile Manufacturing Sector Institutes and related pilot programs should make this a priority area and develop comprehensive programs for achievement of this recommendation.

Single and Multiple Company Integration: Technology developers and demonstrators should attempt a balance between inter-company and intra-company integration requirements, using common approaches where feasible. This requires demonstrations of single firms and teams of firms in IPPD environments.

Small Business Integration: In view of the role of small suppliers in inter-company teaming, special effort should be made to address small business affordability issues. The Industry Forum for Agile Manufacturing is chartered, in part, to work with DoD to address information infrastructure and integration issues at the small business level. It should be used as a liaison with industry on this issue.

Network Services and Distributed Products: DoD should conduct one or more demonstration programs to assess the potential effectiveness of network services in accelerating multi-enterprise integration. This would be an economic alternative or complement to widespread acquisition of products based on either interface standards or generic vendor products. The demonstrations could be part of the S&T Thrust 7 infrastructure program (perhaps the Agile Network demonstrations) and would include product/process definition and EDI services. Value-added network services for design and manufacturing would be an important element of the NII.

NII Manufacturing Services and Interfaces: In general, a plan is needed to develop and demonstrate a family of services and interfaces to support manufacturing applications of the proposed NII. ARPA should take the lead to see that the standards, specifications, and services required for industrial design and manufacturing applications of the NII are developed, demonstrated, and financed. This effort should be aimed at the further integration of the civil and military industrial bases through the use of generically applicable building blocks, available in the open marketplace, that will use the underlying information superhighways. A prototype NII manufacturing demonstration could be planned using ATD-funded design and manufacturing centers connected by the existing Internet.

4.2 DDR&E, ARPA, and Service technology organizations should implement an aggressive technology strategy to develop DoD industrial information infrastructures and to accelerate emerging threshold technologies.

DoD, in concert with leading companies, should formulate an R&D strategy to create a new generation of enterprise architectures, models, tools, and software systems, and to determine the potential for new business operations, engineering practices, and manufacturing concepts. To achieve potential functional and performance improvements, integrators should combine the leverage of several emerging threshold technologies, such as operational integration frameworks, object-based and knowledge-based product and process representations, application-oriented network services, near-term and mid-term solutions to database integration, and wide-area object brokerage and execution.

The strategy should be incremental and evolutionary, balanced more toward bottom-up and middle-out tactics rather than top-down ones, because of the lack of formal disciplines and the need for continuous feedback into the government/industry planning process. Such a strategy requires an exploratory attitude rather than one in which a static, monolithic plan is developed to drive all developments. It also requires underlying technologies that are designed to support evolution.

Operational Frameworks: In particular, ARPA and the Service pilot programs should establish an effort to demonstrate multi-layer operational frameworks for tool and information integration. Each of these operational frameworks should span a multi-company, multi-discipline enterprise. This program should have an objective of providing the United States with the lead in these critical integration framework technologies into the next century. This technology program should specifically address the needs for DoD and its aerospace contractors in more effective management of weapon programs throughout the life cycle. At the same time, the integration frameworks should be developed so as to be applicable, desirable, and transferable for use in civilian applications. To accomplish the latter, it will be necessary to engage appropriate software vendors in each R&D effort. Particular attention will have to be paid to the relative immaturity of open integration (as compared to that in electronics and software) within the domains of mechanical and manufacturing CAD/CAE.

Product/Process Representations: Evolvable product and process representations should be implemented in product-specific, multi-phase programs with a coordinating mechanism established by ARPA to derive and feed back generic technical and architectural approaches for use in later phases. ARPA should review the progress of the PDES/STEP standardization process and determine if additional efforts should be focused on rapid demonstration of approaches more advanced than those emerging from the current process. If so, ARPA should aim beyond current PDES/STEP activities by developing more advanced prototype representations of products and manufacturing processes in the context of ATDs and pilot programs. These advanced representations should enable representation of the semantic content of the data via object classifications, feature types, and knowledge representations as applicable. The representations should have sufficient depth to relate mission performance simulations to design characteristics and manufacturing process characteristics. This product-specific implementation approach allows the representations to be developed independently, encouraging rapid innovation. These advanced developments should be part of programs and projects that are developing new approaches to IPPD for the specific product classes. These independent representation developments should, however, be coordinated with respect to technical strategies so successful prototypes could be combined into a larger, reasonably coherent scheme of representations and form part of the operational integration frameworks required for enterprise integration.

Advanced Services: In addition to delivered-software solutions, some integration applications might best be executed as services on an easily accessible network. This allows for experts to guide execution, for access to unusual execution environments that might not be widely affordable, and for new business and management approaches to control of the software itself.

Legacy Database Integration: The challenge of legacy databases is very real in industry and will require workable near-term solutions such as semi-automatic wrapper generation as well as exploratory demonstrations of mid- and long-term solutions such as mediation and easy-to-tailor artificially intelligent agents. The ARPA Intelligent Integration of Information program is beginning to address these issues. This program should be expanded to cover a wider range of application demonstrations and exploration of more technological approaches.

Persistent Object Brokerage: In addition, ARPA should support recent industry efforts on persistent object brokerage (e.g., CORBA—Common Object Request Broker Architecture) and their extension to wide-area applications so that wide-area enterprises can be more easily integrated.

4.3 DoD technology organizations should take advantage of existing programs and industry cooperative efforts where appropriate.

Even though this study focused on industry rather than government programs, several programs exist with potential to evolve industrial information infrastructures for integration. The topic of information infrastructures is expected to be a significant part of the Technology Reinvestment Project (TRP). Selection and management of TRP programs should follow the overall strategy outlined here. Because of the high leverage of infrastructure to U.S. design and manufacturing, the follow-on to the current TRP should include a focused dual-use infrastructure program supported jointly by ARPA, the Departments of Commerce and Energy, the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF). The Thrust 7 infrastructure program (along with the Agile Manufacturing Program) could provide the national technology lead. The Thrust 7 ATDs should provide a demonstration test bed for intercompany integration focused on effective IPPD. A Thrust 7 ATD plan should be developed to implement this unique combination of IPPD test-beds and infrastructures.

Where applicable, planners, developers, and demonstrators should use forward-thinking, existing and emerging industry cooperative efforts to accomplish required industry liaison. This implies an understanding of the mechanisms and interests of various types of groups such as technology cooperatives (for example, the CAD Framework Initiative), industry-government cooperatives (such as the CALS Industry Steering Group), and formal standardization mechanisms (such as the ESPRIT AMICE consortium, the Object Management Group (OMG), the ISO STEP committees, and the sector-specific Automotive Industry Action Group).

APPENDIX A. GENERAL FINDINGS AND ISSUES

The companies visited reported two major kinds of findings. The first kind includes results that the studied companies are getting from integration activities supported by information infrastructures. These are reported in the main body of this document, Section 3.3.2 on page 59. The second kind consists of general, non-quantitative findings about the intent, extent, and structure of integration activities and their supporting information infrastructures. These findings, presented in Section A.1, are organized according to the same categories as described in Section 1.4 on page 7.

Many issues were raised by the companies visited. Most of these relate to differences of scale between a larger enterprise and a smaller organization. An enterprise must inherently deal with more diversity than its constituent organizations. Several frequently cited issues are discussed in A.2.

Several of the companies visited, especially but not exclusively defense contractors, mentioned that information protection and security were important issues to be considered in integrating the information infrastructure. In A.3, there is a discussion of the issues and the different approaches now used to address security risk management.

A.1 GENERAL FINDINGS

The findings of this study are a reflection of the current state and trends of industry efforts to integrate. They do not capture the state of the art from a research or even leading edge point of view, but rather describe the progress that is being made in the companies addressing integration issues. These findings are organized according to the same categories as described in Section 1.4 on page 7.

A.1.1 SCOPE OF ENTERPRISE INTEGRATION

a. Companies are making significant commitments and executing large efforts in the direction of enterprise integration. Significant results are being achieved,[1] but companies now recognize that achieving significantly more is feasible.

b. The notion of "enterprise" is recognized as encompassing supplier relationships (that is, the "enterprise" is the value chain that results in a distributed and marketed product), but the current implementation of enterprise integration is largely within companies or large divisions. There are exceptions in all three sectors, notably in aircraft projects, where this is due to the number of team members required to produce the large, complex product.

c. The notion of "integration" has several dimensions, each a continuum. For example, a company can be integrated to a greater or lesser extent in the sense of passing design information from the design engineering activity to manufacturing. Or its design engineering and manufacturing engineering activities can be integrated to a greater or lesser extent. Or manufacturing operations themselves can be integrated more or less.

d. Enterprise integration is a way to get groups of people and their machines to work together toward a common goal. It tends to decrease overhead and "hidden enterprise" costs, but it is not magic. A well-integrated company can still make wrong decisions, be affected by financial catastrophe, and the like. People who implement integration feel that it does make the company more quickly adaptable to unforeseen events. Integration is not easy to implement, though largely for cultural-organizational reasons.

e. Change management is a theme that appears in most discussion of enterprise integration and integration infrastructure. Ranging from very large to highly focused, changes may be *ad hoc* or permanent. Information and control flows change both in the human side of the enterprise and the automated side, with the nature of the information itself changing. The issue of "evolvability" and tailorability is a recognized issue. Some companies have made progress in accommodating change in their information systems. The National Center for Manufacturing Sciences (NCMS) project on computer-integrated manufacturing

[1] Selected results are summarized in Section 2.1.3 on page 16.

(CIM) has adopted the catch-phrase "design for change" to reflect the thrust of its efforts.

A.1.2 RELATIONSHIPS AMONG COMPANIES

a. Outsourcing is generally increasing.[2] The reasons for outsourcing include the results of cost/capacity analysis, quality of outsourced goods being better than like items internally produced, and increased internal focus on core competencies.

b. Relationships between supplier and purchaser are being strengthened. Purchasers are using fewer suppliers and are involving them more in end-product design decisions.[3] The decrease in the number of suppliers is being driven by the desire to increase quality both by decreasing variability in (the quality of) supplied items and by developing longer-term partnership-like relationships with suppliers. These partnerships are perceived as allowing greater integration of suppliers into the companies' processes. This trend was reported in many of the companies visited.

c. Subsystem, engineering, and manufacturing suppliers envision the benefit of *generic* information infrastructure solutions, as relieving the suppliers from acquiring and maintaining multiple systems to satisfy multiple customers.[4]

d. Most integration among companies is hierarchical in that one company dominates the integration culture. The dominant company might be a major customer imposing its internal infrastructure on its suppliers, or it might be a prime contractor mandating the program's infrastructure to team members.

e. Prime contractor teaming puts prime contractors in the same position as first-tier suppliers in the automotive industry: they must be prepared to use computer-aided design (CAD) systems that satisfy several different lead contractors. The nature of the negotiation on what systems to use on a given program, though, is a negotiation among more-or-less equals. The absence of standard data interfaces in this case results in higher costs to the government.

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[2] Overcapacity is causing some reversal of the outsourcing trend in some companies studied.

[3] The decrease in suppliers can be quite pronounced. For example, Xerox has decreased its number of suppliers by at least a factor of twelve in a decade.

[4] For example, Modern Engineering maintains 16 different types of CAD systems to satisfy auto industry customers. This has costs, such as personnel inefficiency, beyond the CAD-system costs.

f. DoD's integration with its contractors is characterized to date almost exclusively as interfacing via batched delivery of information one way or the other.[5] Information is not shared on a continuous basis during a project. Many program offices do not possess the infrastructure elements required to integrate with willing contractors. Some companies are concerned that the DoD cannot become more integrated with contractor activities without becoming intrusive.

g. Electronic data interchange (EDI), based on initial available standards and services, is being used increasingly for supplier business transactions. Outside EDI services provide translations of some data.

A.1.3 RELATIONSHIPS WITHIN COMPANIES

a. In many companies management has succeeded in exerting the leadership required to integrate activities and information across independent entities.

b. The baseline organizational structures to which integration has been successfully applied varies considerably among companies.

c. Management of change is a critical problem for all companies studied. There are many notions of "change" with which people are concerned.

d. There is a trend in industry to try to increase efficiency by reducing the number of layers of management. Some high-level managers see information integration as enabling a reduction in management structure.[6] Conversely, some see the downsizing of management as enabling integration through the elimination of empires

e. Quality was used explicitly to justify enterprise integration projects in only a few companies. The companies in this study that have strong quality programs view enterprise integration as a required step after concurrent engineering is adopted.

A.1.4 ROLES, OBJECTIVES, AND PRACTICES OF INFORMATION INFRASTRUCTURES

a. Information sharing and flow (key aspects of "information management") are recognized as critical ingredients of enterprise integration.

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[5] A notable exception is the F-22 program, where the SPO (subsystem project office) is also co-located with Lockheed.

[6] Some futuristic thinkers take the notion of information-system-assisted management further. There is a possibility, based on trends and the literature, that traditional hierarchical and matrix management structures will mutate into more dynamic arrangements. These dynamic arrangements would be based on projects that respond to market developments.

b. Information management, while critical, is viewed as dominated by cultural and organizational issues.

c. Most implementers regard assistance with change management as a key goal of information integration.

d. When error rates are analyzed and hidden costs considered, the argument for paperless systems is compelling to the companies studied. Therefore, they tend not to perform traditional cost-benefit analyses on this issue. One major barrier to paperless systems is the lack of capital to invest in new systems. Even when systems are intended to be paperless, most implementations are not entirely so due to the absence of a legally binding digital signature technology.[7]

e. Companies must deal with legacy systems in their integration plans. One reason, among many, is that the companies must maintain certain data beyond the expected life of the tools and systems in which the data resides. Thus, even a clean start must plan for evolvability. Several approaches being used are described in Section 2.2.2 on page 31.

f. Object-oriented technology is being increasingly used to implement the encapsulation of legacy systems and other integration paradigms.

g. Information modeling and process modeling are being used in some companies for various reasons such as redesigning white-collar processes for efficiency, identifying redundant information, training, and determining information integration priorities.

A.1.5 ARCHITECTURE OF INTEGRATED INFORMATION INFRASTRUCTURES

a. In the absence of generically applicable, widely accepted interface and data exchange standards, most companies are adopting a common-systems approach to integration within increasingly larger islands of automation. This approach is consistent with the current CAD industry consolidation (which has many causes). This consolidation is resulting in a relatively small number of widely used, major CAD systems in each CAD domain (electrical, mechanical, soft-

[7] This appears to be a legal issue, not a technical one.

ware[8]). There are many niche tool vendors; they currently tend to force users to make the effort to interface or integrate with the larger systems.

b. Although an information system supportive of integration need not use publicly available or standard interfaces, it must have a stable and well-understood architecture for interoperability.

c. The level of interoperability required depends on usage patterns of the applications and systems in question.

d. In the computer-aided software engineering (CASE) domain, there are efforts to implement integrated information systems that use models to organize information and to assist in activity management and policy enforcement. The idea here is to make the system behavior easy to tailor and change.

e. Most of the companies studied are implementing a "continents of integration and automation" strategy to support integration goals. This means that they are moving from very large numbers of loosely coupled activities and disconnected information systems ("islands of automation") to a small number of "continents."

f. The current state of most companies is that their information infrastructures include a heterogeneous assortment of computers, software, and communications networks. On the manufacturing flow at the level of the individual workcells, the configuration of hardware and software is among the worst in the enterprise. This is particularly visible by contrast with what has been accomplished at NeXT Computers, which has used its own workstations at each manufacturing cell and has thereby created a common interface across the company.

A.1.6 ROLE OF STANDARDS IN INTEGRATED INFORMATION INFRASTRUCTURES

a. A widespread desire for widely accepted information standards exists in the companies visited. If the demand for standards were articulated with sufficient focus, strength, and indication of priorities, a focused response from the vendors would be elicited. Only a few companies prefer to rely on internally created sys-

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[8] The consolidation is somewhat less evident in the software domain so far. In the software engineering (computer-aided software engineering or CASE) domain, there is a correspondingly greater level of effort to standardize interfaces.

tems with company-specific data representations as a matter of strategic advantage; these companies have relatively less interest in standards. It appears that in most cases, vendors also have an interest in widely accepted standards and would prefer their existence [9]

b. Most companies who use EDI do so through value-added EDI services, which interface, or translate, among various EDI implementations. This reflects common shortcomings of standards with respect to integration requirements. Some standards express the least common denominator of competing technologies and are extended when implemented into products, often in incompatible ways. Other times, the integration of similar products is impeded because the manufacturers use different, incompatible standards for the same information.

c. One can standardize on technologies, information models, interchange formats, procedural interfaces (e.g., Application Program Interfaces (APIs)), and so forth. Standardization of interfaces facilitates integration much more than standardization of technologies or formats. Standards bodies should focus on the maintaining the integrity of their products (standards).

d. There is a natural tendency observed in standardization efforts to concentrate on bottom-up interests according to what is comfortable to the volunteer participants. This is a behavior observed in the actual working groups and may be quite independent of the publicly stated goals of the effort. Efforts carried forward with full-time staff support more quickly accomplish their goals.

e. The companies visited want more integrated infrastructures both because the current infrastructure is viewed as a barrier to integrated activities and because an integrated infrastructure would facilitate the information sharing on which integrated activities depend. One representative reported that for every CAD/CAE dollar his company spends, it spent $1.50 trying to get the systems to work together to support integrated activities.

A.1.7 STATE OF TECHNICAL UNDERSTANDING OF HOW TO ENGINEER INTEGRATED INFORMATION SYSTEMS

Progress is being made in integrating systems. The understanding of engineering issues inherent in such systems could use improvement. This understanding is likely to

[9] Not many CAD/CAM vendors were interviewed for this study. The statement of vendor interest is based on an insider view of vendor activities within the CAD Framework Initiative.

increase through continued industrial efforts, through demonstrations of new approaches in realistic settings, and through directed research and development of new integration products. The following findings focus on issues that surfaced in the implementations reviewed for this study.

a. Understanding of how to represent products and their related processes for efficient use in automated systems varies considerably across product types. Very little effort was found in the area of representing management policies for use in automated systems.

b. Leading user companies are just beginning to discover how to use available technology to design the information infrastructure for evolution. Vendors are beginning to supply systems supportive of evolution.

c. There is a need in user companies, information system vendors, and the research community to provide a basis for system engineering by improving the understanding of relationships among openness, integration, performance of information systems, and performance of end-user processes.[10] Such an understanding could assist in counteracting the tendency of integration implementers to concentrate on local optimizations (for example, by creating larger islands of automation) rather than on what is globally required by the enterprise.

d. Part of the integrated system engineering problem is the absence of widely accepted measures of progress. There is also a cultural barrier to the use of metrics, especially in highly integrated information systems. Middle managers are concerned that increased upper management visibility into day-to-day activities will be counterproductive.

e. For success a high-level sponsor is critical to the task. The sponsor, typically a president or a vice-president, needed to be in the common chain of command so that this one person could resolve impasses between groups and smooth management delays that occurred between the project management level and the sponsor's level. This sponsor tends to be the Least Common Manager above the groups to be integrated. Only very strong, constant, and visible top leadership can overcome the typically encountered cultural barriers.

[10] This thought is a slight variation on a suggestion by George Heilmeier and is borne out by the observations in this study.

A.2 ISSUES

A number of issues were raised by several of the companies visited, reflecting problematic cost-benefit trade-offs, needs for new research and its application, or needs for new policies and operating procedures.

a. Balance between integration and divisional independence. In a situation where autonomous divisions of the same company pursue integration independently, it is hard to achieve a consistent approach to integration, and there is duplication of effort and learning in the various divisions. Localized integration improvements are very important and worthwhile, but the really impressive savings remain largely unrecognized because the result only from improvement of the larger [corporate-wide] "systems." Management is balancing between the costs and benefits of independence. A corporate information systems organization helping to integrate a division or divisions may have goals or approaches to integration that conflict with those of the divisions.

b. Drawbacks of the "continents of integration" approach. The "continents of integration" must be seen as a commonly used, evolving approach to integration. However it has three potential drawbacks, based on investment, consistency, and evolvability. A large investment in an "island" may create an inertia barrier against future integration, since required change may be seen as devaluing the original investment. Coordinating integration efforts across large companies to ensure a consistent evolvable approach to integration is difficult. Without providing for evolvability, separate "islands" may adopt incompatible infrastructure mechanisms, thereby incurring either re-implementation costs or increased system maintenance costs.

c. User acceptance of direction by process models. A process model can be the basic data structure for establishing a set of operational procedures guided or enforced by the information infrastructure to establish work procedures. If an enterprise so desired, a worker would see the process steps for some activity on a screen and indicate what he wanted to do next. The information system could determine from the model and the current state of the enterprise whether such a step were allowed. Several companies voiced concern about the willingness of workers, particularly engineers, to use such a system.

d. Modeling and managing the meaning of information. If all the information managed by the information infrastructure were contained in a machine-sensible information model, there would be a greater chance that the meaning of the information could be conveyed by the infrastructure over great distances in both space and time. However, the capture of meaning for use by computers is at once an available technology and a research issue.

e. Policies and support for information integrity. Current implementations of technical protection have focused on preserving confidentiality of information and have been aimed primarily at supporting DoD requirements. A much broader set of protection policy issues, such as authority, update integrity, and self-protection (error avoidance), remain ignored and their implementation or support in computer systems continues to be a research issue.

A.3 SECURITY RISK MANAGEMENT AND INTEGRATED ENTERPRISE INFORMATION PROTECTION

Integration of enterprise information is currently taking place within many companies along functional lines (e.g., engineering, finance, manufacturing) and will provide "large islands" of processing in logically centralized, possibly widely distributed, functional centers. For many companies, the next step is to integrate across functional lines beginning with key functions such as engineering and manufacturing, manufacturing and finance, etc. Further integration to include suppliers and customers is envisioned by most companies and may occur before cross-functional integration. These integration steps need to be assessed in terms of security risk and information protection. Specific risk management approaches need to be negotiated and defined so that they are suitable to the environment each participant brings to the "integration table."

There are three major approaches available to address and manage risks to information assets or to assets represented by information in automated information systems: legal redress, insurance, and the incorporation of self-protection via various security measures. All three must be considered in assessing the trade-off issues of managing both unique company-oriented and general inherent risks in the integration of enterprise information.

A.3.1 LEGAL REDRESS

Legal redress protects against patent and copyright infringement, provides both a deterrent factor and retribution against fraud, trade secret theft, or other criminal exploitation, and provides for potential restoration of actual losses plus compensation in some cases in the form of punitive damages. This form of risk protection has served industry well to date; however, the legal models suited for manually supported or semi-automated information systems are not necessarily suited for fully integrated automated enterprise information systems. The need for review of legal models with respect to information security and intellectual property rights in computer systems is vital. The most central issue involves the determination of accountability of actions (the binding of evidence of scope of actions of individuals to assigned responsibilities and authority) within an automated information system, and whether "due care" has been taken in establishing controls to manage risk. Laws dealing with a variety of intellectual property rights issues and information security in computer systems are either non-existent, still in the issue analysis and/or law formulation stage, non-enforceable, or untried. The unwillingness of industry to report offenses or to prosecute offenders has been a major contributing factor to the inability to get these laws formulated, enforced, or assessed. As electronic commerce expands along with enterprise integration, this aspect of risk management must be revisited and made effective for the new environment.

A.3.2 INSURANCE

Insurance has two forms. The first protects against actual loss of assets based on a premium payment for risk coverage per unit of time. In this case, insurance is the contingent replacement of asset value and not necessarily the replacement of the asset. Thus, the complete loss of information vital to a company's survival might not be replaceable. It is, in reality, risk management's solution of last resort. This fact promotes the second form of insurance, which is contingent redundancy or fault tolerance. In this case, the vital information assets, and perhaps the processing resources, are backed up in another location where they are able to be used to meet the contingency of loss of the primary information or processing resources. The key to viability of the second form of insurance is not just a contingency plan, but rather the actual periodic exercise of the contingency to ensure currency of preparation and awareness of potentially degraded response. Single point failures should be examined closely. Assessment of availability (e.g., timing constraints and allowable degradations in response to requests for resources or information) must be made; appropriate policies must be established and implemented. Insurance approaches are an overhead burden that must be accepted as the only way to address many of the risks inherent in enterprise information integration.

A.3.3 SECURITY MEASURES

The third approach to managing risks involves the incorporation of physical, administrative, and technical security measures to protect both the information asset and the assets represented by the information (e.g., actual parts inventories, monetary assets, proprietary processes). Physical security involves providing guards, sensors, and barriers to isolate sensitive areas and to control and monitor access in and out of these areas. Administrative security includes personnel screening and procedural controls and monitoring of individuals performing their assigned duties. Technical security, which is the primary focus of the remainder of this section, is the implementation of controls and the monitoring of actions conducted within the computer system.

Technical security addresses the hardware, operating system, networks, databases, and applications that compose the integrated enterprise's automated information system. As one begins to integrate functions through automated information systems, more and more of the mostly manual administrative and physical security controls used in companies today must be migrated into the computer system so that protection policies can continue to be enforced. The normal space and time gaps associated with paper-oriented manual and semi-automated protection processes will no longer exist. This aspect of protection becomes more important as the degree of enterprise integration increases to one of a paperless, electronic commerce environment.

Technical security in automated information systems is typically discussed in terms of three general policies: confidentiality, integrity, and availability. Key aspects of these three policies are highlighted below.

a. Confidentiality policies. What information is to be protected from disclosure (e.g., proprietary processes, personnel information, strategic planning information, proprietary designs)? Who authorizes disclosure? How is this protected information identified? Who changes protection requirements? Key aspects of these policies include confidential information access control, delegation of authority, security administration, distribution control, information marking, auditing, and enforcement monitoring.

b. Integrity policies. An overall integrity policy can be broken down into separation policies, sharing policies, and self-protection policies.

   (1) Separation policies. How will organizational roles and duties be reflected in the system? Who is allowed to execute a particular duty or process? Who is responsible for delegation of authority? How are responsibilities that require separation to be handled? How is the individual accountability for their actions to be handled? Key aspects of these policies include accountability, identification and authentication of both individuals and informa-

tion, encapsulation of the scope of authority, execution access control, software importation, network access, information marking, internal control systems, and systems administration.

(2) Sharing policies. What information is to be shared? Who is responsible for the quality and reliability of the information? How is the quality to be assessed and protected? Key aspects of these policies include configuration management and version control, shared information access control, attribution and accountability of change, information process reliability and quality control, application reliability, and quality control.

(3) Self-protection policies. How will individual users be protected from doing accidental (or perhaps intentional) harm to their work products? How tolerant should the user interface management system (UIMS) be? Should the potential action be validated prior to committing or should error messages be returned at the time of commit? Should there be a universal "undo" capability? How should the use of that capability be monitored? Key aspects of these policies include UIMS design, identification and authentication, error specification and detection, fault tolerance and error recovery, and auditing.

c. Availability policies. What are the response times required for information or resources to be available? What are the sources of competition for services or information? What internal agreements must be specified to ensure response times are met? What are acceptable modes of degraded operations? Key aspects of these policies include single point of failure analysis, system fault tolerance, resource- and/or information-demand management, network management, and real-time system requirements.

Current implementations of technical protection have focused on preserving confidentiality of information and have been aimed primarily at supporting DoD requirements. A much broader set of protection policy issues, as indicated above, remain relatively ignored, and the possibilities of their efficient and near-term implementation or implementation support in computer systems continue to be research questions.

Other issues that are associated with physical and technical protection include confining information, security in large database systems, storage media, the "insider" threat, and expressing protection policy requirements.

a. Confining information. Once information is made available on a system in a sharing mode, how is it to be confined to remain within a cluster of workstations if these workstations are part of a large distributed network of mainframes, system servers, and individually shared workstations, all supporting integration? Physical gaps in certain networks may be a required part of the near-term solution.

b. Security in large database systems. This issue remains a research question. Some of the issues of confidentiality in database management systems are just now being addressed. Research prototypes and early attempts at production systems are emerging. Integrity and availability, to some extent, have been explored since the beginning of database technology, but new understandings of the issues have led to the need for additional research. Transaction volumes and performance requirements in large database systems mandate reduced overhead in security monitoring controls. The concepts embodied in object-oriented approaches indicate some promise to improving security, and, more particularly, to reducing security overhead if implemented in a vertically partitioned system. However, object-oriented approaches and vertically partitioned systems have not been explored sufficiently to claim success objectively.

c. Storage media. As technology becomes more capable of storing an increasing density of information on smaller storage media, two needs arise. The first is the greater need for backup of stored information as a contingency to media failure or damage. The second is the need for new forms of physical security to detect the unauthorized removal or introduction of such media.

d. The "insider" threat. Where access to more of a company's information or to more asset control information is potentially available, the "insider" issue as a component of competitive risk may become more significant. The insider is one who is trusted to have access or possession of key information or to make key decisions. The insider can be vulnerable to outside pressures (e.g., money, extortion) or to internally generated pressures (e.g., greed, retribution) to violate the trust granted to him or her. This trust violation may be to disclose, modify, damage or destroy information, or to commit theft or fraud in the acquisition of assets represented by information. It is important that the most trusted individuals be closely audited to ensure accountability of their actions. It is also be important that they be limited in their capabilities to act independently or to assume privileges that enable them to act as surrogates for subordinates whose actions they supervise and authorize. The insider risks may not be readily apparent now, but they should be closely examined prior to and continually after implementation of the enterprise information integration model.

e. Expressing protection policy requirements. The most difficult issue related to technical security is how to express the protection policy requirements to the community responsible for developing solutions so that they can incorporate policy or policy support into the computing systems. To make integration effective, efficient, and acceptably risk-free as we increase the environment of electronic commerce, each participant should examine current manual policies and procedures to assess what risks they are currently managing and how those risks will be transformed in the electronic environment. This examination will lead to the establishment of new policies and procedures that must be implementable in or via our computing systems. While some of the more local aspects of information can occur now, more significant integration should not occur without a detailed examination of acceptable risks and the requirements for risk management, especially protection requirements for automated systems.

APPENDIX B. ELECTRONICS INDUSTRY RATIONALE

For the purposes of this study, the manufacturing industry was partitioned into three sectors: electronics, automotive, and aerospace.

- The electronics sector included computer manufacturers, electronic components manufacturers, and other companies whose products are based on electronics technology (this appendix).
- The automotive sector is characterized as automobile and heavy equipment manufacturers, and their suppliers (Appendix C).
- The aerospace sector is characterized as airframe and engine manufacturers (Appendix D).

This chapter documents the state of enterprise integration as it exists today in the electronics industry sector, and creates a vision of what enterprise integration might look like in the year 2001. This chapter has five major sections:

- Section B.1, Electronics Industry 1991. Describes the current state of enterprise integration and the integration infrastructures used in achieving the current state of enterprise integration.
- Section B.2, Electronics Industry 2001. Projects what an integrated enterprise and its supporting integration infrastructures might look like in 2001.
- Section B.3, Issues and Barriers. Identifies issues that must be addressed to implement enterprise integration today and barriers that must be overcome to achieve enterprise integration in 2001.
- Section B.4, Recommendations. Provides recommendations for achieving enterprise integration.
- Section. B.5, List of Companies Visited.

B.1 ELECTRONICS INDUSTRY 1991

The information discussed in this chapter is based on visits with 13 companies in the electronics sector. These companies, listed in Appendix A, cover a broad spectrum in the electronics industry in the United States, from semiconductor manufacturers to diversified electronic products manufacturers, including workstation vendors, mainframe computer vendors, and defense products contractor. Most of these companies are multi-divisional and have revenues well in excess of $1 billion annually.

To set the background for our discussion of enterprise integration, we discuss some characteristics of the electronics industry that affect the success of enterprise integration projects. There are four commonly observed cultural factors among companies in the electronics sector: technology, competition, innovation, and autonomy.

Obviously electronics companies use technology in their products, but it is equally important that they are also among the early adopters of technology in their operations. Perhaps this is due to the preponderance of individuals with engineering backgrounds at the executive management level. Whatever the cause, it is significant that these companies are comfortable with technology and readily turn to it to enhance their business.

Competition is a fierce driver among companies in the electronics industry. Time-to-market is a critical factor in business success for this sector. It is well known that a few months' delay in product introduction has much more impact on a product's overall profitability than cost overruns of 50% during product development. Therefore these companies willingly invest in initiatives that will maintain competitiveness, increase efficiency, and reduce time-to-market.

Innovation is key to remaining competitive. With product lifetimes ranging from less than two years to as many as five years, it is vital to reduce development cycles and maintain a flow of new product innovation. Some innovation occurs in response to competition and some occurs in anticipation of future competitive pressures. Examples of responsive innovation are reducing the cost of manufacturing a cellular phone in response to price-pressure, or designing a faster CPU in response to the introduction of a new "hot box" workstation. An example of anticipatory innovation is developing a new semiconductor process to keep up with the increasing transistor densities forecast by Moore's Law.[1] Thus the *ability to innovate* is a strategic competitive resource, and *product engineering* is the most influential portion of an electronics company's staff.

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[1] G. Moore, "VLSI: Some Fundamental Challenges," *IEEE Spectrum*, April 1979, pp. 30-37.

Most electronics companies are composed of many very autonomous groups. In part this is due to divisionalization and the diversity of products, and in part it is due to the innovative character of electronic product development. Many product lines have their own profit and loss responsibility, and ultimately most operational decisions, such as participating in integration projects, are left to each profit and loss center. In addition, since engineers must be innovative, they also must be allowed to try different approaches to product development. This fosters a corporate culture in which swimming against the tide is accepted and individual preferences are given ample consideration.

B.1.1 INTRODUCTION

In this section we discuss what motivates electronics companies to initiate enterprise integration projects. We examine common elements in the enterprise integration decision process, what are some of the drivers, and what are some of the expected benefits. In addition, we discuss the enterprise integration environment and observe the anomalous, but not unexpected, *homogeneous computing* environment that occurs at a computer manufacturer.

Far and away the most frequent reason given for having started an enterprise integration project is "we had to." Primarily, this is based on an intuitive perception that an integrated operation was necessary in order to remain a competitive and viable business entity. Department of Defense (DoD) contractors and vendors also noted required compliance with federal regulations and initiatives, such as the CALS (Computer-Aided Acquisition and Logistics Support) initiative.

Most companies participate in some form of competitive benchmarking in which they exchange best practices information about their business with a few firms that are comparable, including some competitors. The information exchanged serves to characterize their industry without disclosing any key strategic or competitive information. If there is a clear trend that one's competitive segment is pursuing integration along some particular axis, then it would be very uncomfortable to choose to be the laggard and risk becoming non-competitive.

As a consequence, most of the companies visited do not perform a cost-benefit analysis to justify a pending enterprise integration project. Usually, for those enterprise integration projects that are widely implemented, it is intuitive that the benefits far exceed the costs. Where the benefits of an enterprise integration project have been measured, the results have ranged from about break-even to significantly leveraged benefits. (Some results are reported in Section 2.1.3 on page 16.)

Two drivers for enterprise integration are that it facilitates collaboration among groups and individuals, and that an integrated enterprise can be more responsive to change. Ultimately, enterprise integration requires that information within the enterprise be effectively available across functional groups. This enables individuals in different groups who need to share information to access the same information, which enables them to work more closely together.

An integrated system is more responsive to change than is a non-integrated system. Once an interface to a component of an integrated system has been developed, then it is much easier to add another unit of that type of component into the system. So one value of integration is to minimize the cost of future incremental extensions.

Most integration projects not only automate the system, but they also re-engineer the system. That is, while asking how does the current system work, one also asks how should it work. This originates some changes in business operations to a more effective operational structure. In addition, a cleanly architectured integrated system will be responsive to business change in the future.

The integration of an enterprise tends to correlate highly with its quality measures. Improved quality has been mentioned consistently as a benefit of successful integration projects reported in this study. It is interesting to note that while all companies have programs in place to address the quality of their products and processes, only one reported the quality program as a primary driver behind specific integration projects.

The integration infrastructures that underlie enterprise integration fall into three domains: high-speed networks, product data representation, and operational information. In most companies, the choice of computing platforms (workstations and mainframe computers) dictate the kinds of networking, operating systems, electronic mail (e-mail), and other interfaces that are involved in implementing enterprise integration. Note that computing platform choices are sometimes dictated by the software tools that are used within the enterprise, such as tools for computer-aided design (CAD), computer-aided integrated manufacturing (CIM), and so forth.

The typical company uses multiple networks, with various network protocols, file systems, and client-server mechanisms. Integration efforts must begin by bridging or harmonizing the disparate network components into a uniform environment. It would be a significant benefit to an integration project to be able to bypass this initial effort. The one group of companies that can avoid this overhead is the computer vendors.

For those companies that manufacture computers, there is a strong tendency to use their own products. Thus companies like DEC, IBM, Motorola, and NeXT adopt their own platforms, networks, and file systems. This has the benefit that the system tends to be very homogeneous, and where it is heterogeneous, the software to integrate them in a uniform way is already in place. Thus DEC uses DECNet, IBM uses SNA (Systems Network Architecture), and the others use network file system (NFS) and TCP/IP (Transmission Control Protocol/Internet Protocol).

A company that begins with a homogeneous environment has an inherent advantage over a company that must pay the overhead of network integration. This advantage occurs in companies in the electronics sector that are computer vendors, or to companies who have adopted a single vendor's platforms.

B.1.2 BUSINESS STRATEGIES

The electronics industry competes in a global marketplace and purchases from a global supplier base. Most electronics companies have some offshore manufacturing or assembly facilities, as well as world-wide distribution channels.

Because of the diversity in the electronics sector, each company has strategies that are particular to its business areas. We note that following strategies are common across the industry: (1) reduce time-to-market, (2) be innovative, (3) reduce cycle times, (4) improve quality, and (5) build strategic supplier partnerships.

Competition for the U.S. electronics industry comes from Europe, Japan, and the rest of North America, but certainly U.S. companies are highly sensitive to competitive pressure coming from Japanese companies. Four of the strategies cited above target competitive strengths that have historically been associated with Japanese competitiveness.

Time-to-market is perhaps the single most important factor in product success. Each of the four strategies cited above are significant contributors to reducing time-to-market. Every company seeks to improve and lead in time-to-market. Reduced time-to-market enables a company to be responsive with its product offerings and innovative in pursuing emerging markets. In short, reduced time-to-market enhances competitiveness. To give one example, Motorola has reduced its time-to-market for cellular phones by 50% over the last 10 years.

A key asset of each electronics sector company is its engineering resource. The engineering staff embodies the intellectual property of a company through its knowledge of existing product designs and of proprietary engineering processes. And engineering is the source of innovation. Some of the phrases used regarding innovative engineering were "quality people," "zealots who do not know what can't be done," "rise to the occasion," and "expect a miracle."

Automation can reduce cycle times by speeding up one or more steps in the process. Automation can also reduce cycle times by eliminating errors and, consequently eliminating needless repetition of process steps. Integration can reduce cycle time by facilitating faster information flow to the individuals who need that information. When that information is also of higher quality (such as an error-free design), then the benefit is compounded.

An even greater effect of an integration project on cycle time can be obtained when in the course of automating several processes into one integrated process, the processes are re-engineered into a more efficient process. National Semiconductor replaced a multiple (six steps or more) step manual process (in selected cases) with a two-step automated process while integrating its order entry system via EDI (electronic data interchange) and automated ordering and scheduling.

Most companies visited have an explicit corporate quality strategy. Their programs are called by various names, such as Total Quality Management (TQM), NonStop Quality, Six Sigma, and Continuous Improvement. Since errors introduce distortion into cycle times, an effective quality program will contribute to reducing cycle times and time-to-market. For a semiconductor product, quality directly affects yield which determines profitability.

Establishing strategic supplier relationships involves reducing the number of suppliers and building partnerships with the remaining suppliers. Westinghouse Electronic Systems Group reported reducing from 400 to 40 suppliers of machined parts. For a company to maintain a relationship with a supplier, an overhead cost in excess of $1,000 is estimated to occur. Reducing the number of suppliers results in a direct cost savings.

Having a strategic relationship between a company and a supplier benefits both parties. The supplier can anticipate business continuity with the company and can make longer term investments to accommodate the company's way of doing business. Example accommodations are just-in-time (JIT) deliveries on a per day or per shift basis, or subscribing to an EDI service. The company can work with the supplier to adopt some of the company's practices, such as employing the same quality program or using electronic transfer of schematics or drawings of parts. (The company will control access to its proprietary data on a need-to-know basis since in many cases a supplier has a sister division that is the company's competitor.)

The above strategies are common to most companies in the electronics sector. In the following paragraphs we discuss certain strategies that are particular to one specific electronics industry segment.

In the semiconductor industry, a fundamental strategy is to improve silicon fabrication process yield. Moore's Law sets a strategy to increase transistor-per-chip density through a combination of factors including larger die sizes and finer (sub-half-micron) process technology. The industry has a specific cycle time reduction strategy in its fabrication-assembly-test cycle. National Semiconductor also has a service strategy, where they add value "by offering a variety of important services."

Strategies peculiar to the workstation manufacturing industry include the "Hot Box" strategy, which is to develop workstations based on reduced instruction set computer (RISC) architectures, and to attempt to leap-frog the current performance parameters of one's competitors. Offering an open architecture is another common workstation strategy, although no single open architecture standard has yet emerged. A client-server architecture, which is seen as a key enabler of integrated systems, is a significant sub-strategy of the open architecture strategy.

Another sub-strategy is adopting object-oriented technology in implementing some facet of the client-server and open architecture strategies, for example, the NeXT Computer's NeXTStep development environment.

A client-server architecture strategy is also being followed by mainframe computer vendors. They are positioned to provide the server component in such an architecture, and are providing server facilities such as Information Resource Dictionary System (IRDS) of the American National Standards Institute (ANSI) standard repositories. Each company's strategy is to do this in the context of its proprietary, homogeneous network architecture that spans from mainframe computers to workstation and personal computer products.

Both Hughes and Westinghouse have a strategy to increase their commercial products business with new products that are based on technology developed while performing various DoD contracts. In part this is driven by the expected downturn in defense funding during this decade. They need to move from a business dominated by one customer to a more even mix between government and commercial revenue.

B.1.3 STATE OF INTEGRATION

In the community of electronic computer-aided design (ECAD), it has been said that the 1980s were the decade of automation of point tools and the 1990s will be the decade of integration. What has been said about the integration of tools in E-CAD can also truly be said about the integration of organizations in the electronics industry. The 1980s were the decade of "islands of automation" and the 1990s will be the decade of enterprise integration.

John Tegethoff of Motorola's Corporate Enterprise Integration staff believes that "there is more payback now in enterprise integration than ten years ago." This is, in part, attributed to economies of scale. Although a common definition of enterprise integration has not emerged, there are two things that can be said about it with certainty: enterprise integration is occurring, but the approaches being taken by industry are different. Enterprise integration is not happening the same in any two companies (in the electronics industry).

In this section we discuss the state of enterprise integration in 1991 in the electronics industry sector. First, we will offer some general observations that are representative of the state of enterprise integration in the electronics industry. Second, since much more enterprise integration is happening in a piecemeal fashion within the industry than is happening at any one company, we will try to roll this activity up into one hypothetical integrated enterprise and describe the enterprise integration practices that could be attained today. Third, we will discuss four case studies of successful integration projects which reflect the state of different aspects of enterprise integration today.

An enterprise integration view of the enterprise includes all agents that influence the value-chain of the enterprise's products. This view includes the enterprise's interactions with its suppliers and its customers. Thus enterprise integration includes both intra-company integration and inter-company integration, that is, both integration within one company and between different companies.

Most integration activities today are intra-company. Integration projects generally spring from a need to exchange information among groups. The groups may be different organizations, different functional entities within one organization, or geographically dispersed groups within one functional entity. A prerequisite to an integration activity is the awareness that information, which would be beneficial to performing one's task, exists in another group. If this awareness is coupled with an agreement between the groups that efficient access to the information would be mutually advantageous, then the seeds for an integration activity are present. The culture and infrastructure that enable integration are much more likely to occur within a company than across company boundaries. As a result, almost all integration projects are internal to one company.

A fundamental integration activity that underlies and enables many other enterprise integration activities is widespread peer-to-peer communication. Most electronics companies have corporate-wide (and world-wide) computer networks with electronic mail facilities available to exchange e-mail among any two computer users. DEC, Hughes, Intel, IBM, Motorola, NeXT and Texas Instruments each explicitly talked about their e-mail systems. The efforts to bridge multiple e-mail systems (e.g., between personal computer users and workstation users) and to administer corporate-wide user identities are significant issues. But the overwhelmingly important factor is to implicitly encourage peer-to-peer communication within the corporate culture.

The most frequently encountered integration project was creating a product data management (PDM) system to provide the "concurrent engineering" coupling between design engineering and manufacturing engineering. The goal of this integration is to reduce the cycle time to provide correct, manufacturable product designs to manufacturing. The payback from a PDM system is direct, both in the intangible sense of reducing time-to-market and in the tangible sense of cost savings by avoiding false manufacturing starts. Depending on how far an incorrect design gets into the manufacturing cycle before the error is caught, the cost is measured in hundreds of thousands or millions of dollars.

A PDM project involves formalizing and automating the design-release-ECO (engineering change order) process. It uses a database (electronic vault, repository manager, etc.) to keep track of the versions of each design, which designs are used as components in a configured design, and the exact configuration of versions of the components that are used in each version of the configured design. Design data may be physically transferred to PDM storage or it may remain in a workstation's file system with logical ownership transferred to the PDM process. Either way, the PDM system controls access to the design data and provides a check-in/check-out mechanism that synchronizes access and changes to designs. The PDM system will enforce that the released version of a design is accessible as read only, that changes only occur to a new version, and that, at most, one engineer at a time is making changes to a design.

There are many views of a design, for example, a logical or schematic view of a circuit, a circuit board layout view to materialize the circuit, a numerical control view to manufacture the circuit board, and a component placement view to manufacture the fully populated board. In addition, there is a documentation view which includes both engineering documentation for internal use and product documents that are deliverables for the customer. All of these views may be reflected in data elements that are under version control under PDM control in correspondence with released design data.

The most frequent automation task was to replace microfiche and paper design drawings with electronic viewing of designs. This is synergistic with the PDM system since electronic distribution of the current released version of a design interactively is both beneficial to and benefits from electronic viewing capability. Paperless design distribution result in both materials cost savings and time savings. An integrated enterprise could be paperless except that for legal reasons one paper copy of a design or equivalent document must be signed and archived to document the design approval process.

In addition to storing both source design data and derived manufacturing data, several companies have automated the translation of design data to manufacturing data and programming the factory. NeXT Computer has a relatively homogeneous environment, with PCB (printed circuit board) tools[2] from one CAD vendor and a CIM environment controlled on NeXT workstations. They have implemented an application that accesses the CAD file across the network, converts it to machine programs, and optimizes those programs for placement cycle time and machine wear. Tektronix uses a proprietary neutral format (Mitron's integrated data format (IDF)) for connectivity and XY location data, and they use IGES (Initial Graphics Exchange Specification) for geometry. They have built one translator from each PCB tool to the neutral formats and one translator from the neutral formats to each machine tool.

Another integration linkage between design and manufacturing is the approved-parts database. Design engineers identify parts to be placed in the database for required functionality; manufacturing considers the options among parts that provide equivalent functionality, considering such characteristics as availability, reliability, usability, and manufacturability. At Motorola Cellular and NeXT Computer, the component engineering organization that controls the approved-parts database is in the manufacturing organization. In both these companies, the design engineers are familiar with the manufacturing floor and

[2] The PCB tools used by NeXT are not available on NeXT workstations.

they know which components are on-line. In addition, the design engineers participate in starting up the manufacturing line on a new design.

Although most integration is intra-company, there is significant inter-company integration. Some inter-company integration reflects the automation of sales and purchasing activities, while some represents extending engineering integration to suppliers.

Following the lead of the automotive sector, most electronics companies are adopting EDI standards for issuing purchase orders and booking orders, and are making payments by electronic funds transfer. However, of 13 companies surveyed, only 3 reported using EDI for both their customers and their suppliers. Intel has installed equipment capable of communicating via EDI at its smaller suppliers. NeXT Computer, National Semiconductor, and Motorola have integrated their EDI order entry systems with factory scheduling systems.

It is not uncommon to transmit a purchase order to a supplier via EDI and send a hardcopy attachment that contains drawings and other technical data. DEC, Motorola, Texas Instruments, and Westinghouse have extended their systems to electronically transfer drawings to suppliers. Texas Instruments and Westinghouse have each placed equipment for downloading and viewing drawings at their smaller suppliers. In each case the company controls access to the design data, usually placing a copy of the drawing file on an isolated workstation or personal computer that is then accessed by the supplier. Generally the outside supplier does not connect to the engineering network of the company.

It is appropriate at this point to acknowledge the issue of the so-called "legacy systems." A legacy system is a software system that writes data (to disk) in a proprietary format. A legacy system may also have specialized platform requirements, such as a specific release of operating system software. This becomes an issue when the data has a long lifetime and the volume of the data is very large so that it is infeasible or prohibitively costly to convert the data into a new system. A legacy system might be a database management system that uses a hierarchical or network data model (e.g., information management system (IMS) or integrated data management system (IDMS)), or it might be a CAD system that writes a proprietary binary design file format.

Integration of a legacy system is generally difficult. Typically it does not support interactive access to its data, neither by query nor by procedural interface. Usually a special *ad hoc* application or report generation program must be written to navigate through the data and extract the desired information. To integrate a legacy system, there are three options to choose from:

a. Use manual integration, where the legacy system is used in the usual manner and a human manually links the legacy system's information into the rest of the system.

b. Encapsulate the legacy system, where a very general application program (called a wrapper) is written for that specific legacy system. The wrapper will accept data requests for the legacy system and its application is to emulate a query of interactive interface against the legacy system.

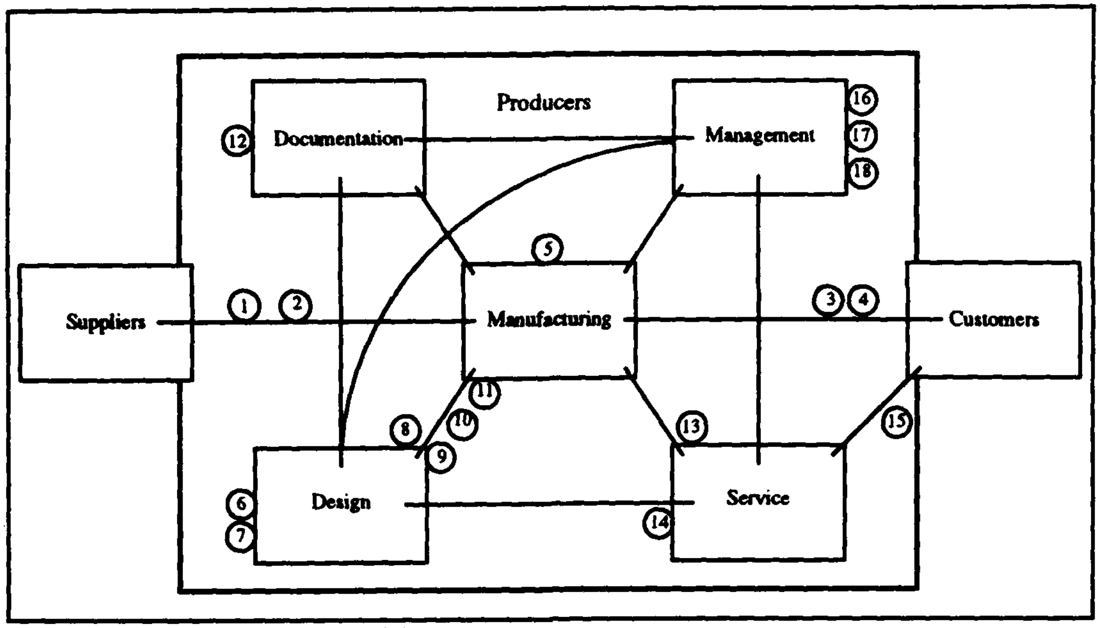
c. Displace the legacy system, maintaining it for archival purposes only. This can be done in an evolutionary manner by extracting and converting data on a "as accessed" basis. There is the possible overhead factor that both the legacy system being displaced and the new replacement system must be operated in parallel for some period until references to unconverted data have ceased, at which time the legacy system can be mothballed and only the replacement system carries on.

B.1.3.1 An Integration Scenario

The integration technology and infrastructure elements available today, in 1993, would enable an enterprise to develop a significant integration infrastructure. However, integration projects are constrained by cultural inertia, financial and resource limitations, and, *significantly*, risk management. Thus enterprise integration projects and their supporting integration infrastructures tend to be deployed in an incremental and evolutionary manner. Since each enterprise chooses its integration path based on particular business needs, the corporations visited in this study each presented a different road map of integration efforts to date and a unique snapshot of current integration infrastructure.

The following scenario presents the profile of a hypothetical integrated enterprise. This profile synthesizes the best practices of 10 corporations visited by the Electronics Sector Team for this study. All the integration infrastructure elements and integration practices described in the scenario are based on current technology and have been validated by deployment in at least one company visited. Figure B-1 depicts this profile of an integrated electronics enterprise.

The seven boxes in Figure B-1 represent seven key actors (functional groups) in the domain of an enterprise. The main horizontal axis corresponds to the product value chain



Enterprise Integration Activities:

1. Transmit purchase orders to suppliers electronically using EDI.
2. Deliver drawings and schematics to suppliers electronically.
3. Receive product orders from customers electronically using EDI.
4. Schedule deliveries electronically using factory capacity, inventory, and work-in-progress databases.
5. Compute manufacturing schedules based on inventory, capacity, orders and delivery commitment databases.
6. Apply downstream rules in design process.
7. Approve design using automated design approval process.
8. Release approved design to manufacturing via an electronic vault.
9. Develop parts database, parts approved by design and manufacturing.
10. Compile manufacturing control programs for PCBs from design database.
11. Plan and optimize manufacturing control programs based on manufacturing schedules.
12. Print manuals and documentation on demand, custom configured to product options.
13. Use repair history database feedback to improve precision of service diagnostics.
14. Use repair history database to drive ECO/MCO for reliability.
15. Respond to customer request for repair or warranty services.
16. Manage quality programs for products, using design, manufacturing and repair data.
17. Select "corporate standards," common platforms, tools, and other technology elements for use on a corporate-wide basis.
18. Have senior management sponsor successful integration projects.

EDI	Electronic Data Interchange
PCB	Printed Circuit Board
ECO/MCO	Engineering Change Order/Manufacturing Change Order

Figure B-1. Functional Groups and Processes in an Integrated Electronics Enterprise

of suppliers-producer-consumers. The suppliers provide materials and component assemblies to the producer, and the consumers purchase the products manufactured by the producer. The producer is partitioned into five actors in the research, development, and production process: managers, design engineers, manufacturing engineers, technical writers (documentation), and field and factory service engineers. A line between a pair of groups indicates an information flow in support of integration of their activities.

Eighteen integrating activities or integrated processes are also shown, each represented by a number within a circle. Where the number is placed next to a box representing a functional group, the activity is undertaken by that group. Where the number is placed next to a line representing an information flow, the activity is performed to the mutual benefit of both functional groups, and effects some of the information flow between them. In the latter case the activity may involve using data from both groups or transferring data from one group to the other. A brief description of each activity is listed in the figure and each is described more fully in the following paragraphs.

B.1.3.1.1 Suppliers, Producers, and Customers

EDI is used to exchange business information, including purchase orders, invoices, and advice of payment. EDI is used between the manufacturing organization and its suppliers, and between customers and the order entry organization (activities 1 and 3). EDI may also be used within the company, between divisions that have a supplier-consumer relationship. The EDI transmissions to suppliers may be issued by manufacturing's MRP (manufacturing resource planning) and JIT systems.

For electronic components, a purchase order must have an attached schematic or technical drawing. Since EDI supports only the transfer of business forms, drawings must be transmitted via a supplementary mechanism (activity 2), such as an interchange format for the CAD system in which the drawing was created, an industry standard graphics interchange format (e.g., IGES), a neutral documentation exchange format (e.g., Standard Generalized Markup Language (SGML)), or a proprietary format used by the enterprise. Frequently, a supplier will not have the necessary equipment or software required to receive drawings, and for smaller suppliers the purchaser will install a system for electronically viewing drawings in the supplier's facility. For security reasons, drawings being transferred to a supplier are either downloaded to the supplier's workstation or copied to an isolated workstation in the producer's plant that the supplier can access as needed. In neither case is the outside supplier given access to the engineering network of the purchaser, and normally the purchaser is not given access to the network of the supplier.

During the process of ordering an electronic component, particularly components available from multiple sources, the customer will seek a committed price quote and delivery schedule. Data involved in responding include finished inventory data, work-in-process data, and manufacturing capacity data. The order entry system will access these data from their various sources within the company in responding to the customer (activity 4).

B.1.3.1.2 Design and Manufacturing

A flexible CIM facility can, in principle, manufacture product in lot sizes of one unit, although there are many potential factors that favor larger manufacturing runs. Schedules for each manufacturing line are computed periodically, the frequency depending largely on lot sizes and setup overhead. (A line with a setup time of 4 hours might be scheduled weekly, while a line with a setup time of 15 minutes might be scheduled prior to each shift.) The scheduling activity (activity 5) uses order and delivery commitment data, finished product, work-in-progress and materials inventories, and manufacturing capacity information.

Practicing concurrent engineering, a design engineer obtains feedback about the suitability of the emerging design for downstream processes in order to efficiently produce a high quality design. The feedback may be provided through tools run by the design engineer (e.g., an expert system) or it may be provided by a formal or informal review. For example, by running an ASIC design through a design rule checker using appropriate design rules and parameters (activity 6), the design engineer verifies that the design conforms to the ASIC foundry's process rules.

When a design engineer completes a design or an engineering change and the design is ready for release, it goes through an approval process. An approval form giving the name and version of the design is routed by electronic mail (activity 7) for the required approvals, which may include the designer, a quality engineer, the project lead, and one or more additional managers. A password-verified signature is entered electronically for each signer. After the electronic design approval has been completed, the design proceeds in the release process while a paper approval form is circulated in parallel for signature. The latter approval form is required because electronic signatures have not been established as legally binding should they be required for contractual purposes.

In the release process (activity 8), the approved configuration of the design (the correct version of the design and the correct versions of the components used in the design) is checked into an electronic vault. There it is available on a "read-only" basis to both design engineering for reuse in future design activities, and to manufacturing engineering for developing the CIM programs used in the manufacture of that design.

When designing, an engineer uses some purchased components. These components are selected from the shared corporate approved-parts database. Frequently there is a choice among several options for parts that provide the required functionality; perhaps a choice among options with identical functionality, but from different suppliers. In this case the choice may be based on manufacturability issues. (For example, by choosing a chip already in use on the manufacturing line, one might avoid additional setup time to custom load an alternative chip into a "pick-and-place" machine.) Manufacturability information, such as reliability, maintainability, and usage, is collected and used by the manufacturing engineers, so the approved corporate approved-parts database is selected (activity 9) either by manufacturing, or jointly by design and manufacturing, with manufacturing having veto power.

To manufacture a PCB, a numerical control (NC) program for control of the fabrication, drilling, stuffing, and soldering processes must be developed. The approved design, as placed in the electronic vault, is the specification for the NC program. Manufacturing acquires the PCB design from the vault and compiles the NC program (activity 10).

Some optimization of an NC program is done during its development (i.e., in activity 10). Much of the optimality of the CIM operation of a facility depends on interactions among the various NC programs for the parts and products being manufactured in that facility. Therefore, after the manufacturing schedule for the facility is established for the day (week, etc.), further CIM optimization is performed (activity 11). This optimization is based on the CIM NC programs, the schedule (from activity 5), and the materials inventory, and outstanding JIT purchases (activity 1).

B.1.3.1.3 Documentation and Service

Documentation in support of products is produced by many groups. It is all collected into a documentation database, and *no* inventory of printed manuals is maintained (other than a supply of blank paper for the printing process). When a unit of product is prepared for shipping to the customer, a manual customized to describe exactly and only the features in that product unit is printed on demand (activity 12) just in time for inclusion in the shipment.

As a side benefit, service documentation reflecting the particular requirements and idiosyncracies of the exact product configuration of a unit under repair can be read electronically by a service engineer. This allows the engineer to focus on the failure modes and repair steps that are relevant to the repair task at hand. Thus, the same diagnostic results for two different configurations of a product might be correlated with two different types of failure. By capturing a reliability and repair history database (activity 13), manufacturing and service can detect such patterns and guide the service engineer to a precise diagnosis and an efficient repair process.

Using the reliability and repair history database, service engineers can detect (activity 14) a recurring pattern of poor reliability or failures. Service engineers can describe to design and manufacturing groups this pattern and together they can arrive at an ECO or an MCO that will address the problem.

After an order is delivered and installed, most interaction with the customer is performed by the field service engineers. By establishing e-mail or EDI communications between the customer and the service engineer, customer requests for service (activity 15) are received with greater timeliness and accuracy than those manually received and processed, and electronic communications provide the opportunity to capture this feedback for the reliability database.

B.1.3.1.4 Management

Quality programs, such as continuous product improvement (CPI), Six Sigma, or TQM, require accurate and timely data on all products. All functions in the enterprise (e.g., design, manufacturing, service, management) must collect accurate data appropriate to quality measurement. To manage the quality of an enterprise (activity 16) requires electronic access to the appropriate data from these disparate sources, coupled with the ability to integrate the data into a model that enables correlation of the overall quality of a product with the data elements from the various functions.

Selection of common tools and platforms (activity 17) has two positive effects. First, it minimizes the cost of training and support. Second, it enables the tool users to focus on fewer tools and to spend more time on using them well; this indirectly increases the quality of the products produced using these tools.

Successful integration projects are characterized by bottom-up opportunities and top-down sponsorship. Opportunities to integrate two related activities or a common activity in two separate but related organizations are first visible to the two groups whose activities would benefit from their integration. Management, particularly a manager whose domain of control spans both groups, must embrace such an opportunity and provide enabling sponsorship (activity 18) to the individuals who will execute the integration project.

B.1.3.2 Success Stories

In this section we will describe briefly five integration projects that have been successful. They are National Semiconductor's Automated Semiconductor Planning and Control System (ASPC), Digital Equipment Corporation's Engineering to Manufacturing BRIDGE System, NeXT Computer's CIM operation and automated factory, and Texas Instruments' Product Drawing Control System and Order Entry Software System.

National Semiconductor - ASPC

For National Semiconductor, the manufacturing process has four steps: fabrication, sort, assembly, and test. Between sort and assembly, the dies are placed in a die bank which provides the die inventory for the assembly operation. The second half of this process is automated, from the die bank to completion. Also the sales and marketing is automated, with 70% of orders received via EDI. ASPC integrates the assembly operation with the sales operation.

ASPC automates quoting delivery times during order processing, based on inventory in the die bank inventory, work-in-progress, and the capacity of the assembly plants. Prior to ASPC, a quote guide was used that gave projected delivery times for each National product, based on average order quantities and frequency of orders.

A pilot system for ASPC is operational, covering about 7% of National's part numbers. On-time delivery for these parts rose from less than 88% to 98% when delivery time estimates were based on the quote guide using the system's delivery dates.

ASPC also puts out a report to the factory, on a daily basis, giving its proposed schedule for assembly that day. ASPC could automatically schedule the assembly lots for the day, but the factory management prefers to evaluate the report and manually release the requested lots into their shop floor system. A positive side-effect of ASPC is a leveling of assembly orders and the correlated inventory control. Prior to ASPC, orders tended to be very bi-modal, with all deliveries scheduled for the 1st or 16th of each month, and each factory tended to have at least 15 days of inventory on hand. Now just-in-time (JIT) inventory deliveries can be leveled out and reduce the actual level of inventory on hand.

Digital Equipment Corporation - BRIDGE

Digital Equipment Corporation's Engineering to Manufacturing BRIDGE system was developed to provide product data management on the VAX 9000 project. BRIDGE provided design-to-manufacturing coupling for the VAX 9000 product, including with outside suppliers. BRIDGE coupled engineering and manufacturing groups in California, Ireland, Massachusetts, and Vermont, leveraging off the infrastructure provided by the DEC corporate network.

Because of the anticipated complexity of the product, and based on the experience of the preceding VAX product, DEC felt that the BRIDGE system may make the difference between a viable and a non-viable product development effort. While developing BRIDGE they sought to re-engineer the product data management and release process, rather than automate the existing system.

The data elements managed by BRIDGE are documentation, drawings, CAD files, and product descriptions. Design engineers work on new versions in their own workspaces. When the design is ready for release and has received management sign-off, it is checked into the BRIDGE system. Following a check-in event, BRIDGE notifies users who need to know about it. Those users, either designers or manufacturers, then access the new version of the data element in BRIDGE.

Notification that a new change has taken place is sent to users dependent on that data element, by automatically generating e-mail messages. Those users subscribe to BRIDGE for notification of various changes of process state (e.g., creation of a new version) on a specific part or combination of parts. BRIDGE reduced the release and dissemination time for a new version of a design from 3 weeks to under 2 hours (the average), with 20 minutes as the best time.

Suppliers accessing data from BRIDGE connect to a spur network that is isolated from the DEC engineering network. They issue their access requests to a BRIDGE server on the isolated network, where the server knows how to validate the access permission, locate the data element (by forwarding the request to the appropriate BRIDGE server node on the corporate network), acquire a copy of the data on the spur network, and disconnect the spur network from the main network. The supplier then accesses this copy in an isolated environment, but if notification comes of a change to the data element, a request for the new version will cause the copy on the spur to be updated.

BRIDGE is now well accepted, a way of life, although the acceptance was gradual and involved cultural change. One quote from the manufacturing side was that a "design is not done until it's checked into the BRIDGE system."

Several metrics attest to the success of BRIDGE:

- One system administrator versus ten in other system.
- Two-and-a-half data coordinators versus twelve to fifteen on preceding product.
- Two hours to disseminate new version, versus three weeks previously.
- No version control errors during development of the VAX 9000.

One version error would have been more costly than the development cost of the BRIDGE system. The configuration and version control meta-data was stored in a DEC proprietary object-oriented database management system (DBMS).

NeXT Computer

The next success story presented will be the CIM at NeXT Computer. When building its manufacturing facility, NeXT had the benefit of starting with a clean slate and having a capable workstation product upon which to base the system.

NeXT adopted three CIM strategies:

- Strive for a single-layer information architecture.
- Create object-oriented software tools, eliminating non-value-added CIM work.
- Develop quality control systems based on real-time access to all the data.

For coupling between design and manufacturing, NeXT implemented a translator, called MENTRANS, that takes PCB CAD files as input and compiles machine programs to control the assembly operations. The first translation takes a few seconds for a 1 megabyte CAD file. The machine programs are then optimized for cycle time and machine wear within four minutes.

The manufacturing line is controlled by NeXT workstations. The bulk of the codes controlling the assembly line is for sequence logic and data gathering, which are handled at the workstation. A minority of the code is actually at the robot level, to pick or place a component.

NeXT uses an approved parts list that is "owned" by manufacturing. On the first NeXT circuit board, manufacturing vetoed 35 components proposed in the original design, due to considerations such as reliability or manufacturability. To further strengthen the coupling between design and manufacturing, all prototypes are assembled on the manufacturing line; this could not be done without the ability of the MENTRANS system to automatically create an assembly program directly from the CAD design. Once a design enters full manufacturing, the designer participates in manufacturing start-up.

The workstations that control the workcells also monitor the workcells and capture data on their operation. Analysis of quality data can be exhaustive and more accurate than if based on statistical sampling. Manufacturing engineers can access historical data about processes, components, and materials. Management (world-wide) can monitor the operation of the manufacturing facility in real time.

Texas Instruments

We will conclude this section by presenting two integration projects at Texas Instruments. The first is Product Drawing Control System (PDCS), an electronic drawing control system used in the Defense Systems and Electronics Group (DSEG). The second is Tooling and Information Engineering System (TIES), a system to manage tooling and information (e.g., photomask data) used in the Semiconductor Group.

The goal of the PDCS is to provide electronic distribution of drawings and to provide paperless viewing of designs. PDCS provides an on-line optical disk storage server and softcopy software used to view a drawing on a workstation.

Drawings are stored in two forms in PDCS. One form is CAD-system dependent, using the native CAD file from whatever CAD system was used to create the design (e.g., AutoCAD or ComputerVision). The second form is a plotfile in either Hewlett Packard Graphics Language (HPGL) or Calcomp plotter format. If a viewer has the proper CAD system, the file can be viewed using the native CAD file. Softcopy can be used to view any drawing in the system, accessing the plotfile. There are over 25,000 drawings in PDCS, occupying over 11 gigabytes of optical disk storage.

The lifetime of a drawing in PDCS is at least 15 years. It is very important that the system provide very high integrity of design identity. When two people have accessed a drawing, they must be able to guarantee that the drawings were of the same versions of the same design. This is provided by softcopy using a PDCS-generated trace number, which depends on the design identity and the drawing data, like a checksum.

PDCS still uses one paper copy of a drawing as the sign-off signature copy. The trace number on this copy can be matched against the trace number rendered by softcopy each time the drawing is viewed to confirm that the released version of the drawing is being used.

DSEG does the majority of its procurement electronically. The purchase order is sent using EDI. They also transfer PCB data files (e.g., tooling data) to the vendor electronically. DSEG used to send paper copies of the drawings as an attachment to the electronic transaction. Now, with PDCS, they can transfer the plotfile to a vendor who can view the drawing (or plot a hardcopy of it) on site. The softcopy software requires a plotter and a workstation, which may be an IBM-compatible personal computer, at the vendor's site. For access control, an approved Texas Instruments person must transfer the drawing data to the vendor's workstation.

Presently about 1% of the DSEG vendors use softcopy. Paper is used for legacy projects that were begun prior to deployment of PDCS.

Softcopy provides a red line editing capability. A red lined drawing may not be placed in PDCS, but it can be transferred to a designer outside of PDCS. The designer can make those edits in the proper CAD tool and place a new version of the drawing in the PDCS system, following the normal release process.

The time to release a drawing is the same using PDCS as it was previously, since it involves carrying a paper copy of the drawing around for signature. The time to obtain a copy of a drawing has been reduced from nine minutes to less than four minutes.

TIES manages filling orders for photomasks. The orders come from a wafer fabrication, an IC design engineer, or a product engineer. TIES will access the design files and invoke generation of the appropriate photomasks. TIES will also archive the data necessary to reproduce the masks.

The goals of TIES are the following:

a. To reduce the cycle time from placement of a photomask order to receiving the required photomasks.

a. To eliminate photomask generation and documentation errors.

b. To reproduce masks for the lifetime of that product.

TIES will leverage the existing Photomask Order Entry System database and the TI world-wide network facility. In 1990, a photomask order was placed in the Order Entry

System, and then manual actions caused the location of the source for photomask generation (e.g., a layout design file), submission of photomask generation, verification, and release of the photomask generation data. Currently this process is time consuming and error prone.

TIES automates the manual actions described above. It reduces the cycle time by over 70 hours per order, reducing labor costs from $420,000 to $40,000, a savings of $380,000. TIES also makes the process less error prone. Prior to TIES there were approximately six errors per year that were not caught until the mask reached manufacturing. In that case, the average error costs $100,000. In addition, errors cause delays and redo of mask generation effort. Delays, which may be measured in months, affect time-to-market and reduce the profitability of the delayed product.

Because a photomask may be reused for up to 15 years, TIES must have the ability to regenerate a mask during its product lifetime. Another component of the TIES architecture is DART, the Design Archive and ReTrieval database. TIES was prototyped basing DART on an Oracle database. They would prefer to use an object-oriented database in the future. TIES must access photomask vendor and wafer fabrication data from legacy information management system (IMS) databases.

Currently TI's world-wide network uses an SNA (Systems Network Architecture) backbone among various IBM mainframe computers. TCP/IP networks of workstations exist in each facility and are gatewayed off the SNA network. They are working on providing a second connectivity path that is all TCP/IP, using bridges between the ethernet networks of various facilities. It would be very powerful to access IMS and relational databases across the network in real time.

Another benefit experienced by TIES is that native language strings in electronic forms are orthogonal to the forms themselves. So the same mask order form could be transmitted to Japan and to the United States. In Japan, the form would use Kanji strings when presented on a workstation screen or printed, while in the United States equivalent English phrases would be used.

B.1.4 INTEGRATION STRATEGIES

In this section we will highlight 15 integration strategies that are practiced in the electronics sector today. The first 10 strategies are widely practiced by 5 or more of the 13 companies visited by the electronics sector team in the course of this study. Of these10 strategies, 3 are general strategies that underlie any integration activity. The other seven are specific strategies that each address one coupling or axis of integration. The final five strategies are not widely practiced, but are considered to have significant merit by the company or companies that did follow these strategies.

B.1.4.1 Architect the Integrated Enterprise

A successful integration must bring a well-thought out structure to the enterprise. Do not begin by automating business as usual, but rather figure out what the business really does and streamline it. Align the structure of the integrated enterprise with its goals and objectives. Look for redundant or unneeded practices. Ask what should be going away. Explore the alternatives for replacing an existing system before you ask if it should be replaced.

Process modeling is one way to determine what the business does. It takes a significant effort, but it can identify needed activities (omissions), redundant activities, and unnecessary activities. The process modeling effort should avoid coupling its model with the existing way of doing business; for example, avoid reflecting organizational structure in the process model and avoid acronyms or buzzwords that imply ownership of a process. Identify processes that are used in multiple applications. Use the correct experts in developing and validating the process model.

For data, avoid assigning ownership of data to organizations, but identify a process responsible for stewardship of each data element. (Note that stewardship can be reassigned at any time it becomes appropriate.) Consider integrating at the data sources, but be open to integrate at any site. Collapse two or more processes at different sites to one process, or co-locate them if it makes sense.

The result should be an architecture for the enterprise and a complementary interface architecture that will enable the processes to interact to implement integration.

B.1.4.2 Recognize the Role of Autonomy

As discussed in section B.1.1, the electronics sector companies represented in this study exhibit individual and organizational autonomy within their corporate cultures. Out of respect for such autonomy, integration projects are not imposed top-down. Rather, integration proceeds from the recognition in two or more groups that they are working to perform the same processes or mutually interacting processes. Generally champions will emerge from these groups who will propose the integration project. At this point, most successful projects find a sponsor in the management chain to whom both (all) the affected groups report. The combination of grass roots championship and common management sponsorship appears in most successful integration projects.

Thus integration projects seek to combine islands of automation. During the integration project, all groups should continuously display their buy-in by funding or staffing the effort. On the other hand, the management sponsor should be alert to recognize requirements of the project that should be provided from the corporate level. For example, if two groups should exchange design data via a product data management repository, rather than either group being required to pay for the repository (which appears optional to their operation), it should be provided as a centralized corporate resource.

Once an integration project is implemented and operational among the first two groups, it serves as a showcase system for other groups with similar needs. Champions in these other groups will quickly line up to extend the system to their own group. Being able to add new clients incrementally is a significant benefit because the project can focus its resources on the new client and improve its chance of success.

B.1.4.3 Enable Peer-to-Peer Communication

A goal of integration is to enable cooperation among geographically separated sites. Motorola describes its vision as the wall-less virtual office. It is important that an individual with a need to know certain information is empowered and able to access that information wherever it may be within the enterprise. A requirement for this capability is a corporate-wide network. In addition, as different islands of integration become integrated, high quality peer-to-peer communication among the groups is essential. One facility that is widely used is corporate electronic mail.

The next six subsections discuss some specific pair-wise integration opportunities.

Increase Order Entry and Manufacturing Coupling.

There is a mutual co-dependence between order processing and manufacturing; orders are limited by the manufacturing capacities, work-in-process, and finished goods inventories. Manufacturing must schedule its capacity to produce a product that can be and is being sold, and the schedule must not cause inventories to balloon unnecessarily. Most manufacturing facilities are automated to the extent of manuf[222zacturing resource planning (MRP) and JIT systems. A first step in automating order entry is to accept EDI orders from customers. Then this on-line order information can be used to order materials and schedule manufacturing.

One form of inventory reduction is in the documentation area. For many products, the configuration of options used in one unit of the product can be unique. An on-demand printing system can print the documents that accompany the product shipment just in time as the product is manufactured, and can be custom configured to the product as built. This capability eliminates document inventories and enables accurate document sets to accompany the product ship. Note that the documents will be accurate both in the sense of being properly configured to match the product unit, and in the timeliness of being up-to-the-minute consistent with the latest release of the product.

Increase Design and Manufacturing Coupling.

There are many opportunities to integrate design and manufacturing. Managing the release of a product design from engineering to manufacturing is perhaps the most important. Automating this process can reduce the cycle time required to disseminate a released design by using an electronic warehouse as a bridge between the designer and manufacturing. The system that provides access to this warehouse will include the product data management system that manages the configuration of the product data, ensuring the correctness of the design data being released.

The integration between engineering and manufacturing can also be synergistic with the automation of the factory floor. The design data from engineering can be used to drive the CIM programs to automate control of factory floor equipment. This being so, the factory can be used to automatically build prototypes of a product by programming the floor to build one unit from the prototype design. Through this process, the design engineers will become familiar with the capabilities of the manufacturing line. Thus the engineer can design for manufacturability, and can play an integral part in setting up the manufacturing line to correctly build product.

Another point of coupling between manufacturing and engineering is an approved parts list. Engineering may propose new parts to be approved and entered onto the list, but manufacturing must approve the part number and sourcing (for manufacturability and reliability).

Automate the Factory.

The manufacturing factory is itself an integration opportunity. There will be a variety of (heterogeneous) numerical control machines, pick-and-place robots, and so forth. These can be controlled by workstations, which provide "intelligence" to both control the machine programming to achieve one manufacturing step, but also to sequence the steps performed. Thus a workstation plus a numerical machine becomes a "brilliant machine."

By varying the control sequences in real time, multiple products can be manufactured on the same factory line in lot sizes as small as 1 or 10 units. This in turn provides the flexibility to schedule the manufacturing line in almost real time (depending on the manufacturing cycle time for one unit of product). The workstations can also monitor the feedback from the numerical machines and accumulate on-line quality information that can be used to tune the manufacturing process.

Establish Strategic Sourcing.

Strategic sourcing refers to having a few selected suppliers who have long-term relationships with the company. The supplier is guaranteed a predictable volume of ongoing business at a fair compensation, and the company has a partner who will try to support the company's way of doing business. This may extend to the supplier practicing the same kind of quality program as the company.

Once suppliers are selected, the coupling with manufacturing can be integrated. EDI can be used for purchase orders. Drawings and product data information can be distributed electronically to the supplier, sometimes even with equipment placed in the supplier's shop at the company's expense.

Select Common CAD/CAM Tools.

By common CAD/CAM tools, we mean selecting one vendor for one type of tool and using that vendor's tools as the common tool of that type across the corporation. The integration of a set of CAD tools into a cohesive suite is a significant task. (Some companies specify the need for a CAD framework to simplify this task.) However, the integration effort for one tool of each type will be much less than the same integration task undertaken with several tools of each type.

Use Integrated Software Development Systems.

There are several integrated software development systems for enterprise integration applications, including Texas Instruments' IEF (Information Engineering Facility), Knowledgeware's IEW (Information Engineering Workbench), and IBM's AD/Cycle. These products each use a repository or database to store a single description of data formats that are used to generate data structure statements in the software developed with the system. Implicitly, applications developed from such systems will be able to integrate and exchange data in a common data format.

B.1.4.4 Replace Legacy Systems.

Almost all companies visited announced their intention to replace legacy systems over time, several companies specifying that this strategy was to occur during the next five years. Replacing a legacy system may involve migrating the data of the system to a new system performing a similar role, or discarding information stored in the legacy system's format, or it may involve keeping one copy of the system functioning in the company's archiving facility, in order to recover the displaced information.

B.1.4.5 Other Strategies

Increase warranty service and manufacturing coupling. There will be certain kinds of failures that will only be detected and corrected by integrating quality information from warranty service (i.e., field service) and manufacturing.

Use customer advisory councils for feedback. Several companies obtain feedback from customers via formal advisory councils. This enables the companies to help fine tune both the processes and the products in an integrated enterprise.

Use a single-layer information hierarchy. NeXT Computer contends that layers are the CIM enemy number one. The assumption here is that the corporate network is a single world-wide network, and that all information access is served peer-to-peer among workstations and computers on this network. This strategy seems synergistic with a goal of flattening management hierarchies and broadening control of a company.

Create object-oriented software tools. Object-oriented tools enable integration efforts to standardize on interfaces and minimize the effort to create interfaces among the various types of objects. This may reduce the amount of work to achieve integration and eliminate non-value added work.

Migrate from mainframes to small computers. This strategy reflects the ongoing miniaturization of computing equipment. Using small computers (e.g., workstations) to control the manufacturing line is an example. It also introduces legacy system issues for the data and the software that had run on the mainframe.

B.1.5 INFORMATION INFRASTRUCTURE

In this section we discuss the technology, both hardware and software, that is used to support integration projects today. These technologies are used to model, store, exchange, and manipulate information as well as present information to the end-users. There are also technologies used in the software development of an integrated system. As a group, these technologies will provide the infrastructure for the integrated enterprise during this decade.

The computing environment for today's enterprise usually includes multiple computing platforms. They come in different sizes (mainframes, workstations, personal computers) from different vendors (Apple Macintoshes, IBM or IBM-compatible personal computers, various workstations, and mainframes). They run various operating systems, from Unix to MS-DOS, from VM to VMS.

Each corporation has a world-wide corporate network that enables each computer to be accessed on-line. There are a variety of network protocols (DECNet, Domain, NetBIOS, SNA, TCP/IP). Most of the corporate networks are heterogeneous, both in the sense that they use more than one network protocol (with gateways between them) and in the sense that they connect computers from multiple vendors, possible running different operating systems software. There does tend to be some homogeneity within a computer manufacturer's own shop. (NeXT Computer, for example, uses an all TCP/IP network, but has Apollo workstations in its CAD group, a Sequent mainframe in its information systems group, and NeXT workstations for development systems and controlling the factory floor.)

An important value-added networking service provides EDI. EDI enables paperless, real-time exchange of purchase orders and other business transactions between a company and its customers or between a company and its suppliers.

The networked computing environment supports on-line access to remote files (files resident on remote computers accessed over the network), usually using Sun Microsystem's *defacto* standard NFS technology. The environment also offers peer-to-peer electronic mail world wide. There is technology to execute a computation on one computer while the interactive user is at another computer (on the network). This includes X windows and windows-oriented user interfaces on PCs and Mcintoshes. In addition to window systems graphics primitives, HPGL and Calcomp plotting formats and the postscript documentation language enable the export and remote presentation of drawings.

Much of the intellectual property of an electronics company is in design data. This data is usually stored in file system files, which may include optical disk or CD ROM media for large capacity archival storage of stable design data.

Data about design data (such as its development history) and other operational data are kept in a data base management system (DBMS). Most business data is still stored using hierarchical and network model DBMSs (e.g., information management systems (IMS), IDMS), the so-called "legacy systems." Relational DBMSs are widely used, and a few early adopters are using object-oriented DBMSs.

One level higher, there are database application systems (built on a DBMS) that manage specific information. Most companies have a product data management system to manage the design release process as well as the configuration and product build information. (These systems are sometimes called Electronic Vaults or Data Warehouses.)

Data dictionaries and repositories enable applications to share data, describing the access paths and format conversions to access a named data field. Many data dictionary systems conform to the IRDS standard.

Two other important database applications are the approved-parts database and a part number cross-reference database (to convert internal part numbers to supplier's part numbers, or between one division's part numbers and another division's part numbers). Both Tektronix and Texas Instruments mentioned Interleaf 5's documentation database, which has an open format that makes it easy to import and export information.

Workstations deserve special mention in the information infrastructure when they are used as device controllers on the factory floor. Other pertinent infrastructure elements are the software development tools used to develop the CIM software, and the translation software that generates factory control and numerical machine programs for a product directly from its CAD design data.

There were several other infrastructure technologies mentioned during site visits. Some of these were mentioned frequently, some only once. We list selected ones here:

- Internationalized text strings (e.g., 16 bit characters for Kanji)
- Software development tools (e.g., IEW, IEF, AD/Cycle)
- Information and process models (e.g., IDEF0, IDEF1X, Entity-Relationship-Attribute models)
- CAD Frameworks (e.g., Falcon Framework)

- Data locator utilities (e.g., OMG's Object Request Broker)
- Open Software Foundation's Distribute Computing Environment (OSF/DCE)

B.1.1 LESSONS LEARNED

The electronics sector companies visited had among them a significant base of experience in integration projects and enterprise integration activities. This experience yielded a number of lessons about success and failure of integration projects. We begin this section with a discussion of the consensus lessons which were related to us by most of the companies visited. Then we conclude with some singular lessons that were each related by a specific company.

Cultural Change

There is unanimous agreement that overcoming cultural resistance and effecting cultural change are the hardest part of an integration project. In preparing for an integration project one should plan for both technical changes and cultural changes. Technical problems are shortly overcome, but cultural change is a long drawn-out process. When an integration project is deployed, one-half of the benefit comes from technology and one-half from cultural factors.

Autonomy

In an organization where each individual is encouraged to be autonomous, no one person is an enabler, but one person can stop an integration project. You need an "approximate consensus" to proceed. You must get and maintain continuous commitment from all participants. Start small, building a showcase system that tells its own success story. When extending the showcase system to integrate another group, sell solutions and benefits to the new group, not features of the system. Integrate by evolution.

Change and Legacy Systems

Data is stable, processes change. That is, the information content of a business is relatively consistent; where the data that represents that information is acquired, stored, and used can change as the structure of the processes that use it changes. Change is caused by programs. Legacy systems tend to be owned by organizations that are resistant to change.

Process Modeling

Form shared models that cross functional areas or organizations. Make sure you do not partition the models in such a way that requires redundant processes. Stay away from the organizational structure—do not reflect it in the process model.

Investing in People

You need to invest the intellectual cost of putting a top person on an integration project. Get the correct experts into the activities. Empower quality people, expect a miracle (the miracle syndrome). You need zealots who do not know what can't be done. You do not want people who feel restricted by past practices.

Re-engineering the Corporation

When you look at a new system, understand the current work process. Identify business practices that will have to change, think about what should be going away, and figure out what it should be. Ask how to replace an old system rather than if it must be replaced.

Sponsorship

You must have senior management sponsorship. This lesson was repeated in some way by every company visited. It should be a single person who is in the chain of command for every group involved in the integration project. We call this the Least Common Manager (LCM) requirement. The LCM should be positioned such that every middle manager involved in the integration project reports (directly or indirectly) to her or him.

Success and failure stories abound that reinforce this lesson. One company reported a project that was started and failed three times. The fourth time, a Director personally involved himself in the project and it succeeded. Sometimes a none-too-subtle nudge is all that is needed. Another company reported that the question "who wants to tell the Vice President that the project cannot be done?" was used at least a few times to break an impasse in project meetings.

In another company, a Director of one group and a Vice President in another group were collaborating on an integration project between their two groups. When the VP objected to some effects the project had on his operation, the implementation foundered (lack of a common manager). The President and CEO (the LCM) intervened and the project was completed, to become one of the company's success stories.

The sponsor must be in a position to intervene both administratively and budgetarily. Several companies reported integration projects that established an electronic vault or design repository. After the system was deployed, it went unused because there was a direct charge for the space used by a program. The program managers would not commit to this charge, even though the cost-benefit study indicated it would save money over the life of the project. In each case a Vice President absorbed the cost of the vault system in his group budget (charged back to the programs as overhead) and the systems became utilized and successes.

In another situation, funds for operating an integrated system were allocated at too low a level within Divisions. Over a few years each Division reduced its support staff for the system, either by reassignment or by attrition. When the once successful system was inadequately supported, it fell into disuse and was eventually abandoned. Integration should cross the corporation and be a central function, which removes it from local funding decisions.

Technology and Standards

Technology is not a barrier to integration. The absence of widely accepted standards is a problem. Where standards exist, the absence of products that implement the standards is a problem.

Other Lessons

There were several other valuable lessons related to us during the site visits. The following lessons were each mentioned in a unique way by one company and we list them with the respective company in the following paragraphs.

The following six lessons are from **Digital Equipment Corporation**:

(1) Look at the reward systems of middle managers, which can reinforce changing or not changing their organization.

(2) The BRIDGE system succeeded because they kept bounding the project. When it had been successfully deployed for one program, they carefully took on new programs, incrementally extending the project.

(3) The value of integration is the diminishing incremental effort to extend the system.

(4) Uptime of the integrated system is the most important user requirement.

(5) An architecture (i.e., functional boundaries) and an integration architecture (function interfaces) should complement each other.

(6) CIM gets confused with automation. Several "integration projects" that were unsuccessful turned out to be projects that automated business as usual.

The following three lessons are from **Hughes Aircraft Company**:

(1) A multi-group initiative is effective but less efficient than a single organization.

(2) Information systems are oriented toward the present (short-term); business strategies are oriented toward the future (longer term).

(3) Do integration at data sources.

Two lessons from **IBM** are as follows:

(1) While designing an integrated system, identify the integration services that serve all applications.

(2) Get both management and engineering level input on an integration project.

A lesson from **Intel** is that after investing in a system, you must address how one wants to run the business using the system.

Motorola observed that there is more payback in enterprise integration now than 10 years ago, partially due to economies of scale.

National Semiconductor related the lesson to integrate a multi-site process at one site when it makes sense. Work-in-transit can be a significant inhibitor to reducing cycle time.

At **NeXT Computer** the Approved Parts List is owned by manufacturing; they vetoed 35 components in the first product. NeXT also concluded that offshore manufacturing introduces a three- to six-month delay in time-to-market.

Tektronix observed that the same stream model (i.e., process model) exists for each engineering discipline, but there is little cross-talk.

Texas Instruments told us that a client-server model has solid cost benefits. They also noted that implementing change or automation is quick if it fits the current structure, but takes a long time if it goes against the current culture or facilities.

Westinghouse suggests that integration projects should evolve via redundancy; that is, operate parallel systems until the integrated system is accepted and then cut over to the integrated system. They also observe that you should be prepared to integrate at any site.

B.2 ELECTRONICS INDUSTRY 2001

This section presents the state of the electronics industry in the year 2001. In section A.1.1, we discussed four commonly observed cultural factors among companies in the electronics sector: technology, competition, innovation, and autonomy. In this section we use these same four factors to characterize the state of the industry in the year 2001.

Over the past 10 years technology has made significant advances that enabled it to better support integration infrastructures. Semiconductor technology continued to track Moore's Law. Processors are eight times faster and eight times cheaper than in 1991. Memory and storage devices are eight times larger and eight times cheaper than in 1991. Workstations are multiprocessor systems with multiple multi-media displays. Networks have eight times the capacity and are eight times more reliable than in 1991.

Competition continues to be a fierce driver among companies in the electronics industry. Time-to-market is still a critical factor in business success for this sector. Product development cycles, from conception to shipped product, are between two and three months. Engineering and manufacturing are integrated so a design can be downloaded to manufacturing in a few seconds. Products are manufactured economically in lot sizes of one, and customer-specific products are a viable business strategy.

Innovation continues to be the key to remaining competitive. Engineering uses product specification languages that are input to product synthesis tools. Key intellectual properties are the libraries of designs of reusable components that are used by these synthesis tools.

Enterprises have been 60 to 70% integrated for the last half of the 1990s, so integration activities are part of the culture in the industry As a side-effect, information, both design data and operational data, is widely shared across the company and is viewed as an important corporate resource. However, companies are still composed of many autonomous groups. Entrepreneurial projects are given reasonable autonomy and license to achieve product success.

In the next section we describe a vision of the integrated enterprise in 2001, and in the section B.2.2 we describe the information infrastructure that will be necessary to support enterprise integration 2001.

B.2.1 THE VISION

In the year 2001, the major companies in the electronics industry are global companies with engineering and business operations in every major market: North America, Japan, Europe, Asia, the former Soviet Union, Australia, Africa, and South America. These companies are globally integrated enterprises, transferring and sharing data around the world on an hourly and daily basis.

Engineers, and any employee, using interactive video workstations and personal computers routinely open a window on their monitor and dial up another engineer for a video conference that is displayed in that interactive video window. In another window, all employees involved in the conference simultaneously view the design or report that is under discussion.

The CAD Framework Initiative has had success in defining a framework standard for CAD tools, and both tool vendors and computer vendors support the framework standard. The character of the standard is a published set of procedure protocols for requesting services from the framework or the tools registered in the framework.

The Object Management Group (OMG) has developed a similar standard for procedure protocols for business and office automation applications. Industry has led the effort to harmonize the two standards in order to support enterprise integration that spans both technical and business sides of the enterprise.

All servers register their functionality with the object service broker (the follow-on to the OMG's Object Request Broker of 1992) and describe their protocols in the Information and Protocol Encyclopedia (a follow-on to the IRDS-2 data dictionary).

The intellectual property of a company is composed of engineering information about its products, strategic information about its product plans, and its rule base of operating policies. This information is the major asset of the company. The cost of creating the data and its ongoing value dictate that it be on-line and used in the operation of the integrated enterprise.

B.2.2 FUTURE INFORMATION INFRASTRUCTURE

The key technologies, that underlie the information infrastructures of 2001 are object-oriented services, distributed computing, Open System Interconnection (OSI) networks, documentation tools, database management systems, and advanced manufacturing cells. Each of these is briefly discussed in the following paragraphs.

Objects provide computational services, from accessing a data element to controlling a manufacturing cell. An object owns certain d [illegible] ch these services are based. Defining an object class, with a published protocol for accessing its services is how facilities in one part of an enterprise become integrated with activities in another part of the enterprise. Objects occur everywhere in the enterprise's distributed network. An object service broker locates objects and transmits service requests to it.

Distributed computing follows a client-server architecture. Mainframe computers have evolved into servers for data found in their voluminous storage capacities. Workstations and personal computers are used on the desktop to access servers and data.

In the early part of 1990, OSI network standards were maturing to displace proprietary protocols (SNA, NetBIOS) and older standards (TCP/IP). The application layer offered an opportunity to add value and semantics to networks in an integrated enterprise. For example, EDI has added value to a network to enable exchange of business forms (purchase orders, shipping slips) between suppliers and a company.

Much of the operation of an enterprise is the processing of documents (e.g., for approval) or disseminating information. Documentation tools are used to publish information to be disseminated. These tools are also used to model various documents used in the enterprise, such as a purchase order or a process specification. An integrated enterprise has harmonized and integrated the various sources of documents.

Database management system technology has evolved to enhance information usability and support object interfaces. Relational and object-oriented data models are understood as two views on the same data services. Tables or spreadsheets are the conventional mechanism for accessing and manipulating enterprise data. The semantics associated with the data objects are supported by a cell object in a cell of the table. Hybrid databases have been developed as a mechanism to evolve "legacy" databases, such as those contained in older hierarchical or relational database management systems, into the newer database servers.

On top of documentation tools and database management systems, enterprise integration vendors build product data management tools and integrated resource management tools. Using resource management, the integrated enterprise processes orders and purchases; schedules inventory deliveries, manufacturing, staff; and supports financial activities necessary for the operation of the enterprise.

Advanced manufacturing cells are modular, capable of efficiently manufacturing various products in lot size one. They have workstations as controllers so that significant computation can be performed locally (e.g., for quality control) and the manufacturing control can be compiled from designs by computations on the workstations.

B.3 ISSUES AND BARRIERS

In this section we discuss issues involved in implementing enterprise integration today and barriers that might prevent the electronics industry from meeting the projected vision of enterprise integration 2001.

As can be seen from the "high water mark" integration scenario (see section B.1.3.1), current technology is not the barrier to achieving greater enterprise integration in 1991. If the maxim "be all that you can be" is applied by the electronics industry to integration, it will do a lot of building on the technology and information infrastructure available today.

Although technology is not a barrier to integration, the absence of widely accepted standards is a problem. Where standards exist, the absence of products that implement the standards is a problem.

It has been observed several times in this report that cultural issues are more than half of the problem. An integrated enterprise seeks to achieve business practices that are globally optimized across the enterprise. In most optimization problems, the global optimum is not obtained by combining a set of steps that are local optima. One cultural issue is the mismatch of goals between the enterprise and the profit and loss (P&L) center, when the enterprise is trying to optimize through integration and the P&L center is working to optimize its net profit. To the P&L center, integration is likely to seem to be an expensive intrusion.

Another potential cultural mismatch, at a higher level, is how one views the enterprise when planning integration. There is at least an operational view and a financial view, perhaps a distinct business view as well. The chief operating officer may want to integrate engineering, manufacturing, and field service, while the chief financial officer may want to integrate manufacturing, budgeting, and finance. Today, most integration activities are strictly in the realm of operations. The point is that to plan and carry out enterprise integration projects, the sponsor should have defined the Enterprise as it is being viewed for these projects and the goals of integration.

The need to re-engineer the corporation was cited repeatedly in our site visits. The task of re-engineering the way you do business will spread cultural issues as the wind spreads dandelion seeds. One way to manage the re-engineering task is to state as rigorously and formally as possible the goals and objectives of the integration activity. Then develop a process model of the enterprise that is structured to be aligned with the enterprise as expressed in these goals and objectives. There may be a threshold, measured in the complexity of the part of the enterprise being integrated, below which integration guided by intuition can succeed, and above which more formal planning, such as developing the enterprise process model, is required. The role of process modeling in enterprise integration 1991 is an open issue.

Legacy systems have also been referred to consistently in our interview visits. To some extent legacy systems are an understood issue, but each legacy system dealt with is an open issue until it is decided how that legacy system will be incorporated into the integrated enterprise.

The last issue we mention here is the role of integrated software development systems. Various systems (AD/Cycle, IEF, IEW) have been reported during site visits. These systems use repositories, encyclopedias, and shared databases for the applications they generate, and they do enforce the model of the enterprise as specified to the development system. The question of the necessity of an integrated software development system remains unresolved.

In the remainder of this section we discuss four barriers to enterprise integration 2001. The four barriers, electronic signatures, standards, adaptive interfaces, and database migration, all have underpinnings in technology and require some technical progress before they are overcome. Problems that have only a cultural basis are discussed in the issues above; perhaps some of them are actually barriers to successful integration. Although the discussion of barriers will focus on the technical components, we recognize that with each of these technology-based barriers there is a cultural component as well.

Electronic Signatures

A characteristic of an integrated enterprise is that paper tends to be replaced by electronic media for information dissemination. We noted that even where electronic transmission of drawings is implemented, one paper signature copy is required in the approval process, primarily for legal purposes.

There are other activities, EDI transactions for example, that require authentication of the sender's identity. EDI provides authentication services that are essentially based on mutual trust between each of the parties to the transaction and the EDI service provider. This is why EDI uses a value-added network service and not just simply dial-up network connections.

There are several public key encryption methods, some even becoming standards that could solve the electronic signature's technical requirements, so perhaps this is a cultural barrier. The two steps to remove this barrier are to have widely available encryption implementations and some established laws or rulings that electronic documents with valid electronic signatures have proper and acceptable legal standing. It would be preferable that the encryption implementation be available as compatible shrink-wrap software for all of the major computer vendor's products.

Standards

A second barrier is involves the lack of effective standards. Standards are intended to remove barriers to communication and integration, but many barriers remain even with several standards that attempt to address the barrier.

One problem stems from the standards process itself. Standards tend to gain approval by building consensus, and it is easiest to get agreement on common technology and common practice. Many standards seem to have emerged as the least common denominator of potentially conflicting practices. IGES is one example. Two comments made during interview visits were "IGES is not enough" and "the important stuff gets through." In the latter case the necessary "*un*important stuff" was sent in separate files using proprietary formats to complete the design description.

Standards tend to address niche problems. For example, EDI defines a limited number of document formats that it can accept and deliver. One company said that we need "harmonization of office automation with engineering" in the EDI standards. Another example is Product Data Management. There is no common format for a bill-of-materials or product configuration that is used in electronic engineering, mechanical engineering, and software engineering (i.e., ECAD, electronic CAD; MCAD, mechanical CAD; and CASE, computer-aided software engineering).

Another problem is that we need products that implement standards. Part of this story is that the standards development process is much slower than the product development process (years versus months). This leads to companies offering products with so-called proprietary or *de facto* standards. These work fine when all of one's tools come from a single vendor, but they may not remove this barrier to integration in a heterogeneous environment.

Adaptive Interfaces

Integration depends on the ability to acquire and interpret shared data. By "interpret" we mean to use the data in the manner in which it was intended to be used. Object-oriented technology uses published interface protocols to specify what data is available from an object and how it may be used. Protocols also specify what services are provided on the object, and what are the semantics of those services. Procedurally oriented standards like those emerging from the Object Management Group, the CAD Framework Initiative, and PDES (in its application program interface (API) work) provide these protocol specifications for specific classes of applications.

A barrier arises when different objects, conforming to different standards or offering only proprietary interface specifications, offer similar services through different procedures. A meta-object model, which might also be called an adaptive interface model, would provide a description of the services offered by an object and how to access those services in an interpretive way. In this way, if a system wanted the "phone home" service from an ET[3]-type object, it would access the description of an ET class of objects, determine that it had a "phone home" procedure, and obtain a description of the number, type, and sequence of parameters required to invoke the service. Similarly, if a program wanted the "phone home" service from a student-type object, it would obtain the appropriate information about a student class of objects. These descriptions are obtained using a "meta-object" interface protocol that specifies how to obtain information from an object class dictionary about specific object-level interface protocols and how to invoke those object interfaces through a generic (higher-level) procedure call.

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[3] Extra-Terrestrial

Database Migration

The legacy database issue introduces another technical barrier, that of data migration. Technologically, we know how to access data in an IMS database, and we know how to encapsulate or put a wrapper around an IMS database that provides services like an SQL database. However, neither these approaches nor converting a large IMS database to a (for example) DB2 database are desirable technical solutions for dealing with a legacy database.

If we put a wrapper around a legacy database and access a data element, call it X, then we have to pay the cost of processing a query that returns X. If we need to access X 10 times, we pay 10 times the cost of processing the query. Since the cost of a query, through a wrapper, against an IMS database is much more than the expected cost of the equivalent query against a DB2 database, it would be a better strategy to query the IMS database once, store the resulting data element X into the DB2 database, and for the next nine accesses to X, query the DB2 database.

This is similar to incremental database reorganization or data migration. (The alternative to incremental reorganization is total reorganization.) Typically in an IMS-like database, incremental reorganization (if it is done at all) is done on a segment or record-type basis, that is, to convert all the records of the same type at the same time. In the strategy *outlined previously, conversion* would occur on a per record basis (one record at a time). In an object-oriented database, object-at-a-time (i.e., record-at-a-time) type migration has been studied and can be done. But an object-oriented database management system has type meta-data about each object that is not present in an IMS database. So we have no known mechanism to keep track of which records have been migrated and which have yet to be migrated. This is the research problem that, when solved, will remove the barrier of data model migration.

B.4 RECOMMENDATIONS

In this section we present five specific recommendations to the electronics industry. We conclude with a discussion of the structure of standards organization.

Recommendation 1. Define enterprise integration first. Since enterprise integration is not something that would be the same in every situation, define what you mean by integration within your enterprise before starting on integration projects. By setting a stable context for an integration project and understanding what you hope to accomplish with that project, you can improve your focus and expectations for a successful project.

Recommendation 2. Re-engineer management's mindset, then re-engineer the corporation. It appears to be good integration practice to re-engineer the part of the corporation being integrated. To be successful, this requires the sponsorship of a high-level manager. Since integration projects are at least 50% cultural, start your re-engineering work on the mindset of your sponsor and his or her immediate subordinates.

Recommendation 3. Learn by doing. If your goal is to integrate the enterprise, start with a useful, small, first step. If an integration project is staggering, bound (reduce) its scope and achieve a focused success. From a basis of one successful project, incrementally extend the system to include another group. Consolidate the larger system and make it successful before growing again.

Recommendation 4. Support government action to give electronic signatures legal standing.

Recommendation 5. Proactively support promising standards organizations. The output of a standards activity is commensurate with the quality of its input. Don't expect great and useful standards to just happen. There are really two ways to participate in a standards effort, actively or observing. Active participation requires that people do their homework between meetings, perhaps spending half-time or more between going to meetings, and technical preparations ("homework"). Observing "just" requires attending meetings. For most companies, it is a better investment to actively participate in a few standards efforts (with several people active in each) than to "monitor" many efforts by sending one observer to each.

To support enterprise integration, a standard must be useful and capable of servicing a complete task. This requires that the emerging standard be reviewed for usefulness in addition to consensus. Trying to quickly build a consensus can lead to identification of the common functionality among various approaches to a standard. It might be infeasible to use the "least common denominator" without technical extensions.

A standards organization must have effective technical leadership. Most standards activities participants are volunteers who tend to work on the aspect of the standard that is their particular interest. This can be very limiting, initiating too many technical thrusts, each without the critical mass needed to complete any one of them. One company can put critical mass into a working group, providing *de facto* leadership, or the standards organization can have a strong technical executive. This technical executive may be a technical director who is on the full-time staff of the standards organization (like the Object Management Group), it may be an executive committee, or it maybe contracted out to a company to provide the leadership (as occurred with the development of VHDL).

The technical executive should establish his or her own vision for the target standards, in order to provide leadership. On occasions he or she must have the ability to tell a volunteer that her or his efforts, although interesting, are not aligned with the current standards activities and to reassign the person to a task that is needed to get closure on the standard. Companies supporting a specific standards committee should consider assigning a half-time or full-time technical contributor to the organization.

In addition, some standards organization have a sustaining level of membership whose fees provide the primary support for the organization (e.g., CFI or PDES, Inc.). Companies who judge that they have a vested interest in obtaining an approved standard should participate in the standards organization at this level. These sustaining companies should bring technology to the table, to leverage the standards development effort. They should also require that reasonable performance goals be met, with precise annual objectives, project schedules, stated milestones, and acceptance criteria commensurate with the level of resources provided by the sustaining members.

B.5 LIST OF COMPANIES VISITED

(1) Digital Equipment Corporation

(2) Enterprise Integration Technology Inc./Stanford University

(3) Hughes

(4) IBM

(5) Intel

(6) Motorola

(7) National Semiconductor

(8) NeXT Computers

(9) Tektronix

(10) Texas Instruments

(11) Westinghouse

APPENDIX C. AUTOMOTIVE INDUSTRY RATIONALE

C.1 AUTOMOTIVE INDUSTRY 1991

The purpose of this report is to document the state of enterprise integration as it exists today in the automotive industry, create a vision of how it might look in the year 2001, and determine the information infrastructure necessary to support that vision.

The automobile is an integration of many complex systems. Mass manufacturing techniques for the automobile make it a very accessible appliance for most people in developed countries. Due to the complexity of both product and process, the production of automobiles can be considered the most complex industrial undertaking in the developed world. While a few products may be more complex, none engage the industrial infrastructure as does the automobile. Further, its size ensures that advances made in this industry will receive interest from all sections that serve manufacturing and the wider economy. For these reasons, it is important that the automotive industry be a driver of an information infrastructure backbone for enterprise integration.

The report presents the automotive business rationale for new information infrastructures to support enterprise integration. It has five sections: Automotive Industry 1991, Automotive Industry 2001, Issues and Barriers, Recommendations, and a List of Companies Visited. The observations, conclusions, and visions discussed in this report are based on site visits and roundtable discussions with automotive executives and consultants who know the automotive enterprise. Additional information was taken from documents listed in the references, and the experience of the professional staff at Industrial Technology Institute (ITI).

C.1.1 INTRODUCTION: STATE OF COMPETITION

Most current studies suggest that the U.S. automotive industry is lagging significantly behind the Japanese and perhaps the European automotive industry in almost every critical measurement: cost, quality, and time-to-market (TTM). For the last two years (1989-1991), the Honda Accord has been the highest selling automobile in North America.

On the coasts of North America, American cars are becoming the exception rather than the rule.

In a recent book by Kim Clark and Takahiro Fujimoto,[1] comparative statistics on the engineering hours and elapsed time needed to produce a small car with two models were published (see Table C-1).

Table C-1. Auto Engineering and Schedule by Locale

	Japan	USA	Europe High Volume	Europe Speciality
Engineer hours (millions)	1.7	3.2	3.0	3.0
Lead time adjusted (months)	45	60	57	63

Japan clearly has the advantage, and strikingly so, in both cost and time. The same report lists only 2 American vehicles in the top 15 in terms of a total product quality index. These figures may not be totally inclusive, but the trend is clear.

Chrysler, which was number three in the world market, is now fighting for survival. It has been marketing and selling cars built on its K frame for the last 10 years. Its big seller has been its popular minivan. They are currently trying to refinance some of their operations because of a current and projected cash flow problem. Similarly, neither Ford nor General Motors (GM) has made a profit on the North American automotive business in the last few years. GM, which only a few years ago was concerned about antitrust legislation because it controlled significantly more than 50% of the domestic market, now has about 35% of the market and has been closing plants the last several years.

Until the late 1970s, GM was not only its own competition but also its own supply base. The GM Oldsmobile division looked upon the Pontiac and Buick divisions as its competition in the large family-car market. There were over 15 divisions of GM supplying over 55% of the valued added to the GM family of vehicles. These were independent, competing businesses which would not consider sharing processing ideas or information systems with

1 Clark, K.B. and Fujimoto, T. *Product Development Performance*. Boston: Harvard Business School Press, 1991.

one another, or sharing cost information with a car division to which they supplied parts. As a result, a major player in the world-wide automotive business had trouble communicating internally with its over 200 plants, let alone with the rest of the enterprise. Corporate standards for internal communications (CISCO) were put in place during the mid-1970s in an effort to correct this problem.

During the 1980s, GM has moved from a corporation that is its own supply base to a corporation that increasingly out sources engineering services, design services, and parts supply. This transition has a great influence on the diminishing effect of its internal communications standards. GM now finds that a large part of its business involves communicating with companies that are not part of its communication network and who do not use the GM standards for communications. As a result, GM imposes its standards on large, or first tier, suppliers, and forces smaller suppliers of services and parts into a sub-tier position. This evolution is not exclusive to GM as Ford and Chrysler are also outsourcing, forcing their own standards on first-tier suppliers, and rationalizing the supplier base, forcing the smaller companies into sub-tier supplier positions.

Table C-2 lists the key sections within the auto industry with which the original equipment manufacturers (OEMs) must communicate directly or indirectly in designing and building cars. The table shows only a subset of the many industries involved in the auto industry. Many players, including both large and small companies, are involved. Interaction in goods, services, and information among these companies is essential to a successful automotive enterprise.

The automotive enterprise is made up of thousands of facilities. These facilities assemble vehicles, manufacture parts, make tools and dies, engineer vehicles and subsystems, design and manufacture machine tools, sell and service vehicles, and sell replacement parts. In Michigan alone, there are between 500 and 600 small manufacturers and dealers who are part of this total enterprise. The technology gap between the OEMs and the smallest of these suppliers is significant. The larger firms use state-of-the-art computer-based manufacturing technology, while many of the smaller firms function completely manually with perhaps a single personal computer (PC) for accounting and communications. A recent study[2] on small tool and die manufacturing in Michigan concluded that tool-

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[2] Fleischer, M.F, Phelps, T.A. and Ensing, M. *CAD/CAM Data Problems and Costs in the Tool and Die Industry.* Final Report of the Industrial Technology Institute and the Detroit Chapter of the National Tooling and Machining Association, 1991 (ITI Report CR-91-03).

Table C-2. Key Sectors Within the Automotive Industry.

AUTOMAKERS

- Assembly plants (vehicle, engine, and transmission)
- Captive parts plants
- Corporate functions
  - Advanced engineering
  - Product planning
  - Marketing
  - Financial

INDEPENDENT ENGINEERING FIRMS

MACHINE TOOL MAKERS

TOOL AND DIE MAKERS

PARTS SUPPLIERS

- Stamping
- Plastics
- Others

CONTRACT MACHINE SHOPS

MATERIAL PROVIDERS

ing and die costs could be reduced as much as 20% through improved information transfer between the OEMs and the many layers of suppliers.

The following table (Table C-3) and figure (Figure C-1) show just some of the tasks and responsibilities that must be coordinated to design a minor change to a vehicle. The information that must accompany the tasks goes through a series of uncoordinated manual and computerized information systems. This chart demonstrates the complexity of the design process which is described in greater detail in the next section.

This simplified description illustrates some of the complexity in the design process. It leaves out the continuing interactions that occur as production begins, and eventually as replacement part production commences. These phases require additional coordination among the players in the process.

C.1.2 EXAMPLES OF PROBLEMS IN THE DESIGN PROCESS

The following list gives some of the most common problems in the design process, focusing on those most relevant to enterprise integration activities. These are not the only

Table C-3. Steps in the Automotive Design Process (A Minor Product Change)

TASK	BY WHOM
Product change goals established	OEM marketing groups
Product sketched Clay model constructed Digitized model created	OEM stylists, drafters, designers
Examine tooling & assembly issues (DFM, DFA)	OEM manufacturing engineers
Make/buy decision	OEM (with supplier input)
Make soft tool (from clay and CAD) and prototypes	Model shop
Select partmaker	OEM
Manage die design/parts production	Part maker
Consult with stylists re features	Die designer, parts supplier, OEM designers
Design hard tool (major source of potential delay)	Die designer
Approve hard tool, part	OEM

DFA Design for Assembly
DFM Design for Manufacturing
OEM Original Equipment Manufacturers

problems associated with U.S. automotive manufacturing, but since 70 to 80% of the vehicle costs are determined during the design process, they are good examples of the types of problems encountered. Although technical problems exist, the underlying problems are more business-oriented. As we note later in our recommendations, addressing these problems requires commitment at the upper levels of the enterprises involved.

- Companies are unable to share product data electronically.
- There is poor communication between parties in the process.
- Reward systems do not encourage reusable designs.
- True sharing of information is difficult, due to lack of universal technology and management systems to support their use.

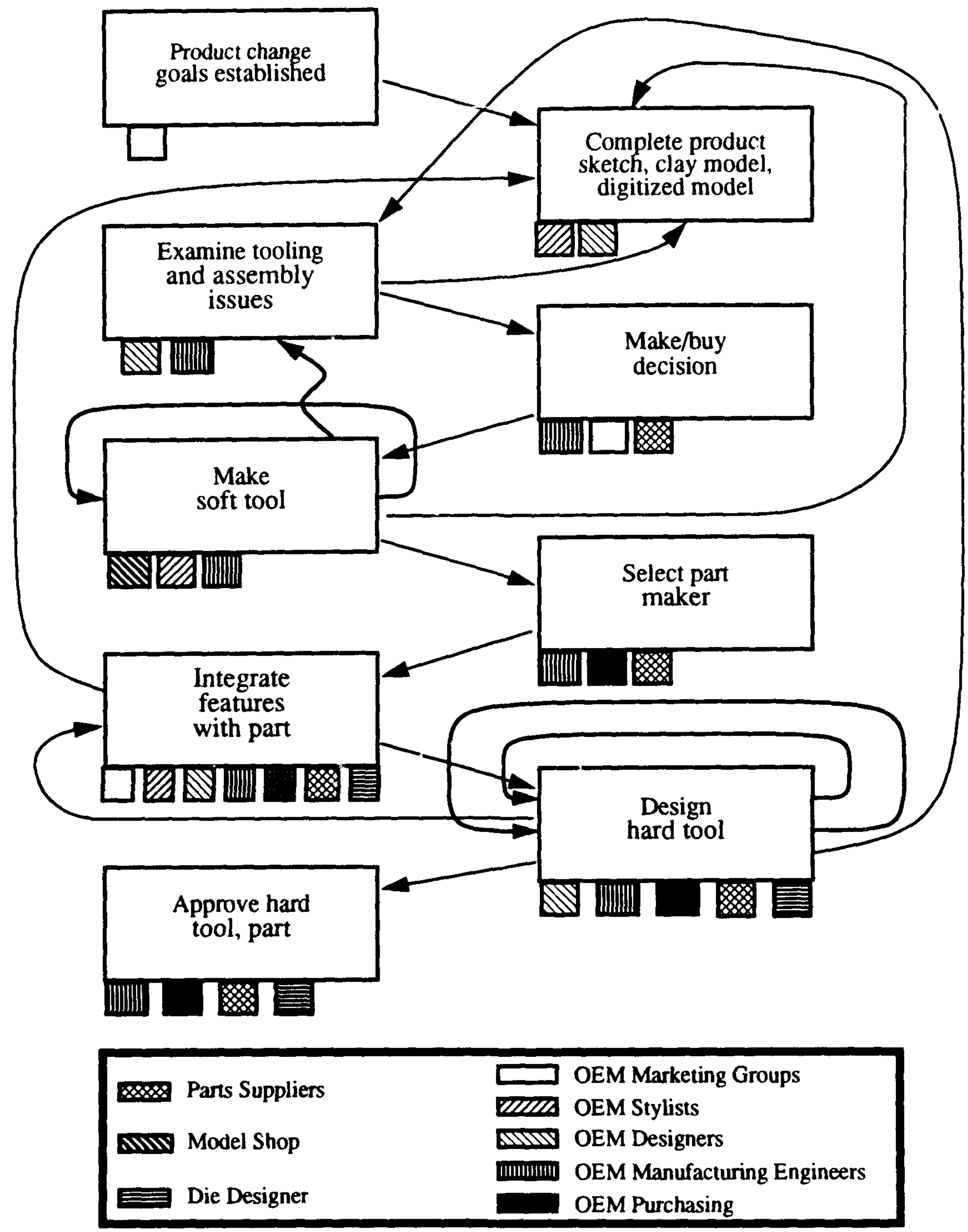

Figure C-1. Information Flow in the Automotive Design Process (A Minor Product Change)

- OEMs still treat suppliers unfairly. For example, suppliers are brought in too late and without requisite information.

From a technical standpoint, CAD is the most important technology in the design process. However, addressing the problems identified below requires not only advances in technical capabilities but changes in the business environment that will allow the technical solutions to flourish. Enterprise integration must address each of these areas, even when it is dealing with technical areas such as CAD.

- Use of both CAD and manual design methods throughout the process adds time and complexity.
- There is difficulty sharing CAD data among players.
- The multiplicity of CAD systems in use confounds data translation efforts.
- CAD libraries are often proprietary, leading to the re-creation of existing designs.

In addition to those problems, a variety of issues inherent in the supplier-customer relationship frustrates the product-development process:

- Emphasis on delivered price starves supplier firms, thus making it difficult for them to invest in needed technology and training.
- Lack of ongoing communication between those who design parts, those who make dies, and those who make parts requires constant adjustment of dies and parts throughout the process.
- Dies are often "overengineered" to account for outdated equipment or poorly trained workforce, thus adding cost and time.
- Many firms lack accurate production data from customers, thus frustrating attempts to produce on a JIT basis.
- Major customers sometimes cancel or delay design projects due to financial constraints.

During the late 1970s and early 1980s, when the problems of competition became apparent, management blamed the major problems on the high cost of labor or the dollar-to-yen exchange rates. We now recognize the problem to be many-faceted, with labor and the exchange rates being very minor contributors. The major problems are in the areas of planning, execution, culture, organization, and information sharing across the many parts of the enterprise.

In recent years, the Big Three (GM, Ford, and Chrysler) have recognized the importance of early communication between themselves and their suppliers (including links between their own divisions and other parts of the corporation that drive the design and production process). The result has been the establishment of product development teams and long-term relationships between customer and supplier. The OEMs have been more successful at utilizing internal or inter-departmental product development teams. There are still weaknesses in the links to the supplier members of the team. Communication typically consists of the OEMs telling the suppliers what they think they need to know. The communication is rarely two-way. The suppliers cannot give feedback or implement change in the design process in any way. Product development groups exist, *but* they generally *pass information* rather than *share information* or even more to the point, *use information.* Another constraint to the communications process is that suppliers are not effectively connected to the automated information systems that the OEMs have implemented.

C.1.3 STATE OF INTEGRATION 1991

Many now believe that some of the foregoing problems can be solved by implementing a concept called *enterprise integration.* Enterprise integration refers to a condition in which accurate and timely information flows smoothly within a company, and between the company and its suppliers, customers, and partners. In the integrated enterprise, all parts of the organization work cooperatively toward the satisfaction of common goals and objectives. Systems, procedures, and technologies are coordinated to minimize waste. The value of enterprise integration lies in its potential to help companies speed the development of better products and services, capitalize on business opportunities, and reduce operating cost.

Enterprise integration is a broad concept that sets the technology of integration within the context of the organization, the culture, and the work force. Enterprise integration has several characteristics:

- Approaches such as concurrent engineering, QFD, Design for Manufacturing, CPI, and TQM are used across the organization to achieve common strategies, goals, and objectives.

- The capabilities and relationships of people, processes, and tools are employed to optimize the use of critical resources to meet corporate goals and objectives.
- The redundancy of data, processes, and tools to perform a process is minimized.
- The data, processes, and tools needed to perform a function are readily available.
- Measurement and reward systems are designed and implemented to encourage cooperation and team efforts to achieve corporate goals and objectives.
- Clear, understandable strategies, business plans, and goals are visible and communicated to all parts of the organization.
- Organizational structures are designed to facilitate cooperation and timely decisions within the enterprise.

While many aspects of enterprise integration focus on people and organizational issues, one of the necessary building blocks is an information infrastructure for integration in place among all parts of the organization, including the partners.

All U.S. automotive OEMs have programs in place today to integrate their information and business systems. They realize that the information they use to run and coordinate their business, both in the short-term and long-term, is taken from their information systems. Today, in the North American OEMs, the same information resides in several different databases which are updated at different times from different sources. This results in uncoordinated planning, engineering, manufacturing, and scheduling systems.

Companies are all working towards single logical data bases, common platforms, common software; reducing the number of different CAD systems: and the leveraging of standards. The problem with these efforts is that they are aimed at the needs of the individual companies, with little consideration of the needs of their hundreds of suppliers. OEMs are treating each supplier as an extension of only their own companies, while in reality most supplier companies must do business with several OEMs to survive. This results in a multitude of systems and related expenses in the supply base.

Engineering services suppliers are concerned about the lack of standards in the computer-aided design/computer-aided manufacturing (CAD/CAM) area, and their need to buy and operate as many as 15 different CAD/CAM systems to do engineering work for the Big Three. The suppliers noted computer cost inefficiencies as high as 350% to run CAD systems that were proprietary to one company and necessary to get business from that company. The inefficiencies in use of people were estimated to be over 20% because of training and learning-curve problems when switching between systems and OEM programs.

This situation is also affecting small part-suppliers. Interviewing a supplier of trim parts for the Big Three revealed that they are being forced to purchase and have trained people on three different CAD systems. Other part suppliers were considering getting out of the automotive business because of poorly timed and uncoordinated cost-cutting programs. The purchasing departments want reduced costs, but the engineering and manufacturing groups need to participate actively in meaningful cost-saving design and specification changes via better integrated activities.

The SATURN project at General Motors may give some hints of how the production process will evolve in coming years. One SATURN practice relevant to enterprise integration is the "partnership" approach with component suppliers. While this term is certainly not new, SATURN is attempting to breathe life into the rhetoric that often accompanies supplier partnerships. Suppliers share more of the development costs, but also share the rewards and risks. In a recent recall, the responsible supplier was liable for the costs of the recall. Suppliers must clearly see the rewards of this approach in order for this process to take root.

GM is trying to transfer SATURN advances to the rest of GM by transferring key SATURN employees back to GM and having them sit on design committees as new products begin development. Process engineering for new products is being guided by SATURN's experience. Activities such as these may enable GM in particular, and the auto industry in general, to improve their time-to-market results. Enterprise integration, as practiced in a relatively small application at SATURN, may branch out across the industry.

Other contemporary examples of applying some enterprise integration principles are given below. Information flow in these examples is still manual as there were no intercompany information systems in place. The examples illustrate the benefits of team formation, and of accelerating the information flow between the OEM and its suppliers.

GM's H-car development used a four-phase development process:

- Phase 0: Establish budget, business case, and plan for engineering and design.
- Phase 1: Tooling is designed and working prototypes are built.
- Phase 2: Product and process validation culminate in pilot production.
- Phase 4: Normal production.

Supplier involvement begins early in Phase 0 which is the most complex phase of the process and includes many steps not discussed here. Communication within the automaker and between automaker and supplier must begin in Phase 0. The information communicated during this phase is highly design oriented. In later phases the information communicated is simpler and includes process plans, schedules, or JIT flags.

Ford and Chrysler also have their advanced-concept projects like SATURN, Alpha and Liberty, respectively. However, they are not yet marketing or manufacturing a product; these projects appear to be product and process teams with little disclosed about their specific activities.

At Ford, a program manager is responsible for new car development from start to finish. The development process generally occurs on four fronts: quality improvement, customer requirements, competition, and costs. Early in one project, as costs were being determined, the project team went to Ford plants and independent suppliers to understand the cost parameters. This method contrasted with development programs of the past where costs were dictated without such research that ensured targets could be met. Hourly workers were also part of the process, dealing with 2,000 issues of tooling through the process. This approach suggests that the information infrastructure supporting enterprise integration be designed so as to produce information from both the customer and the supplier levels that can be used by the production worker as well as management.

At Chrysler, four platform teams combine representatives from engineering, procurement, manufacturing, design, strategic development, sales and marketing, finance, and outside suppliers. With these groups, product development teams are formed for specific vehicles such as Chrysler's Grand Cherokee. The Cherokee team was given unusual authority in product definition and design. Changes were made (with supplier input) without approval from high-level managers; the only proviso was that overall cost and quality targets were met. Supplier activity occurred well before product approval from the company's policy committee had been obtained. After that point, senior management limited its direct involvement with the program: quarterly reviews were held and prototypes were driven.

C.1.4 BUSINESS STRATEGIES

The North American OEMs are all international companies and, because of their financial problems in this country, are relying more and more on offshore strategic partners for many functions, including some vehicle production. GM currently has a complete line of foreign cars which it markets under the GEO nameplate. One of these cars was designed in Germany, and is produced in South Korea and sold in North America. Ford has partnerships with Mazda and Nissan and recently purchased Jaguar. Chrysler has joint ventures with Mitsubitshi and Maserati. Figure C-2 summarizes these relationships as they existed in the late 1980s.

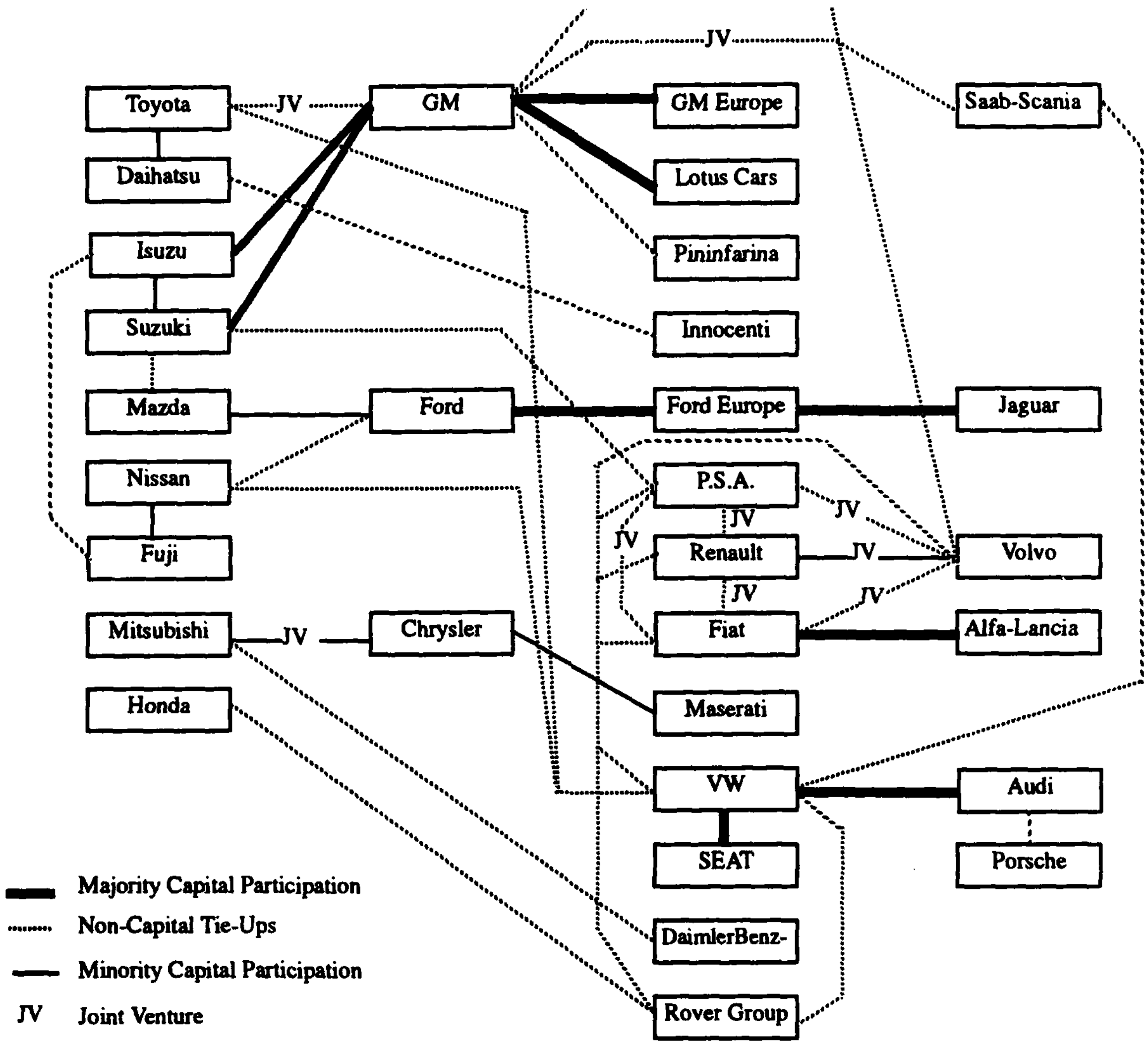

Figure C-2. Global Network of Automobile Producers in the Late 1980s

Source: Clark & Fujimoto, *Product Development Performance*, Harvard Business School Press.

The University of Michigan Office for the Study of Automotive Transportation (OSAT) activity predicts that Honda and Mazda will continue to be assemblers of cars and producers of selected components in North America, but the critical engineering and product-development work will continue to be done in Japan. However, OSAT also predicts that Toyota and Nissan will truly become world car companies with design, engineering and manufacturing in Japan, North America, and Europe. The transplants are currently adding only 15 to 20% of total value in this country. The product development and the engineering, both product and manufacturing, are being done in Japan, and many of the components (particularly the powertrain) are being shipped in from other parts of the world.

All the North American automotive companies, including the transplants, are developing business strategies aimed at manufacturing simplification and flexibility. These strategies include concepts such as re-engineering business procedures, concurrent engineering, standards and common platforms, and taking advantage of strategic partners from around the world.

GM is working on a rationalization of its product life cycle called "Four Phase." A "systems engineering center" with people from GM, EDS, and Hughes has been established for that purpose. They are defining and documenting in great detail the task and timing for each step needed to build a quality car in minimal time. GM is also working with its supplier base to implement a process called synchronous manufacturing. This process incorporates features of TQM, JIT, and CPI. One company, General Physics, is already offering training in this process. Some GM divisions have developed supplier development programs to help suppliers understand and implement new systems and technology. One of the leaders in this area, GM Truck and Bus, was cited by one of the companies we interviewed as very easy to work with. GM has formed a "Manufacturing Technology Council," made up of high-level managers who are defining and implementing strategies for world-class manufacturing. These strategies are all part of enterprise integration.

Ford has a vision for continuous improvement that is driven by cost, quality and time. It has assigned a high-level manager to each first-tier supplier to identify and solve any problem associated with cost, time, or quality of any part that the supplier sells to Ford. Ford believes in new technology and has a program to search the world for technology it thinks will be a winner and implement it as soon as practical. Ford believes it cannot wait for standards for new technology, which normally take 4 to10 years to develop. From a business point of view, Ford follows the development of standards but is not interested in participating in their development. Ford, like GM, has spent considerable time in studying its product life cycle. Several months have been taken out of their sheet metal development time while improving quality.

One source said, "Ford today is getting their dies for exterior panels from five companies, four of which are offshore. The U.S. company is currently filing for Chapter 11 bankruptcy." All of the Big Three are reducing the number of first-tier suppliers to reduce their communication problems.

C.1.5 INFORMATION INFRASTRUCTURE

Currently the automotive companies have many information systems within the confines of the company. They are characterized as local, in that a system will serve a department, site, or even an entire company, but does not span companies to cover an enterprise. Today's systems are fairly static. Once they are configured for such things as data storage capacity, communications interconnections, and processing capability, they are not easily changed to meet the demands of an ever-changing organization. Additionally, the information systems are typically used for limited functions. For example, CAD systems for design are completely isolated from accounting information systems or automated scheduling systems. Any type of cross-system processing must be done manually.

There are very few, if any, provisions for cross-organization automated information flow. If there is to be any flow of this nature, both organizations must have similar systems, or the data representing the information cannot be interpreted. For example, all three U.S. automotive companies have their preferred CAD package, and each sees its choice as a competitive advantage. Chrysler uses Catia, Ford has a Prime-based system, and GM has the Corporate Graphics System (CGS). They all force the use of their system on suppliers of major sheet metal exterior panels. Engineering service firms supplying all three with design services must purchase, be trained on, and maintain each of the proprietary systems required by the client. The cost of maintaining a proprietary system is enormous. For the automotive OEM, this cost can reach $10 million per year, using a staff of around 100 people. The service and supplier organizations, while maintaining much smaller versions, must also bear large costs of maintenance for multiple proprietary systems.

GM over the years has been a decentralized company with as many as 25 divisions competing with one another for some part of their business. This competition has lead to many different sets of business and engineering systems and procedures. Under the direction of David Hill, Executive in Charge of Information Systems, GM is in the process of rationalizing and integrating all of their systems. GM constructed a corporate vision for integration in which all of the major groups participated. They are working on common systems in all of their functional areas: marketing, engineering, manufacturing, accounting, materials, and office management. Their C-4 project is working toward the rationalization of their engineering community. They are also working on common data elements and a dictionary. In this program, they will be reducing the number of CAD systems in GM from 12 to 4, including CGS, CADAM, and Unigraphics. In this total process, they are developing a variety of data, information, and reference models using various modeling techniques. These systems will be based on existing national and international standards. GM has been a very active player in the standards development community.

In Ford, according to S.I. Gilman, because of centralized control and minimal internal competition, problems of integration have not been as severe. Today Ford has two CAD systems, one for exterior panels and one for component parts. Ford has a single engineering release system and reasonable standards in its manufacturing, dealer, and office systems. Ford is working toward common platforms and common software in most parts of its business, but not across the total corporation. For example, powertrain plants have one common platform and set of standards, while components plants may have another platform and set of standards. Their standards for the most part appear to be Ford standards, rather than national or international. However, Ford does clearly see the need for international standards and appears to be willing to use them when appropriate. Ford complained that standards take too long to develop and voiced an unwillingness to participate in their development. Even though it is working toward common platforms and standards, it is not clear that Ford has a vision for total integration.

C.1.5.1 Electronic Data Transfer

One result of the weakness of existing data exchange standards in the auto industry is the recent rise of companies offering services in support of electronic data interchange (EDI). Automotive supplier companies can, for a price, take product data that has come from their customers to one of these services to be translated into a form that they can use on their own systems. Services can provide two basic kinds of transformation: medium-to-medium transfer (e.g., nine-track tape to floppy disk) and data-file translation (e.g., Intergraph to AutoCAD). If a particular transformation is not a common one for the supplier, then using a service makes sense. However, such services are costly and add to the time it takes to produce a product. They are also outside the control of the supplier, leading to errors and delays, and thus problems with the customer. Data transformations with which a supplier must deal frequently are best handled by bringing the capability in house. Unfortunately, many suppliers do not have the technical capability to handle such problems. They may be afraid to undertake the transformations themselves. Worse, they may purchase inappropriate tools with which they try (and fail) to do the transformations, wasting further money and time. Electronic data transfer services can perform a useful task here, but if data exchange standards were well defined and widely adopted, such services would be much less necessary.

C.1.6 LESSONS LEARNED

The GM SATURN Corporation was conceived with integration of people, technology, and information in its mission statement. In visiting a SATURN plant, we noticed a strong relationship between information, people, and activity on the production floor. This integration appears to have contributed to a very efficient operation with extremely low inventory, high quality, and a highly motivated workforce.

SATURN learned a number of lessons during the implementation of integrated information systems:

- Standards are essential.
- Strategic partners (suppliers of parts, services or technologies) are important.
- Data ownership implies the responsibility of data administration.
- Change management for information systems requires a high degree of coordination.
- SATURN feels that MAP (Manufacturing Automation Protocol) is the right direction for manufacturing communications.
- People in all levels of the workforce must play a role in defining the information needs to run the business.
- A single CAD system is essential.
- Common applications can be used across most of manufacturing.

In visiting other automotive OEMs, first-tier suppliers, and OSAT, we reached additional conclusions about integration:

- Most large companies have information standards and are working toward some level of information integration within their own company, with little consideration for their suppliers.
- Companies can integrate their own internal operations, but suppliers who work for multiple OEMs need help in the form of enablers.

- Automotive OEMs have business interests in proprietary CAD systems, which they force on suppliers of engineering services.
- Integration can reduce the lead TTM and engineering by 30% and reduce cost by 20%.
- Most of the automotive OEMs are international companies and want international standards.
- Some large companies will follow standards if they exist but do not want to participate in their development.
- The Automotive Industry Action Group (AIAG) is moving in the right direction of automotive standards, but they need help in moving faster.

C.1.7 COOPERATIVE EFFORTS

C.1.7.1 The AIAG

The AIAG is a cooperative effort that was widely cited by our interviewers and panelists. It is an organization, that was formed in the early 1980s by a group of materials engineers who saw that a new kind of cooperative effort by North American vehicle manufacturers could improve productivity, strengthen quality, and reduce non-value-added costs throughout the industry. It now has over 700 corporate members. AIAG is operated by a team of 6 full-time executives on loan from member companies, supported by an administrative staff and a 21-member Board of Directors.

The real work of AIAG is accomplished by nine project teams and their associated work groups. These teams and groups are made up of some 900 volunteers from the member companies. AIAG has two types of project teams. One focuses on technology and the other deals with business functions. The technology project teams are EDI, CAD/CAM, Returnable Containers, and Automatic Identification (Bar Coding). The business project teams are Continuous Quality Improvement, Finance, Materials Management, Transportation, and Purchasing.

The project teams develop standards, guidelines, and conventions that apply to technological and business function areas. All EDI standards are approved at the American National Standards Institute (ANSI) X.12 level. AIAG also cooperates with various standards organizations such as ANSI, the Initial Graphics Exchange Specification/Product Description Exchange Standard (IGES/PDES) Organization (IPO), and the Organization for Data Exchange by Tele Transmission in Europe (ODETTE).

Many in the auto industry look to AIAG as an important resource for making the industry more competitive internationally. However, the general feeling is that AIAG is not living up to its potential. Activities are seen as too limited in scope and too slow in accomplishing their goals. Furthermore, there are real questions among those who take part in AIAG work groups that the industry will appreciate and accept their work.

For example, the CAD/CAM Project Team's Data Exchange Work Group is trying to improve the movement of CAD data down the supplier chain. This is not easy, as there are numerous CAD and CAM systems being used by automotive suppliers. Theoretically, IGES should support the movement of such data between dissimilar systems. Unfortunately, there are many problems between IGES itself and the systems that use it. The result is difficulty in the movement of data. A major concern among those who participate in the Data Exchange Work Group is that they will come up with tools and methods to improve IGES data exchanges, but the big automotive manufacturers will not use them. Indeed, it is the stated policy of some of the automakers that their suppliers must use their proprietary or captive CAD systems. This policy is adhered to in spite of the inability of small suppliers to support one such expensive CAD system, much less two or three. In other words, AIAG has a problem getting buy-in from its own members, not to mention the auto industry as a whole. This concern applies across most of AIAG's work groups.

A further problem is that, the 900 volunteers listed by AIAG as working on the work groups are too few to accomplish major efforts. There are about 40 work groups and therefore roughly 20 volunteers per group. At any one meeting many will be absent, and the AIAG work comes after their regular responsibilities, so the actual number of people available to do work per group is quite small. A slow progress with limited results should be no surprise.

For AIAG to fulfill its potential, it needs to have real buy-in by all its member corporations, manifested by the broad adoption and use of the standards promulgated by AIAG work groups and the dedication of more people and time to the effort. Until that happens, AIAG will continue to be disappointing in its overall effect on the auto industry.

C.1.7.2 CAM-I

CAM-I is a broad consortium of companies, the U.S. Navy, and the U.S. Air Force that forms teams and expertise to solve common manufacturing industry problems. The consortium provides applied research plans for developing and testing new concepts. Its initiatives focus on process planning, quality assurance, advanced numerical control, product modeling, and manufacturing management programs. CAM-I has conducted case studies of exemplary programs under its CIE (Computer Integrated Enterprise) program, and has generally underscored the importance of issues of organizational culture in approaching world-class manufacturing. Because CAM-I is convinced that the issues facing the small supplier are of paramount importance, the consortium is establishing a new group to focus on supplier development. The interest in the suppliers' relationship to enterprise integration is strong.

C.1.7.3 NCMS

The National Center for Manufacturing Sciences (NCMS) in Ann Arbor, Michigan, has two groups working on Integration for the Automotive Industry. One group is working on a reference model and the management issues that are a barrier to integration. This group has strong membership from Ford and GM as well as non-automotive companies.

C.2 AUTOMOTIVE INDUSTRY: 2001

C.2.1 THE VISION

The vision described here is based principally upon two workshops involving a panel of auto industry experts. The two days of roundtable panel discussions were supplemented with written documents describing and projecting automotive concepts and activities in the United States[3] and Japan.[4] The roundtable panel first established a vision that took into account key dimensions of the automotive product, manufacturing processes, people, suppliers, facilities, dealers, and information systems. Initial discussions of elements of the vision were reviewed and integrated by the project team for the second workshop, involving the same panel, which occurred about two weeks later. At that time, the panel developed a vision reflecting four essential aspects of the automotive process:

(1) The product

(2) Concept design and marketing of the product

(3) Concurrent detailed product and process design

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[3] Ernst & Young. *The Car Company of the Future: A Study of People and Change.* A Joint Research Project of Ernst & Young and the University of Michigan, 1991 (SCORE Retrieval File No. T00002).

[4] Association for Manufacturing Excellence. *Manufacturing 21 Report: The Future of Japanese Manufacturing*. Sponsored by Japan Machinery Federation, System Institute of Waseda University. Translated from *Articles in Communications of the Operations Research Society of Japan*, written by M. Iwata, A. Makashima, A. Tateishi, J. Nakane, S. Kurosu, & T. Takahashi. Wheeling, IL: AME (380 West Palatine Road, 60090).

(4) Operations and service

From those four elements of the vision, implications were drawn for the information structure that would support that vision. Those information infrastructure implications are discussed in a subsequent section.

C.2.1.1 Product

Definition of the product is the first essential aspect of the automotive business rationale. In general, there will be more automobile models, and those models will have shorter production lives. The life cycle of all the models, from concept to end-of-production, will be much shorter. Production time will be shorter, and cars will last longer. The products will be characterized by high quality and environmental and social acceptability.

A key feature of the automotive product of 2001 will be customization for niche markets. Quality and cost will approach uniformity and will give way to customization, flexibility, and programmability of features as the drivers of competitive advantage. Smaller-volume niche cars are becoming an important portion of the automobile market. Current examples are import luxury cars, custom vans, and low-volume sports cars. In general, this low-volume, niche-car set of markets will continue to evolve and grow through the 1990s. That trend is supported by the growing number of multi-car families, where the second car is a "niche" car. The family typically has one vehicle for transporting the family, while individual family members may have high-performance, luxury, or other specialty vehicles for daily or recreational use.

The move toward models with shorter life cycles will occur in the context of bounded customization, dictated by the demographics and needs of the customer marketplace. Currently, customers are adopting longer lifetimes for vehicle use, based principally on price and financing. As national demographics change, the definition of the customer base and niche-buyers will also change. Lower-volume production niches will also be accommodated by different customer-use patterns, especially the increasing trend toward leasing and fleets for business use.

The ability to provide unique features in cars will supplement this emphasis on customization. Customizable features will go beyond today's capabilities for and provision of option selection. Customizable features could range from exterior and interior finishes to custom body skins. Buyers could thus put their personal "mark" on their vehicle and, to a certain extent, contribute to the design of the car to suit their own needs or interests.

Uniqueness could also be captured in programmable features including seats, dash controls and instrumentation, and convenience features of the car.

The feasibility of including custom features in the vehicles will be supported by new materials and production processes. More vehicles will have plastic skins, and advanced composites, while not in high-volume production in 2001, will be moving rapidly upward on the development curve. Newer composite materials will start coming into use. Different lines of vehicles will share common subsystems. Incorporating these subsystems and meeting goals of more models with shorter life cycles will involve assembling larger components into the final automobile. The components will be in the form of assemblies and subsystems received from first-tier suppliers at centralized assembly plants.

The potential for programmable customization implies that automobiles will have increasing software content. Software is already evident in a number of features, including audio systems and computer-controlled braking systems. Currently the bulk of the software is contained in dedicated, embedded systems over which the driver and passenger have no control. In the future, programmable features will allow some user control. Some possibilities for programmable features include reconfigurable instrument clusters that allow the user to program a display by the position, size, and contrast of indicators; programmable seating systems positioning: more programmable suspension systems; and variable steering and transmissions. Drivers would be able to configure the operational features of the car to fit preferences for driveability.

Economic and environmental concerns will drive requirements that the automobile of 2001 be recyclable and reusable. This trend is already beginning to occur in Europe, where Germany is in the process of ratifying recycling laws for automobiles sold in that country. The automotive manufacturer will be responsible for the recycling process. To achieve that, the customer will essentially be a user of the vehicle that the automotive company will "own." At the end of the product's useful life, the manufacturer will get it back for disposal and recycling of parts. If predictions of increases in society's division of wealth prove correct, the widening gap between the "haves" and "have nots" in society[5] will create a larger market for used vehicles. There will be reusable parts and subsystems within cars that have, on the whole, reached the end of their useful product lives. Usable subsystems could then be upgraded for incorporation in reconditioned cars that could become part of the used-car market.

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[5] Ernst & Young. *The Car Company of the Future: A Study of People and Change*. A Joint Research Project of Ernst & Young and the University of Michigan, 1991 (SCORE Retrieval File No. T00002).

C.2.1.2 Conceptual Design and Marketing

Customization and niche cars will dictate the need for more intense and individualized market testing and conceptual design. To meet the variable definition of desired products, there will need to be faster customized product definition. Model development, to be competitive, simply has to be faster and cheaper.[6] A current typical model life runs around 10 years. In all likelihood, this life span will shorten considerably for companies to remain competitive. Demographic market studies can be reduced from a current three- to five-year perspective to one to three years. Niches of need and preference can be identified in that time frame for main vehicle areas of performance, powertrain, or styling. Products can be better defined for entry level and midscale vehicles. This concept design and marketing phase will also assist in the early identification of customizable features for design and common parts families for manufacture.

Concepts can be tested with the technology of "virtual reality." Virtual reality, in which the user gets direct control of and sensory feedback from manipulations of the envisioned product, will replace the use of sketches and costly market clinics. Concept testing will involve virtual cars with instantaneous capabilities and information for interchangeability, redesign and cost. With CAD and graphics packages, one can show potential cars and simulate test drives for the prosumer (formerly conceived as the "consumer") at the dealership. Dealers will be more involved in the enterprise partnership by having inputs to design.

Simulations will be more extensively used for prototyping. Clay models may still be used to confirm mathematically derived surfaces and overall visual perspectives. But simulations via computer can replace hand-built functional prototypes for testing buildability and assembly processes. The computer will play a greater role in prototyping, with less of a need for physically tangible prototypes. Simulations, testing, and go/no-go decisions will rest less on senior management and more so the design/build team. Physical protoypes will be used where necessary for such activities as crash-testing and fuel-efficiency assessments.

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[6] Association for Manufacturing Excellence. *Manufacturing 21 Report: The Future of Japanese Manufacturing*. Sponsored by Japan Machinery Federation, System Institute of Waseda University. Translated from *Articles in Communications of the Operations Research Society of Japan*, written by M. Iwata, A. Makashima, A. Tateishi, J. Nakane, S. Kurosu, & T. Takahashi. Wheeling, IL: AME (380 West Palatine Road, 60090).

Designs will become more modular. Since not every subsystem need go through redesign for new models, a more modular design and product will facilitate product customization and more rapid model introduction. Modularity will also increase the commonality of subsystems and subassemblies across models for those systems that are not viewed as unique to a model. Current examples include window mechanisms and exhaust systems. Modularity can also be extended to drivetrains and electronics systems within the automobile.

C.2.1.3 Concurrent Detailed Product and Process Design

The design of the product and processes for manufacturing will become even more simultaneous activities.[7] Concurrent engineering and design can be structurally facilitated by design teams of people from multiple functions and by design centers of physically co-located team members. Design teams will involve higher degrees of business functional integration, not just among product and process design, but extending to sales, production, and materials. There may be many concurrent design teams (for different models, or as tiger teams in the design process) operating within a firm or location. The emphasis is on functionally broadened, not numerically larger, design teams. The information systems can be appropriately distributed, but the design team concept must preserve scalability by bounding the cost to accomplish the process. The design teams will be composed of many autonomous but interacting elements,[8] which will require extensive information exchange. Design teams will be able to be informed instantly of changes in designs and requirements, through an enhanced information infrastructure.

The acceleration of joint product/process design is also likely to permit greater attention to both the front and back ends of the manufacturing life cycle including design for "disassembly" as well as the traditional emphasis on design for assembly and manufacture. The emphasis on design of the end of the process will facilitate the product objective of recyclability and reusability discussed earlier.

Information from concept and design development efforts will be captured and saved, even if potential auto programs are cancelled in midstream. Rejected concepts will

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[7] Association for Manufacturing Excellence. *Manufacturing 21 Report: The Future of Japanese Manufacturing*. Sponsored by Japan Machinery Federation, System Institute of Waseda University. Translated from *Articles in Communications of the Operations Research Society of Japan*, written by M. Iwata, A. Makashima, A. Tateishi, J. Nakane, S. Kurosu, & T. Takahashi. Wheeling, IL: AME (380 West Palatine Road, 60090).

[8] Ibid.

be stored for possible resurrection and modification for other applications. This capability will require increased storage and access capabilities and mechanisms that allow designers to capture design intent. Firms will capture lessons learned in order to reduce future mistakes.

In addition to enhancing the product design, the concurrent design process will also improve manufacturing tools and systems. CAD/CAM systems will quickly produce dies and tooling from product designs and process plans. Die manufacture will include only "critical tolerancing." Critical tolerances will not be required for aspects of the die that do not make a difference in fit or usage. Equipment will be better and more easily retooled or reprogrammed for building new products.

C.2.1.4 Operations and Service

The rapid introduction of concurrently designed, customized products utilizing new materials and larger subassemblies has direct implications for the vision of production operations and service follow-up in 2001.

By designing the product and the process in parallel, manufacturers can realize coordinated process planning when interfaces develop among different process plans. Process planning will be linked among OEMs, suppliers, and equipment vendors. There will be coordinated but autonomous design for existing processes and equipment to build different vehicles, helping to link elements in enterprise partnership. Supplier partners will possess broader technical OEMs capabilities and have better managed relationships with their major-manufacturer customers. This phenomenon will lead to an industry structure of greater distributed manufacturing, involving a host of smaller, more "manufacturing-expert" companies. The vision of distributed manufacturing operations could involve a "virtual corporation," or an enterprise, of more than 250 suppliers.

The introduction of new advanced materials and subassemblies previously described will have implications for operations, in that many basic manufacturing operations will change. New materials will reduce the requirements for metal stamping capacity and impose needs for new kinds of forming and processing. Drivetrain components are likely to be manufactured using "near net shape" processes. Precision building of the vehicle chassis will be required to facilitate automated manufacturing activities. Overall manufacturing systems will have to be more flexible to accommodate rapidly changing product models and shorter life cycles. Assembling vehicles will consist of putting together fewer, larger subassemblies, as opposed to piece-by-piece assembly. Assembly plants will have to handle "batches of one," as more niche cars and custom vehicles become reality.

The timing and technologies for production scheduling will change in the vision of 2001. Much of the scheduling activity will be driven by the desire for the "rapid delivery" car,[9] in which the time from order to delivery of a new car is matter of days. The notion of rapid delivery pervades other functional components of design as well as production. Currently, it takes less than two days to assemble a vehicle; the majority of the turnaround time involves the time required to process and queue up the order for assembly and delivery. Scheduling in the future might be initiated at the dealership or other central ordering site. Build schedules will be tied to order assignment from the dealers and engineering changes in process. As a by-product of being able to assemble subsystems instead of smaller components of the product, a model can be assembled in many locations, and many models can be assembled at a single location. Since it will be possible to assemble a given model at any number of plants, the scheduling will also have to accommodate leveling of plant schedules, requiring an information infrastructure component of electronic schedule information exchange. This scheduling process also implies that principles of JIT delivery will become even more deeply ingrained than they are now, and directed to the link between assembler and customer, as well as that between supplier and assembler. That situation, coupled with the notion of batches-of-one, indicates that first-tier and sub-tier suppliers will be closely tied into the scheduling system.

Many functions of scheduling vehicle build will have to be performed in parallel to facilitate rapid introduction of niche vehicles. Along with streamlined scheduling and the inclusion of more information content in schedules, our scenario includes tighter lot tracking for purposes of JIT, greater quality control, and increased traceability of the vehicle through the life cycle. Material lots required for the build will be tied to the build schedule.

The operational vision calls for new methods of quality control of the manufacturing process. Techniques of Statistical Process Control (SPC) and Statistical Quality Control (SQC) will be replaced by analyzing more process and quality data on a closed loop, real-time basis to achieve timely control and to maintain high quality requirements. Quality experiments will be prescriptively designed to bring about process change. Centralized

[9] Association for Manufacturing Excellence. *Manufacturing 21 Report: The Future of Japanese Manufacturing*, sponsored by Japan Machinery Federation, System Institute of Waseda University. Translated from *Articles in Communications of the Operations Research Society of Japan*, written by M. Iwata, A. Makashima, A. Tateishi, J. Nakane, S. Kurosu, & T. Takahashi. Wheeling, IL: AME (380 West Palatine Road, 60090).

control and maintenance will be crucial to this aspect of the production scenario. The vehicle assembly line will start to resemble continuous process production in that isolated breakdowns will halt the entire process. Repair crews will have to be dispatched immediately. Control rooms will become more prevalent. Control rooms have been used for several decades to monitor overall plant operations, anticipate problems, and address failures quickly in the process and electrical power industries. Control rooms are beginning to take greater hold, for the same purposes, in the auto industry. To support rapid dispatch and problem resolution, the information system may include portable maintenance information.

In addition to being more portable, production and maintenance systems will become increasingly complex, diversified, and flexible. That vision will impose requirements on the compatibility of information systems and human resources. People will be working on a wide variety of product and process equipment. Knowledge-based production and maintenance will be required for rapid solution, or avoidance, of production problems.

Aftermarket service will also involve the expanded role of the dealership and the customer in the auto enterprise. In addition to driving some aspects of design, the service centers (integrated within or separated from sales outlet "dealerships") will continue to increase their focus on service and reliability. They will also be more effective at dealing with the problem of having replacement parts on hand when needed. Dealerships might become integrated with the array of design, ordering, final assembly, and delivery functions in co-located auto malls.

Societal demands and manufacturing economy considerations will require the automobile of 2001 to be completely traceable in terms of the ownership, operation, and service of the vehicle and its subsystems. Traceability is required to meet the previously suggested needs for environmental protection and product recycling. Tracking service and performance and maintaining records of upgrades will provide means of accountability for disposing of the vehicle. That practice will also provide indications of required upgrading of subsystems prior to reuse. Traceability may be accomplished as a programmable feature within the automobile. Records can be kept and retrieved at times of service, either locally or remotely, for use by the auto manufacturer.

Some of the requirements for an information infrastructure to support this vision for 2001 are implicit in the descriptions of product, design, and operations. Those implications are drawn out in more detail, in the context of key elements of an information infrastructure, in the next section of this chapter. The vision also suggests that there will be some nontechnological barriers to achieving the vision. Those issues and barriers are summarized in Section C.3.

C.2.2 INFORMATION INFRASTRUCTURE IMPLICATIONS

An architecture can be viewed as a two-dimensional function. One dimension consists of the parameters of principles, inventory, models, and standards. The other dimension consists of the elements of infrastructure (hardware, system software, and communications), data, applications, and organization.[10] The architecture begins with the development of overall and specific principles derived from the enterprise business rationale. These principles span infrastructure, data, applications, and organization. Only then can the other elements of inventory, models, and standards be defined and developed in detail.

The information infrastructure is a component of the enterprise information architecture, predominantly covering architectural infrastructure and data. This study synthesized a composite picture of the automotive enterprise in 2001. From that scenario, elements of a national information infrastructure have been identified. The principles that govern how this infrastructure crystallizes must be formed and ratified prior to development of the details. The high-level needs as identified by the automotive vision for 2001 are given below without the technical details that are required for realization. The implications are derived from the principles which, in turn, are derived from the business vision.

By the year 2001, an information processing system to support the automotive enterprise will be very different from what we have today. The systems of today are static. Once they are configured for interconnections, data storage, and processing capability, they are not easily changed. The system of 2001 must be dynamic, easily reconfigurable to allow new paths of information flow and new types of information. It should allow remote data access and processing. The information system must allow and enforce high degrees of security and allow communications across applications as well as between users.

A very important concept is the need for the information infrastructure to assist corporate and enterprise globalization. Today, every North American automobile manufacturer has international operations. Also, the look of automobile manufacturing in the United States is taking on an international character as more transplants appear. Thus, the use of

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[10] PRISM. *Dispersion and Interconnection: Approaches to Distributed Systems Architecture*. Final Report of the Partnership for Research in Information Systems Management (PRISM) Project, by Index Systems, Inc. and Hammer and Company, Inc., June, 1986.

international standards in communication and data representation is a requirement of the National Information Infrastructure.

Due to the distributed nature of the business enterprise of the future, the information system needs to be a distributed national information infrastructure that will provide a wide range of services that can be accessed remotely on an owned, leased, or usage basis. A National Information Infrastructure could be viewed as a new utility. Upon this utility a whole new layer of service suppliers will emerge, providing one or more services to different companies. The services required to support the automotive enterprise vision for 2001 include communications, data storage and management, processing, security, presentation and costing.

C.2.2.1 Communications Services

Communication services will allow automated information flow between different locations and different organizations. The communication service will have to transfer huge amounts of data rapidly and inexpensively if it is to be used. Various media will implement the communications network: satellite, optical fiber, radio, and wire. The network will be engineered to satisfy fault tolerance, cost, and bandwidth requirements.

Due to the foreseen continuous development and dissolution of permanent product teams, or a constantly changing and dynamic "virtual" corporation of manufacturers, suppliers, dealers, and service providers, the information infrastructure must be capable of providing and breaking communication links for all the business functions requiring data exchange and processing. The information infrastructure will need multiple nodes and flexibility for responding, altering, adding, and deleting linkages.

The communication services will have to be extremely reliable as any interruption in service will necessarily cause disruption throughout the enterprises dependent on it. The information must be transmitted quickly in order to realize the rapid delivery car and to achieve shorter concept to market time.

Communication will occur in two basic ways. Vast amounts of data will be exchanged between organizations that may then do some local or internal processing of the data, and communications across applications will occur as more parallel processing of information becomes necessary. Examples of simple data exchange related to the auto industry in 2001 are new car order data, supplier scheduling, and vehicle traceability information. Possible use of inter-application communications could be new car orders interacting with supplier scheduling, accounting processes, and transportation services.

More complex, high-volume information, such as geometric models for product design and process plans for automated manufacturing, will also have to flow between organizations. This flow is necessary to allow more effective use of outside design and engineering services, shorten the design life cycle, and provide automated support for concurrent engineering. A variety of design representations will have to be accommodated, such as lines, frame, and solid CAD representation.

There are multiple schools of thought on how data should be used and exchanged: common data representation and data interpretation. The first view espouses development and use of a common data representation. A parallel to this is the use of English as a common language where everyone using the language knows the meaning of each word in it. The second view allows each organization to use its own language or data representation as it sees fit, with data exchange being possible, and to provide interpretation services to translate the "remote" representation into the "local" representation required for use. In the third view, translations are always between the local language and the universal one, thus requiring fewer translations than the second view and causing less internal disruption than the first.

Over the long run, development of a common data representation will probably be the most cost effective for two reasons. First, new interpreters will not be required as new organizations and information systems develop. Second, interpretation will require substantial computing power, but will add no real value to the data. The collection of data models can be enlarged without loss of usefulness of those already in use. However, the common representation approach requires consensus and standards for data representation. The infrastructure will then allow mutual definition and exchange of feature data by multiple manufacturers and suppliers using standard terminology and exchange formats.

C.2.2.2 Data Storage and Management Services

The information infrastructure must provide capability for distributed data storage, local data storage, and large data repositories. A much greater amount of data will be stored as well as transferred than is processed today. The automotive vision for 2001 suggests automated design processing, virtual reality representations rather than physical mock-ups and prototypes, computerized process plans, storage of designs for future use, knowledge-based systems for worker support and enhanced productivity, and many other techniques requiring high volumes of computer data. Additionally, the data will have to be accessed by a number of organizations within the enterprise. The service will have to provide security against unauthorized access, ensure data integrity, and ensure reliability so that no data will be lost.

Data storage services must provide usable, accessible, and easily updatable libraries of designs, parts, concepts, and features that can be recalled and used in new applications. Such libraries will help realize shorter design life cycles and aid in using modular and interchangeable subsystems in the design of a new vehicle or custom vehicle.

Data management services will provide maintenance, archiving, and compression of files for storage and archival services. These functions are typically performed transparently as system overhead tasks.

Data management services must provide reliable transfer and update of information in a timely manner. The system will have multiple levels of develop, read, alter, and retain features that allow simultaneous, continuous design and updating by multiple concurrent engineering teams.

C.2.2.3 Processing Services

Data processing includes the three basic functions of modeling, simulation, and calculation. Today some processing services are purchased (for example, payroll processing).

In ten years, processing will become increasing complex as more functions of a business enterprise use automated information processing and more application environments exist. Modeling will occur for all aspects of the business, including simulations and virtual reality used for marketing. CAD/CAM/CIM will become common in the automotive enterprise, and the infrastructure must seek to maximize the utility of that linkage between design and manufacture.

Economies of scale will dominate decision-making processes. Automotive companies must become sensitive to and make decisions based on manufacturing smaller numbers of a certain model. This shift will create a need for new accounting processes, which will be another service for use by companies within the enterprise. Accounting services will be a tool for controlling as well as calculating costs, requiring activity-based accounting and control of cost drivers through an integrated information system.

The information infrastructure will contain computerized systems for simulating prototype tests ranging from preliminary safety and crash tests to fuel efficiency simulations.

It may not be cost effective for every automotive enterprise or supplier organization to develop the complex models and algorithms needed to perform these tasks, even though they will be required to stay competitive. The information infrastructure will provide the means of accessing the more complex processing services on an "as needed" basis. In this way, both large automotive OEMs and small suppliers will benefit from these processing capabilities. The OEMs and first-tier suppliers can focus their efforts more on the process of making cars and less on ancillary support activities. Sub-tier suppliers and smaller companies within the automotive enterprise will benefit from being able to access processing capabilities that they would not be able to afford otherwise.

A new processing service identified during the development of the automotive vision for 2001 is a market-sensing activity that will continuously scan the demographics and needs of the auto user community and the options available to fulfill those needs, potentially including cost-benefit information on options.

Order-processing services are another potential application for a National Information Infrastructure and the services it might provide. In the automotive enterprise of the future, the process of purchasing a vehicle may be quite different. In addition to having a dealer for one or a limited number of brands there may be a central sales site for many or all vehicle brands. In this case, order processing becomes more complex, and probably cannot be directly handled by the automotive OEMs. An intermediate service may be required.

C.2.2.4 Security Services

As processing and data storage become distributed and information systems connected to the information infrastructure become more open, security becomes an increasingly important issue. Control of data access will be needed for new product model information, critical marketing data, business strategies and planning, employee records, process planning, and other data of a proprietary nature. In the automotive scenario of 2001, proprietary data will have to be accessible by people in many organizations without sacrificing control and security. *Security-by-view* is a concept that needs to be developed for control of large databases.

Another security service that will be desirable for data exchange will be high-performance encryption services. The information infrastructure must provide security services that ensure data integrity and ownership protection of data.

C.2.2.5 Presentation Services

As the automotive vision for 2001 developed, people issues kept surfacing. As automated information processing becomes part of everybody's job, the human interface issues must be addressed. The complexity of the processing for the vision also indicates that human interfaces must go beyond alphanumeric displays and keypad or push-button entries.

The infrastructure must include proper information presentation, including various means of aggregation and display that allow immediate comprehensible and system-wide incorporation of new information. For example, if features are modified during the design process, an information system must ensure that this type of data is immediately transmitted to the proper entities in an understandable and relevant manner. Hypermedia can be one means to this end.

Presentation services available from third parties can address this issue. Standards for information presentation and interface will aid in solving this problem, and the use of standards will make people more flexible and aid in developing cross-disciplinary skills. As one learns new capabilities on an information system, the effort to learn new interface patterns will be minimal with the use of common interfaces.

Presentation services will also include the use of graphics and text to convey information. The information infrastructure must accommodate three-dimensional math-based CAD information systems coupled with advanced graphics packages to show potential designs and to simulate potential drive features and passenger interface features of vehicles.

C.2.2.6 Costing Services

The information system should be a managed organizational resource for enhanced and explainable decisions and coordination. Costing of these information resources and services will be an important issue. Managers want to know if the use of outside services, rather than internal development and maintenance, will be cost effective. The information infrastructure will need to support the costing of services with respect to the scope of specified work (Table C-4).

The need for a National Information Infrastructure is becoming more and more apparent as enterprises rethink their business strategies and develop new partnerships and product teams. Automated information processing and storage will become increasingly important to maintain combativeness of product, cost, and quality. People in every sector of the workforce will interface with information systems. Common data will have to be

Table C-4. Services to Support the Automotive Enterprise

	PRODUCT	MARKETING/ CONCEPT DESIGN	PRODUCT/ PROCESS DESIGN	OPERATIONS/ STORAGE
COMMUNICATIONS	traceability; smart highways; rapid delivery car; shorter life cycle.	demographic; hypermedia marketing; concept costing; distributed teams; shorter life cycle; quick design changes.	integrated program teams; rapid dissemination of design change information.	scheduling; traceability; service feedback to manufacturing; control room monitoring of process; batches of one.
DATA STORAGE AND MANAGEMENT	traceability, quality control (QC); lot tracking; compression; updating trace data; customized design.	"concepts on a shelf"; prototypes; lessons learned; reusable subsystem designs; previous design retrieval; concept/cost relationships; version maintenance; design data compression and recycling.	archive of design & process plan; store lessons learned; continuous improvement (CI); retooling; reprogramming; store design intent; rapid retrieval of stored data; version control; compression for efficiency; modular subsystems.	knowledge-based maintenance; knowledge-based workers; service records; traceability; archival; engineering change management; process plan backups; lot tracking.
PROCESSING	software content; program features; rapid delivery car.	hypermedia market tests; concept cost development; simulations; demographic studies; preliminary CAFE and safety simulation; regulatory cross-checks.	joint product/process design; process simulation; real-time, closed loop control; CAD/CAM realization; rapid tooling; continuous cost improvements; activity-based accounting.	production control; process control; parallel order processing; JIT scheduling; schedule leveling; accounting/administrative reports; service/dealer feedback to process.
SECURITY		prevent unauthorized access; encryption of design and marketing data prior to transmittal.	owner protection; prevent unauthorized access; maintain process competitive edge; encryption of design data.	prevent unauthorized access; personnel record integrity; customer privacy.
PRESENTATION		virtual reality; simulations; hypermedia for marketing; cost analysis reports.	cross-disciplinary representation; good operator interface development.	cross-business function report generation; management by information.

accessed by many people in multiple organizations. Data will be accessed and stored locally, in distributed fashion, and within large data repositories. Open systems and a common, high-speed communication network will be needed as the backbone of the information infrastructure.

National and international standards governing data representation, exchange, and transmittal must be in place to facilitate the effective and efficient use of the information infrastructure. Use of proprietary systems and standards will not facilitate the formation of virtual corporations and automotive enterprises that will be able to compete in the international marketplace of 2001.

The information utility and services must be available to all organizations involved in each automotive enterprise. Complex data processing services and data repositories will allow large and small firms alike access to technologies that might otherwise be prohibitive. A whole new sector of service providers will emerge to provide these services in the most cost-effective manner. Cooperation and information sharing will be achieved by standardization of data representations, modeling methodologies, and a fast, reliable transport network.

C.3 ISSUES AND BARRIERS

Our description of the state of current automotive industry activities in 1991 and the delineation of a vision for 2001 generated some areas of concern among the project team, the people interviewed, and the panel members who participated in the vision-setting roundtable discussions. Those concerns reflect issues that need to be addressed and barriers in the existing organizational and information infrastructure environments to achieving the vision. Some of those barriers are technical. However, it was a consensus that technology is *not* the barrier to the vision. Rather, the principal barriers lie in people: their skills, attitudes, and general resistance to change. The barriers were cast by our roundtable panelists as "qualifiers" underlying the successful implementation of the Automotive Industry 2001 vision and its accompanying information infrastructure.

C.3.1 GOALS AND ECONOMIES OF SCALE

North American auto companies seem to be striving to keep pace with or catch up to the Japanese. It is widely acknowledged that Japan knows what it wants and is organized to attain it. North American industry appears to lack any clear goal of excellence in the sense of surpassing the Japanese and learning from the broader base of international manufacturing models, especially European ones.

North American automotive manufacturers tend to think "big change" and "quick results." The vision emphasis on bounded customization suggests a need to redress company perspectives in the form of several sets of smaller-scale niche markets and lower-volume production. An emphasis on continuous improvement, rather than a "big bang" view of change, would, for example, helps to overcome problems of staff continuity on design teams, which Honda appears to have solved constructively.

C.3.2 MANAGEMENT ACTION AND LEADERSHIP

Organizational tradition, size, and rigidity may limit management leadership's ability to achieve the vision. Leadership needs to solve problems associated with long-term planning, championship of new infrastructures, and supportive organizational cultures to link information structures with business enterprise goals.

Within firms, the barrier is characterized by less than optimal structuring and processes to support the vision. Insufficient attention has yet been focused on teams for information exchange and use, solution-oriented task definition, and thorough, open processes for effective communication. Units in joint planning activities typically fail to mesh with each other or worse, bottleneck the process.

Beyond the boundaries of firms, partnerships, where they exist, are pretty much top-down arrangements, wherein the OEM "owns" the partner, or the partners are brought into processes (e.g., design) late or without sufficient information and tools to participate effectively.

There is a lack of incentives, encompassing the entire product and partnership spans, by which people can be rewarded for their contributions as team members to different phases and functions of the product.

C.3.3 LACK OF AN ENTERPRISE CONCEPT

The industry lacks principles of enterprise integration. By principles, we mean a philosophy of information system objectives for technology and its management driven by common values.[11] Those principles would apply to different components of the overall architecture, including the infrastructure (hardware, software, and communications), data,

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[11] PRISM. *Dispersion and Interconnection: Approaches to Distributed Systems Architecture*. Final Report of the Partnership for Research in Information Systems Management (PRISM) Project by Index Systems, Inc. and Hammer and Company, Inc., June 1986.

applications, and organization. Example principles would be "We are committed to a multi-vendor environment" or "Applications will be processed where the data reside."

Perhaps even more fundamental than principles for integration is the lack of initial definitions of the enterprise. The vision supports the concept of enterprises as "virtual corporations" of 250 or more companies. But the particular elements of the enterprise and their roles need to be clearly specified. The present situation suggests that companies can integrate but enterprises cannot. For that to happen, the enterprise has to be defined and its infrastructure has to be built.

C.3.4 UNREALIZED TECHNOLOGY OPPORTUNITIES

New technologies for design, marketing, and linking information to the business enterprise are not being fully used, partly due to the problem of legacy systems. Legacy systems tend to "hang on" because they represent significant pieces of organizational turf and massive investments in staff and dollars. Users often may not know how much of a legacy system is really being used in today's applications.

The resistance to change and investment may impede new marketing and design concepts such as virtual reality, hypermedia, advanced prototyping, and dealer involvement. There is insufficient risk taking for innovation. Legacy systems, coupled with suppliers' needing to maintain multiple design (CAD) systems, limit basic awareness of new technologies or applications.

C.3.5 LACK OF A SUFFICIENT INFORMATION NETWORK

The United States lacks a national high-speed information network that can dynamically link the elements of the auto enterprise. Constructing such a network poses logistical problems. Installation will be expensive. Network reliability issues need to be solved. Schemes for error detection, fault detection redundancy, or other fault tolerant approaches need to be chosen. Network management for handling different and increasing volumes of data with appropriate security must be developed. Governing principles of a national data transmission resource will be required. Network accounting methods have to provide for fair and economic cost burdens on the users.

C.3.6 LACK OF INFORMATION STANDARDS

There are no standards for a high-speed, high-volume transmission infrastructure. Some standards development is underway, especially in the area of product data definition and exchange. However, greater progress and application protocol development are needed. Plans for internationalizing the data exchange in a high-speed network are needed. North American automotive companies lack international standards to which they believe they can comply while protecting their advantage in a competitive, capitalist society. They need to realize that their competitive advantage resides in how they use a system rather than in the abstract features that it processes.

C.3.7 THE PROBLEM OF ARCHIVING AND THE LACK OF TOOLS

While we earlier suggested a barrier associated with unwillingness to invest sufficiently, there is also a current mode of not saving, archiving, storing, and protecting information for later, as yet unspecified, uses. Companies typically do not archive and store design information, or, when they do, it "goes stale." This difficulty is also related to a lack of true concurrent engineering with the early participation of all the players in design and manufacturing planning. Architectures and methods for concurrent engineering are being developed, but firms will also need more tools for design and manufacture that embody standards, appeal to users, and contribute significantly to applications.

C.3.8 FEW VISIBLE SUCCESS STORIES

To make the vision happen throughout the industry, success stories of attained benefits will go a long way toward motivating firms and people to embrace enterprise integration and new information infrastructures. But there are few cases of really broad, multi-company integration, or at least few that are being publicly reported. It has been suggested that enterprise integration can reduce TTM by 30%, and design cost by 20%. Stories like GM's SATURN and Chrysler's Grand Cherokee need to be told.

C.4 RECOMMENDATIONS

Even though the primary role of IDA documents is to analyze issues for and make recommendations to entities within the Department of Defense, the auto industry participants in this study felt that recommendations to their industry are warranted and would be helpful. The following recommendations are a distillation of thoughts from the industry visits and the roundtable panel. They do not, however, necessarily represent an industry consensus. They reflect our suggestions for what the automotive companies and suppliers could do to foster the success of the vision for 2001. These activities could be done independently of, but also in support of, potential actions by the government to enhance the information infrastructure of the future. These recommendations go beyond the specific information infrastructure implications of the vision to address broader organizational and enterprise implications of the linked business rationale and infrastructure. The recommendations address several of the barriers described in the previous chapter.

Strengthen or expand the culture of the organization to accommodate visions, people, and practices for integration.

- Define and embrace a *vision*, with global strategies and a basis for common mechanics of operation. Maintain company *leadership*, commitment, and championship of the enterprise to make the vision happen. Focus management planning more on process capabilities than short-term results. Delegate key decisions, such as prototype go/no-go to functional experts. Engender self- and team-based discipline to act and move forward.

- Base the organizational culture on true, meaningful, and practical *partnerships* among actors in the auto enterprise, developing and implementing partnerships for strategy and activities both within the boundaries of the organization and outside it in its enterprise network. Partnerships mean early and thorough life cycle involvement of multiple sets of players in the enterprise: cross-functional teams within the organization, employees and (especially mid-level and program) managers, customers, dealers, and suppliers at all levels in the design and production chain. Partnerships will accommodate the coexistence and cooperation of autonomous and interrelating organizations.

- *Focus* and *accelerate* progress toward manageable sets of objectives, but, at the same time, embrace *long-term perspectives* in setting goals and anticipating results. Adopt or maintain perspectives and incentives for change throughout the organization and continuous improvement of the product and the company. Involve people in continuous improvement efforts. Focus on integrating human capabilities, with integration being the major focus of computer-integrated manufacturing (CIM).

- Treat *people as fixed assets* rather than variable costs in the partnership: fully utilize human capabilities in the array of organizational tasks, delegate responsibilities, and trust knowledge-based decisions below senior management. Recognize and use the expanding roles of engineers and operational staff in planning and execution. At the same time one is recognizing and fully utilizing people's talents, the firm must also prepare to cope with the increasing transience of employees, moving more rapidly within and outside the firm. Companies might consider franchising some facets of indirect labor, such as selected functions of administration, finance, and human resources.

- Incorporate as part of the culture a results- and process-based interest in really *sharing information,* not just passing data. This process will involve developing or maintaining structures and senses of teamwork within the organization and mutual interdependencies on information and communication. Maintaining the sharing culture will also require developing mechanisms for sharing and/or protecting proprietary information elements, such as may exist in CAD libraries of concept designs.

Develop, continue, or foster organizational systems and practices to implement and sustain the culture.

- Redefine and establish new *reward systems* to provide incentives for, and recognition of, effective work related to integration objectives. Such reward systems should consider incorporating meaningful intrinsic and extrinsic rewards for knowledge-based performance, including opportunities for dual career ladders within firms. Rewards should be contingent on vision-related performance of individuals and teams, and the substance of rewards should be sufficiently flexible to accommodate different individual interests.

- Implement *structures for coordinating* interrelating functional units so as to facilitate workflow, information transmission, and information use. Provide those structures with people having capabilities to act as team members and to use information tools. Embed those structures and processes in the culture for continuing communication and decision making.

- Establish major, identifiable functions for *managing supplier development and relations*. All levels of the supplier chain in the enterprise need to be recognized and their information needs accommodated in a non-hierarchical fashion, even though tiers will continue to exist. The particular roles of smaller suppliers can be identified to establish their needs and mechanisms for including them in the enterprise information structure. For example, not all may require total information exchange capabilities or common CAD systems. Partnerships with suppliers will require early and total life cycle involvement of the supplier organizations in product and process planning.

- *Streamline and integrate* internal design and operations functions. Team approaches to the design of minimally overlapping tasks can streamline the design function through concurrent engineering, design teams, and design centers. Similarly, functions of order processing, which account for so much time in the overall production-to-customer cycle, can be monitored and improved. Some of these functions can be made more efficient with continuation of electronic data exchange for parts ordering and billing, which might be broadened beyond the typical involvement of first-tier suppliers.
- *Think "custom."* Approach future opportunities for customization of the product in an aggressive manner. Given that cost and quality will be essential for future survival, product planning should increasingly concentrate on gaining competitive advantage through customizing features of the product. Design teams, with input about customer demographics/needs and technology capabilities, can identify ways and niches for customization and/or user programmability of components, features, and options. Bound the customization for economy in terms of market demographics and customer demands.
- *Computerize* as much of the design-production-reuse life cycle as possible. Continued efforts toward functional automation involve embracing the technology of virtual reality for elements of marketing, design, and prototyping.

Develop and implement appropriate and refined information infrastructures to accommodate the business strategies, visions, and practices of the enterprise.

- Company progress toward next-generation information infrastructures can be assisted by focusing on the *information infrastructure implications* briefly described in the previous section of our report.
- The infrastructure should focus on company and enterprise *commonalities*, in terms of common systems for engineering, common mechanisms for integrating autonomous interacting units, coordinated databases, and common platforms and standards.
- The infrastructure must emphasize *flexibility* for design and production activities throughout the enterprise, so that, for example, suppliers can deal with CAD requirements for multiple customers without investing in multiple CAD systems or foregoing all legacy systems.

- The infrastructure should also focus on fully utilizing the *CAD-CAM linkage* for transfer of information from design to production. This priority may involve establishing structural mechanisms in the enterprise for facilitating change and development of new interchange nodes and processes in the information system.

Auto companies can coordinate their efforts to influence each other's and society's practices toward integrated enterprises and information systems.

- Companies can push further and faster development of guidelines and practices by the AIAG and various *trade associations* contributing to the development of the supplier base, including the National Tooling and Machining Association (NTMA), the Society for Plastics Industries, the Precision Metalforming Association, the Advanced Manufacturing Technology (AMT), the American Management Association, and the American Society for Training and Development.
- Companies can form groups or committees to act together on areas of common interest. Cross-company, within-industry groups can be established and maintained in auto (as well as aerospace and electronics) for developing *innovations in interconnected functions* of purchasing, engineering, management, etc. Coordinated efforts can also occur or be expanded, as in the National Center for Manufacturing Sciences (NCMS) model, to deal with new technologies or processes, as is the case for battery technology and advanced composite materials. Company *consortia* should be provided with the necessary resources, proper mix of interests and competencies, and authority to get things done. Consortium members should be empowered to speak for their companies, and technically grounded in the objectives of the consortium.
- Companies can sustain concerted effort to *influence development of standards* and bring about government support for improved information infrastructures. Auto companies can expand their involvement in emerging standards definitions such as IGES and PDES efforts by the ANSI, the ISO, and related organizations. They can also lobby for, present a unified business rationale for, and help to define the parameters of a government initiative for a national high-speed information network.
- Coordinated company efforts can also be directed to *education and training* to develop, implement, and use new information infrastructure components.

Through federal and local governments, educational institutions, and professional associations, auto companies can influence the development and mutual awareness of cross-functional and new skill repertoires for management and the workforce. People in the auto industry of 2001 are going to have to be "cross skilled," but not to the point of being abstract "generalists." Enhanced company training and educational programs from kindergarten through post-secondary institutions should bring about greater and more diverse knowledge. As noted by one of our contributors, David Cole, management of that expanded knowledge base will be one of the keys to success in the 21st century.

C.5 LIST OF COMPANIES VISITED

(1) Allison Gas Turbine, Division of GM

(2) CDI/Modern Engineering

(3) The Cross Company

(4) Ford Motor Company of North America

(5) General Motors

(6) Ryobi Die Casting (USA), Inc.

(7) Saturn

(8) University of Michigan, Office for the Study of Automotive Transportation.

APPENDIX D. AEROSPACE INDUSTRY RATIONALE

This appendix documents the current state of enterprise integration in the aerospace industry sector and provides a vision of where this industry sector will be with respect to enterprise integration in the year 2001.

In contrast to the other appendices, Appendix D was updated in 1993 to reflect new information collected since the first draft of the document was produced in 1991. For this reason, this appendix refers to information contained in Appendix B, Electronics Rationale, and Appendix C, Automotive Rationale, in comparing and contrasting the status and direction of the industry.

Appendix D has five sections:

- Aerospace Industry 1993. Describes the business strategies employed to move toward enterprise integration, the technical approaches to enterprise integration, including the information infrastructures required to accomplish the goals, and a summary of the lessons learned to date regarding a transition to more fully integrated enterprises.
- Aerospace Industry 2001. Describes a vision for the future of enterprise integration and the changes that will be required in the information infrastructures to support that vision.
- Issues and Barriers. Summarizes the unresolved problems that the companies visited during the study have identified. Some problems are issues that must be addressed within the individual companies, while others must be solved jointly by the industry acting in consensus, and others require government action. Many of the issues and barriers identified by the aerospace companies are the same as those identified by the other industry sectors visited.
- Recommendations. Provides recommendations to both members of industry and to government agencies regarding actions to be taken to enable and facilitate enterprise integration

- List of Companies Visited.

D.1 AEROSPACE INDUSTRY 1993

The following aerospac ˜ompanies were visited during 1991 and again during 1993:

- General Electric Aircraft Engine Division, Cincinnati, OH
- Lockheed Aeronautical Systems, Marietta, GA
- Martin Marietta Missiles Systems, Orlando, FL
- Northrop Aircraft Company, Hawthorne, CA
- Pratt and Whitney Government Engine Business, East Hartford, CT

These companies represent the top tier or primary contractors in the commercial and military aircraft manufacturing sector.

Some of the information collected during these visits reflects the state of enterprise integration within a particular company. Other integration efforts were driven by partnerships among a group of the aerospace companies, and the information we collected reflects this teaming relationship.

Appendix B, Electronics Industry Rationale, describes four characteristics of that industry sector that drive enterprise integration efforts: technology, competition, innovation, and autonomy. In the aerospace industry, technology and competition are also significant factors in the success of enterprise integration. However, the characteristics of innovation and autonomy as described in Appendix B are less apparent. Instead, *partnerships and teaming arrangements* and *long-lived systems and safety concerns* are characteristics of particular importance to the aerospace industry, and thus drive the success of any integration effort.

These four characteristics (technology, competition, partnerships and teaming arrangements, and long-lived systems and safety concerns) assume varying levels of importance depending upon whether the product being produced is for commercial or military use.

Aerospace companies producing a military aircraft often push the state of the art in their product. This may require the adoption of new technologies to support the design, development, manufacture, and maintenance processes associated with that product. Examples of these technologies include advanced computer-aided design (CAD) systems for electronic mock-ups, integrated tool sets and object management systems, and electronic information exchange. Military products may also force companies to use new technologies through specific requirements statements. Electronic sign-off, Computer-Aided Acquisition and Logistics Support (CALS) requirements, and electronic data interchange (EDI) are examples of government-imposed requirements that would drive the implementation of new technologies.

Commercial aerospace companies are facing severe economic conditions. Fewer customers for new aircraft and an excess of still viable aircraft now for sale by ailing airlines means that aerospace companies are both cutting back production and trying to make that production more efficient. New technologies are seen as one approach to cutting costs and increasing efficiency.

With shrinking commercial and military market, competition among the aerospace companies is increasing. In addition, European aircraft manufacturers now hold a significant market share. Subsidized aircraft production in foreign countries makes it difficult for U.S. manufacturers to compete. For this reason, many companies are initiating efforts, such as enterprise integration, that they believe will make them more competitive.

Teaming and partnership arrangements have always been an integral part of the aerospace industry. The large, highly complex nature of the product requires significant capital investments and a very broad range of highly specialized technical competence. It would not be possible for a single aerospace company to deliver a product without the involvement of partners and a significant number of subcontractors. By forming partnerships, companies can enter into mutually beneficial, temporary arrangements that provide mechanisms to share the expense, risk, and potential profit for a significant undertaking like fielding a new aircraft. Enterprise integration supports teaming by allowing information sharing and management. Aerospace companies recognize this.

Unlike the electronics and automotive industries, the aerospace industry produces products that are expected to have very long life times. Aircraft may remain in service 30 to 40 years. Aircraft also have critical safety requirements. For these reasons, information on the development of the aircraft must be managed for the life of the aircraft to support maintenance. Any changes or upgrades to the product must be carefully developed, then certified before they can be implemented. Commercial and military aerospace companies recognize the need and are looking for better ways to manage the vast amounts of data associated with their products.

D.1.1 INTRODUCTION

In this section we describe the rationale used by the aerospace companies in determining whether to implement an enterprise integration effort. We discuss the real and perceived barriers to an enterprise integration effort and the expected benefits.

All of the aerospace companies we visited have begun to define and implement enterprise integration programs. These programs vary widely. The companies are in various phases of developing corporate goals, architectures, information systems, and implementation strategies. They are making decisions regarding the selection of hardware and software vendors, and about involving suppliers and customers in their integration effort.

Without exception, all the aerospace companies we visited started their enterprise integration implementation activities by expanding their integrated CAD activities to broader areas within the company and to a greater number of subcontractors, key suppliers, and customers.

As in the electronics sector, aerospace companies are initiating enterprise integration efforts largely because they feel they "have no choice." The perception within the aerospace community is that enterprise integration will improve their competitiveness. In addition, contract requirements including the CALS initiative are driving them toward improved information management and sharing.

Teaming arrangements among several prime aerospace companies for large Department of Defense (DoD) procurements have acted to accelerate efforts to support external exchange of product data. The impact of this and the resulting enterprise integration is most evident in the B-2 (Northrop, Boeing, and Vought) and F-22 (Lockheed, General Dynamics, and Boeing) development and production programs.

The rationale for implementing enterprise integration within each of the companies we visited varied. Fundamentally, most aerospace companies felt that enterprise integration is an essential element in ensuring that the company remained competitive and in business. From this reason all other reasons the resulting actions flowed.

Being competitive is generally associated with having better products (quality), at lower cost (price), delivered to the marketplace in a timely fashion (schedule). In the three industry sectors we visited, the belief is that better quality can be driven by integrating the product and process development.

Many aerospace companies viewed enterprise integration as the next logical step in their concurrent engineering, Total Quality Management (TQM), CALS and/or Product Definition Exchange Specification (PDES) activities.

Frequently, a manufacturing process is physically separated from the design process. Designers and developers must ensure that subsystems interface properly. The effectiveness of integrated product development (IPD) teams is greatly facilitated by an integrated development environment populated with tools and providing the appropriate services.

A *requirement for achieving* an effective IPD team was the timely transference of product and process data. This led to significant interest in modeling both the product and the process. The greatest technical concern for implementing information infrastructures to the companies we visited is product data representation.

In a number of cases, the ability to remain competitive was expressed by the need to reduce the product development cycle time. This resulted in the additional emphasis on concurrent engineering techniques such as expanded product development teams with more extensive involvement of subcontractors and suppliers.

Each company acknowledged the requirement or desire to have a method that would allow them to measure the progress brought about by implementing components of an enterprise integration plan. This is understandable since the cost estimates to fully implement enterprise integration provided to the study team were in the tens of millions of dollars. However, in some cases, the ability to identify meaningful metrics was difficult. Part of that difficulty was staff resistance. Fear that the metrics would be interpreted as a measure of their own performance discouraged full participation by many employees. Often the net cost benefits or savings cited were expressed as the result of avoiding costs through more effective ways of doing business.

The single most frequently identified barrier to the implementation of enterprise integration was the cultural change required by the employees. This finding parallels that in the electronics and automotive industry sectors. All employees of the company, including top management, will possibly be required to change how they deal with one another. Corporate changes may also be required in most cases. Policies and practices will need to be rewritten. In enterprise integration systems there are open availability and wide exchange of meaningful data which results in more widely recognizable and known performance of all the individuals and their corresponding organizational elements.

The single most frequently identified technical barrier, particularly when the enterprise expanded beyond the primary company, was the large number of different and not easily integrated engineering, business information, and two-dimensional and three-dimensional design hardware and software systems which are being utilized and sold. Internal and external integration problems have been compounded by different standards, hardware requirements, and software interfaces. Yet in all cases where a consistent set of standards was identified, the companies did not feel that there were any major technical impediments to implementing enterprise integration.

D.1.2 BUSINESS STRATEGIES

Both the military and commercial aerospace companies are being strongly affected by contracting markets and increased competition. The business strategies being formulated at these companies reflects this.

With a declining defense budget and a reduced number of DoD procurements, aerospace companies are increasing their emphasis on identifying core competencies and relying on partnerships to improve their overall competitive position on DoD procurements, and to share costs and risks.

In the commercial aerospace sector, continued pressures from foreign competition, and the perception that U.S. aerospace firms are not competing on a level playing field due to foreign subsidies, have driven the formulation of new business strategies and a call for changes in government regulations.

A declining airline market and a move within this market to purchase and reuse older or unused equipment has resulted in reductions (and in some cases losses) in corporate profits. This has also resulted in smaller internal research and development (IR&D) programs, bid and proposal (B&P) budgets, and R&D contracts. This combination has forced most companies to reassess their business positions and strategies.

Generally, across the aerospace industry we found some common themes among companies. Aerospace companies are reassessing their position within their market area (defense or commercial) and identifying new corporate goals. Pratt and Whitney found that its customers were dissatisfied with their product support, and that Pratt and Whitney was not meeting its goals of being a "world class supplier." This goal was reaffirmed and specific programs were initiated to track and resolve customer problems expeditiously. These programs are based on deploying enterprise integration across all divisions of the company.

As part of their effort to reassess their market position, most of the companies we visited have begun planning and implementing programs to enhance the total quality of their processes as the primary way of achieving their stated goals and objectives. These programs generally involve improved management and sharing of information which is the foundation of enterprise integration.

At GE, the first step was to get a concurrent engineering program in place as quickly as possible. This program, which will include both manufacturing and engineering, is expected to be fully deployed by 1995. Lockheed has a corporate-wide TQM program to decrease costs and schedules, while increasing quality and enabling continuous process improvement. Northrop sought to decrease the number of people required to support the business and save money.

The programs within the companies bore a strong similarity to each other. They only differed in two areas: the progress that had been made, and the underlying driver for the program. Lockheed, GE, and Northrop were strongly driven by contract and government requirements while other companies tended to be driven by competitive market factors.

The factors affecting the implementation of the enterprise integration programs are both cultural and contractual. Cultural factors include the speed with which corporate cultural change could take place, and new company policies and practices could be written and imposed. Contractual factors include issues like allowing sufficient contract flexibility to permit a company to implement new processes for cost savings, and the availability of funding to implement needed projects.

The companies we visited were working with their key subcontractors and suppliers to strengthen their relationships in a strategy to increase the sharing of risks. In most companies this strategy included reducing the number of suppliers. In one company the trend to reduce the number of suppliers has been reversed recently.

Most of the aerospace companies recognized the need for both inter- and intra-enterprise integration. Currently, inter-enterprise integration remains a problem for very small companies who lack the infrastructure investments required to support it. Integration of activities and collaborative work are seen by many, to be of fundamental importance.

Finally, the companies we visited were making an effort to identify the core technologies that the company would retain, and in which areas investments would be made so as to assure itself a place in future markets. These efforts frequently included an involvement in selected standards committees.

At all the aerospace companies we visited, top management defined the corporate goals and objectives and became personally involved in implementing programs to achieve them. Expanding upon the earlier successes of their concurrent engineering or TQM efforts, each begun to establish IPD teams within all the organizational elements and functional processes involved with the design, production, operation, and support of their products. In all cases, reducing the time involved in the total process was a key element in achieving established elements goals, and this, in turn, was tied to the need and ability to transfer data quickly and accurately, which lead to the requirement for inter- and intra-company integrated enterprise system.

D.1.3 STATE OF INTEGRATION

In this section we describe the state of enterprise integration in the aerospace industry. The information which forms the basis for this overview was collected during our visits to the aerospace companies in 1991 and again in 1993.

Of particular interest and note was the progress and the changes we observed between the first and second visits. The aerospace industry is under stress due to the financial pressures of a shrinking marketplace, declining orders, and increased competition from foreign sources. Given this economic climate, the response of the aerospace companies has been telling. In each case, the company has maintained its commitment to enterprise integration. Although projects to deploy enterprise integration require an initial, sometimes substantial investment, the aerospace companies we spoke to all felt that the benefits justified the effort. In many cases we did observe a reassessment of priorities, a lengthening of deployment schedules, or a minor modification of the plans. But between the first and second visits we saw significant forward progress in most cases.

Every aerospace company we visited has an enterprise integration effort underway. These efforts varied widely in both the approach that was being taken and the progress that had been made by the time of our last visit.

Enterprise integration efforts often begin within an organization by automating selected functions of the business, creating *islands of automation*. The next step is often to begin to connect these islands of automation, creating *continents of automation*. This process may continue until the entire company is fully integrated. These intra-enterprise integration efforts may result in benefits such as cost and schedule savings, and improved quality.

While substantial benefits may result from intra-enterprise integration, additional benefits can result from efforts to integrate operations with subcontractors, suppliers, and customers. This inter-enterprise integration is more difficult to achieve, and requires a company to assess and understand its existing business and engineering processes. These processes include both those exclusively inside a company and those involving outside players, such as customers, suppliers, and subcontractors. By understanding all these processes, progress can be made in streamlining and improving those processes, and then finally automating them. There is unanimous agreement among the aerospace companies that automating business and engineering processes before fully understanding them is dangerous.

Several of the aerospace companies we visited have made significant efforts to understand and improve their processes through process modeling. Lockheed applied the Zachman framework to develop its Computer Integrated Systems, Technologies, and Resources (CISTAR) architecture. This architecture will bring together previously disjoint processes into a seamless integrated product development and support system.

By analyzing its business processes, Pratt and Whitney discovered that its product support service needs were not being met largely due to its approach to data management. The Vision 2000 program has produced a data management architecture that will tie together the business and technical processes required to support Pratt and Whitney products. The same architecture will lead to cost savings, shorter development times, and better quality products.

After identifying, analyzing and possibly refining its business processes, a company may begin to integrate the activities associated with these processes. Integration of activities implies an exchange and sharing of the information used and generated by the activities. An infrastructure for communication, data management, and data manipulation is needed for this exchange and sharing of information.

The aerospace companies we visited were using various tools and technologies to provide this infrastructure. Electronic mail is a minimum requirement and is often the first step taken in an enterprise integration effort.

Data management is an area where significant work has been done. GE has developed ADSRS (Automated Drawing Storage and Retrieval System), an electronic storage and retrieval system, as one component of its infrastructure. This system has substantially reduced the time it takes to check out, modify, and check back in a drawing.

Pratt and Whitney has developed an enterprise integration data management system to support its IPD process. This system supports every phase of the business process, including supplying engineering tools, managing the information, coordinating the process activities, and managing the process.

The Integrated Weapons Systems Database (IWSDB) developed by Lockheed and Advanced Research Projects Agency (ARPA) manages both technical and management data. This system provides the sponsor access to schedule, logistics, and technical data. This system will allow most contract data requirements lists (CDRLs) to be delivered electronically.

The aerospace industry may be characterized as a collection of companies coming together to form fluid, temporary alliances for the purposes of bidding on or satisfying a procurement request. With this type of arrangement, communication becomes critical. Some of the factors driving the requirements for team communication include the following:

- The physical separation of the team members
- The size of the team
- The type of the data to be shared among team members
- The volume of data to be transmitted
- The time constraints on data transmission
- Security concerns

The need to transmit large amounts of data over great distances in a timely fashion, or to permit geographically separated design-team members to simultaneously work on the same design, has been underscored by the teaming of aerospace companies on recent major DoD weapon system procurement programs. Most notable examples of teaming have been the B-2 procurement (Northrop, Boeing, and Vought) and the F-22 development program (Lockheed, General Dynamics, and Boeing).

Pratt and Whitney has established a hierarchy of teams as part of its IPD Process. The hierarchy includes an Integrated Product Management Team (IPMT) for each of its major products. Under each IPMT is a collection of Component Integrated Product Teams

(CIPT). Reporting to each CIPT is a group of Integrated Product Teams (IPT). This team hierarchy includes members from all functional and operational groups.

GE has established an IPD Management Team for all its products. These teams include members from design, production, purchasing, product engineering, logistics, and the customer.

A critical need for a team is to be able to exchange information. For the exchange of business data, EDI, provides the capability needed to support the business. This is a commonly accepted and widely used standard. EDI is typically used between suppliers or customers and the aerospace company.

The exchange of technical data (product data) is more difficult. Non-standard exchange formats often prevent efficient sharing of information. The technical aspects of all enterprise integration programs investigated started by expanding upon the electronic data exchange of the two-dimensional and three-dimensional CAD systems and their related computer-aided engineering (CAE) and computer-aided manufacturing (CAM) systems.

Electronic data exchange has shortened problem resolution and program decision times and has enhanced the involvement and commitment of many DoD organizations.

The following were key technical drivers for enterprise integration within the B-2, F-22, and other programs:

- Ensuring that during design phase, product components and subsystems would work together properly (that is, the ability to generate electronic 3-D mock-ups to model interfaces and motion occurring as parts are assembled or operated).
- Designing the product and developing the manufacture/assembly processes simultaneously with input from each aspect influencing the other.
- Involving subcontractors and suppliers as early as possible in the product design and development process.
- The early exchange of product design data with tool designers.
- Exchanging of CDRLs and data requirements lists.

The improved effectiveness of all organizations using three-dimensional CAD electronic information data exchange systems was expressed in terms of cost avoidance, time savings, product development team understanding, and project decision making. These improvements have been documented by each of the companies visited. Northrop and its

B-2 teammates, Boeing and Vought, were able to rapidly prototype, with minimal rework, many of the B-2 components because of the accuracy, resolution, and interference checking attributes of the Northrop CAD (NCAD) system which all parties used. Several senior aerospace managers felt that it was totally reasonable to look forward to being able to handle all prototyping electronically and to eliminate the cost of full scale mock-ups. The B-2, LH, 767 (RB-211 engine strut design), and the 777 programs have all used forms of electronic mock-ups.

Strategic sourcing, as described in Appendix B.1.3.8, is also an important strategy in the aerospace industry. Some companies, for example, Pratt and Whitney, have begun a concerted effort to reduce their supplier base. Pratt and Whitney has expressed a desire to move toward a single supplier for some items. In doing so, it hopes to develop a shared risk arrangement with the supplier. Other companies, like GE, have adopted a different strategy. They had begun to reduce their supplier base with the goal of moving toward a single supplier. During a recent downturn in business, they found that they needed to hold prices to retain market share. Their supplier however continued to raise prices. This prompted a decision to maintain at least two suppliers for all items.

Like the electronics and automotive industries, CAD/CAM tool selection has a major impact on the enterprise integration effort within the aerospace industry.

Enterprise integration is seen by many companies as the next step in the implementation of concurrent engineering or TQM, or as an extension of the CALS and PDES programs. The aerospace industry has a unique requirement based on the long life of its products, and the overriding concern with safety. The requirement that the data associated with their products be available at all times implies an evolutionary move to enterprise integration. While integrating or replacing legacy information systems, the data must remain available and usable. Due to this requirement some technologies, for example, object-oriented databases for the management of design data, are viewed as being too leading edge and not yet proven.

One definition of a legacy system is a system where the data is embedded within the application that uses it. Thus, a new application designed to be intertwined with the data it operates on immediately becomes a legacy system. Like the electronics and automotive industries, companies in the aerospace industry have a significant number of large legacy systems to deal with during an integration effort.

There are three options for a company with legacy system. A company may retain the existing legacy system. This may be done for legal or safety reasons in the aerospace industry. It may also be done for cost reasons.

A company may choose to re-engineer legacy systems. Lockheed has elected to re-engineer some of its existing systems. At Pratt and Whitney, the entire data management system was redesigned to support the IPD process after that process was defined. During this change, the 75 to 80 existing change management systems were forced to tie into a common system, forcing a phase-out of many of the local change management systems.

GE replaced the legacy drawing storage and retrieval system based on microfilm records with digitized drawings in the ADSRS system. This change has resulted in a 50% reduction in the time required to make drawing changes and a savings of $5 million to $8 million per year.

A third option for companies is to encapsulate or integrate existing systems. Lockheed has done this with its automated shop floor scheduler. This system integrates several older systems previously used to perform manual scheduling. The IWSDB also includes several older systems that were not re-engineered but rather encapsulated and provided with interfaces to the new system.

D.1.3.1 Success Stories

Integration *within* an enterprise (intra-enterprise integration) includes integration across functional and operational areas such as engineering, manufacturing, testing, logistics and support, and program management. Intra-enterprise integration results in cost and time savings due to increased process efficiency.

Inter-enterprise integration, integration *among* contractor teams including subcontractors, suppliers and customers, further increases the potential cost and time savings.

Key to any enterprise integration effort is extending the range of data that may be exchanged and shared across the enterprise. Examples of the type of data that are currently being exchanged include three-dimensional CAD model data, product description data, EDI data, and program management data.

In this section we describe some of the results of inter- and intra-enterprise integration reported from the aerospace industry. Where possible, specific metrics are given to illustrate the magnitude of the savings possible.

- A decrease from an average of 5 changes in printed circuit board (PCB) drawings during the pre-ECAD design process to an average of 2.2 changes per drawing with ECAD. This amounted to an annual savings of over $168 million (2.8 fewer changes made to 12,000 drawings in 1990, at a cost of $5,000 per change). The goal is to further reduce this number to 1.9 changes per drawing.
- The number of iterative design cycles needed to produce a printed circuit board (PCB) was reduced from 2.5 to 1.5.
- The number of engineering man-hours to prepare a mock-up of a complete system was reduced from 2,100 hours to 900 hours by moving from a physical to an electronic mock-up.
- Using the old system of developing physical mock-ups resulted in a 131% increase in materials and labor during design, development, and fabrication. Using electronic mock-up and pre-assembly, there was virtually no rework, no scrap, and the components could be assembled the first time with no interference. Although the mock-up process incurred an up-front schedule slip, there was no redesign required and no time was lost during manufacture. The result was project completion ahead of schedule.
- Using three-dimensional modeling decreased the cycle time from design initiation to release to manufacturing by 40%.
- The use of stereo lithography for preliminary modeling of mechanical parts from plastic has helped engineering and management visualize the product much more economically than when wooden or metallic mock-ups were fabricated.
- A gross measurement of the improvement in effectiveness of a division's integration efforts and process improvements was an increase in total sales from a smaller work force, i.e., from $750 million annual sales with 15,000 employees in 1979 to $2.5 billion sales with 8,600 employees in 1990.
- A 9.4% reduction in engineering hours, a 34% reduction in weight, and a 43% reduction in shop floor real estate occurred during design and production of a major aircraft assembly.
- A significant reduction in error rate occurred for the first-time bending of hydraulic lines and fabricating electrical wiring harnesses. The original error

rate using conventional paper drawings was 95%, then was reduced to 50% with the use of two-dimensional CAD systems, and further reduced to 5% through use of an integrated three-dimensional CAD system.

- A $5 million savings resulted when, by using an integrated three-dimensional CAD system, a specification change was made on a large number of drawings.

- Ten percent of an engineer's time was typically wasted due to poor configuration management and the use of outdated or poorly integrated databases. An integrated data management system with appropriate configuration controls can eliminate this.

- The utilization of a CALS-like graphics text editor system allowed a company proposing on two program areas to show considerable cost savings when compared to previous methods of doing the work. These tasks were conducting the needed Logistic Support Analyses, a $10 million savings, and production of technical orders, a $20 million savings. This computer-based system also reduced costs to produce reports meeting Airlines Transport Association and Federal Aviation Administration (FAA) specifications.

- One company estimates that 40% of processing and 25% of labor costs are attributable to data translation. Twenty-four *million dollars in* savings was realized by re-designing and integrating data management functions across all its business processes.

- An on-line electronic drawing storage and retrieval system decreased the time required to make engineering changes by 50%, and produced savings of between $5 million and $8 million per year. This system also decreased the number of people required to provide that service.

- Nearly all first-made special, high performance mechanical and avionics parts had such a good fit due to using three-dimensional CAD electronic mock-ups that two companies expect to eliminate the need for producing future physical mock-ups.

- A company has modified its contract to include electronic delivery of CDRLs to the SPO (subsystem project office) and several supporting DoD organizations. It found that the electronic interchange of data led to a much closer involvement of all parties in the development of the product and the consequent avoidance of numerous problems that would have surfaced later in the development, production, and support cycle. This resulted in significant cost avoidance savings. One measure of the improvement was a reduction from 6 months for approved release of provisioning lists to 60 minutes.

- Electronic distribution and review of data decreased the attendance at formal design reviews by 50%, saving $72,000 per review meeting.
- Use of the Contractor Integrated Technical Information Service (CITIS) was projected to decrease the need for informal technical interchange meetings, saving around $3.5 million over the remaining contract period.
- Product problem resolution decreased from 100 days (from entry into the system to closeout) to less than 20 days.
- Providing customers with electronic access to a problem resolution database and the system account of a single responsible engineer increased customer confidence and satisfaction.
- Using an integrated data management system the cost of exchanging problem reports, engineering change orders, and configuration control data among world-wide partners dropped from $1.5 million per year to $120,000 per year.
- Providing critical infrastructure components, such as hardware and software site licenses, to sub-tier partners too small to make the financial investments in an infrastructure, enabled inter-enterprise integration with those partners.
- Data management costs decreased by moving from a mainframe to a distributed system.

D.1.4 INTEGRATION STRATEGIES

In this section we will discuss integration strategies identified by the aerospace companies during this study. Individual strategies differ in significance between the commercial and military aerospace companies. Where these strategies differ or coincide with those employed in the electronics and automotive sectors, we will provide a rationale.

D.1.4.1 Architect the Integrated Enterprise

As described in B.1.4.1, integrating an enterprise involves understanding the existing business and engineering processes, streamlining and improving those processes, and then finally automating them. It also involves managing the data associated with those processes in a way that supports appropriate exchange and sharing. This approach applies equally well to the electronics, automotive, and aerospace industries.

The characteristics of the aerospace industry that influence the strategy of integrating the enterprise include the extended, complex nature of the team structure, the involvement of a DoD sponsor, and the safety concerns and long-lived product life cycle.

- The teaming structure associated with most aerospace products requires that the enterprise architect consider duplicated processes across the team members, differing company policies and practices, and the use of different standards.
- The presence of a DoD sponsor may require the implementation of specific processes to fulfill government contract requirements. Opportunities for electronic CDRL and other data delivery, and electronic sign-off should be pursued.
- The long life and safety concerns for aerospace products may require certain legacy systems and development and test tools to be maintained for the life of the product despite the new integrated enterprise infrastructure.

D.1.4.2 Enable Team Communication

The same requirements for peer-to-peer communication that exist for the electronics sector as described in Appendix B.1.4.3 also apply in the aerospace industry. The only difference is that the teams in the aerospace industry tend to be larger and consist of many more companies than in the electronics industry. This makes the need for effective communication even critical.

D.1.4.3 Support Both Intra- and Inter-Enterprise Integration

Enterprise integration efforts generally begin within an organization by automating and integrating selected functions of the business. Substantial benefits may result from these efforts. These benefits may include cost and schedule savings, and improved quality. A company can then use these benefits as an incentive to continue its integration efforts further. Recognizing the benefits derived from its intra-integration efforts, a company may extrapolate these benefits for the scenario when they are integrated with customers, suppliers, and subcontractors. While substantial benefits may result from intra-enterprise integration, additional benefits can result from efforts to inter-enterprise integration. This inter-enterprise integration is more difficult to achieve, due to the involvement of separate companies with differing corporate cultures, policies, and procedures, standards and tools in use, and financial constraints.

D.1.4.4 Establish Strategic Sourcing

Strategic sourcing, as described in Appendix B.1.3.8, is also an important strategy in the aerospace industry. By establishing strategic partnerships, aerospace companies can share the risks and costs associated with developing large, complex expensive products. Long-term alliances allow the companies to establish quality standards, and help each other achieve them. These partnerships may also be required to ensure that critical components remain available as needed over the product life cycle.

D.1.4.5 Select Common CAD/CAM Tools

Like the electronics and automotive industries, CAD/CAM tool selection has a major impact on the enterprise integration effort within the aerospace industry. Aerospace sector teams generally involve a larger number of companies. This makes the requirement to adhere to a selected set of tools or standards even more critical.

D.1.4.6 Evolve Predictably to Enterprise Integration

Aerospace companies must identify their need for maintaining certain product data for either safety or contractual requirements. This information is then used during the enterprise architecture design phase before enterprise integration is begun.

Companies may begin by automating and integrating areas where the largest payoff is expected to result. This way the benefits of enterprise integration may be seen immediately. Enterprise integration may then be expanded into other areas and to suppliers, customers, and subcontractors.

It is critical that the business processes are not disrupted during integration, and that the critical data remains available both during and after the integration effort.

D.1.4.7 Replace Legacy Systems

Like the electronics and automotive industries, companies in the aerospace industry have a significant number of large legacy systems to deal with during an integration effort. A decision must be made based on what to do with these legacy systems, based on cost/benefit studies, and safety or contractual concerns. Integration, encapsulation, interfacing or bridging, and re-design are all options that may be appropriate in different instances.

D.1.4.8 Other Strategies

Many of the integration strategies discussed in the electronics section apply to the aerospace industry as well. These include establishing customer advisory councils as a mechanism to include customers in the IPD team, and exploring the use of state-of-the-art tools and services like object management systems.

D.1.5 INFORMATION INFRASTRUCTURE

The components of an information infrastructure are largely the same for the electronic, automotive, and aerospace sectors. Thus, the discussion in Appendix B.1.5 applies equally as well here. However, the aerospace industry is structured slightly differently and is driven by some unique characteristics not shared by the electronics sector.

In this section we describe the components of an information infrastructure and how they are used to support the integration of enterprises in the aerospace industry. Both the software and hardware components of the infrastructure will be discussed.

In both intra- and inter-enterprise integration the companies composing the enterprise or team are connected by a computer network. A network provides the only efficient mechanism for information exchange and sharing. The ability of a network to provide flexibility and dynamic configuration is what enables the fluid structure of the enterprise. Companies or divisions are able to form and dissolve partnerships dynamically without any physical or outward changes. Team members can remain remotely located during the partnership. Physical location of a team member has virtually no impact on the access to or use of project information.

In the aerospace industry, enterprises typically involve a large number of members representing many companies. This is because aerospace products are complex and involve many components. Each enterprise member company contributes in a narrow technical area. The network is able to bring the large number of players together seamlessly, obscuring company boundaries.

The complex nature of an aerospace product results in large amounts of sometimes complex data being generated throughout the life cycle of that product. Three-dimensional CAD modeling may be required during several phases of the development process, including design and analysis, pre-assembly, testing, and maintenance analysis. Networks must provide high-speed, high-bandwidth communication of this data among the appropriate team members.

Data management systems are used by the enterprise to organize and control the data generated by the team members. A data management system may provide services such as configuration control and management, notification, check-in and check-out, and audit trails. A data management system may provide a common data model for the enterprise to ease the complexity of information exchange among the companies.

In the aerospace industry, the size of the enterprises formed to develop products, as well as the safety concerns regarding those products, requires that a sophisticated data management system be used to support the enterprise.

A data management system will potentially manage one or more legacy databases. The options for these legacy systems include re-engineering, integrating or encapsulating, or simply retaining them. A small number of CAD tools use object bases for the storage of design data.

Another component of the infrastructure to support an integrated enterprise is an integrated development system. This system supports an IPD team by providing a multifunction tool environment. The system allows tool registration and access. It can be used to enforce certain standards. It can also be used to control the development process by automating policies and business practices.

The hardware to support an aerospace industry integrated enterprise is often a heterogenous platform mix. The trend is away from main frames toward a client-server architecture with the storage of very large design files on servers. Fairly powerful workstations are often required to run some of the CAD tools used in the aerospace industry. CAD tool licenses are expensive. As a result, these tools are often installed on a few workstations so that a smaller number of seat licenses can be purchased to save money. These CAD tools typically provide an extension language used by members of the team to add specific capabilities to the tool.

In the aerospace sector both hardware and software costs still limit the ability of low-level tier subcontractors and suppliers to become integrated with the enterprise. Smaller companies do not have the financial ability to invest in the necessary infrastructure components.

Another member of the enterprise, the DoD sponsor, is also often not integrated with the rest of the team. Lack of hardware and software prevent the sponsor from participating in the electronic partnership. Typically, DoD contracts often do not allow the contractor to provide these infrastructure components for the sponsor.

D.1.6 LESSONS LEARNED

The aerospace companies interviewed during our site visits have significant enterprise integration efforts underway and were able to report observations and findings from their work to date. Many of the experiences reported to us by the companies are similar across the industry, and, in fact, across the three industry sectors included in this study. In this section we will describe some of the lessons learned in the aerospace industry regarding its enterprise integration efforts. We will describe similarities or differences between the aerospace industry and the other industry sectors where necessary.

D.1.6.1 Cultural Change

As in the electronics and automotive industries, cultural changes remain the single hardest problem encountered during enterprise integration. All the aerospace companies visited agreed that the biggest barrier to overcome during enterprise integration is not the "hard" or technical issues, but the "soft" or cultural and management issues.

One approach to effect a cultural change is to champion the changes from the top-down by getting corporate involvement, and implement the changes from the bottom-up by getting employee buy-in.

In some cases, a new management approach is required. Management tends to oppose radical changes involving itself. One company found that replacing or retraining management, and moving new people in to deploy enterprise integration was a successful approach.

D.1.6.2 Legacy Systems

The data associated with aerospace industry products must be retained for safety and legal reasons far longer than data in either the electronics or automotive industries. Thus, the data in the aerospace industry is extremely stable even while the industry undergoes continual change associated with mergers and teaming arrangements. This data must be retained at any cost. Recognizing this constraint, legacy systems are considered less of a problem in the aerospace industry than in other industry sectors.

D.1.6.3 Paradigm Shift in Data Management

A conclusion by many of the companies we visited is that data must be managed where and when it is produced. In the past, data associated with a product was managed by a system that was built to reflect the organization of the company. That is, the organization of the company was driving its business processes. Companies are continually reorganizing. Despite this, data tends to remain relatively stable. This then results in redundancies and inconsistencies in the data. One company realized that they had been employing a smokestack mentality with regard to its data management, and found it necessary to move toward a more horizontal data flow and management. Without an integrated data management system, data is recreated unnecessarily across the enterprise.

Teaming arrangements bring partners in contact with proprietary information. Companies can be partners one day and competitors the next. Legal issues and security mechanisms must be handled carefully.

D.1.6.4 Justifying Enterprise Integration

In some cases aerospace companies have participated in competitive benchmarking efforts to evaluate their business. Often the results of this benchmarking are used to justify plans and funding for an enterprise integration program within one or more of the participating companies.

Some companies collect metrics internally, evaluate their business, and project the enhanced market position based on an enterprise integration effort. In at least one case, corporate management had difficulty accepting this cost justification, but decided that it needed the program anyway.

Some companies have been able to justify an enterprise integration program on the sheer common sense of it.

D.1.6.5 Automation

Technology should only be brought to bear where it makes sense, rather than for the sake of the technology itself. Automating a poor process does not fix the process. The process should be re-engineered before any thought is given to whether to automate it or not. The two are independent of each other.

D.1.6.6 Teaming

Fluid teaming arrangements spread the risk and capitol investment associated with a large project. In the aerospace industry, projects are much larger, more costly, and higher risk than in either the electronics or automotive industries. Teaming arrangements are a necessity. Enterprise integration vastly improves the functioning of a team.

In the aerospace industry, teams consist of both very large and very small players. The smaller players often find it difficult or financially impossible to conform to standards or practices established within the enterprise by the larger players.

D.1.6.7 Standards

Throughout the aerospace industry we found concern for the standards being developed to support the industry. Standards for product and process description are developing too slowly. Many companies have elected not to wait for a single standard to emerge or to be blessed formally. Their businesses cannot afford to wait. Instead, they are using what exists. In this way several *de facto* standards seem to be emerging.

CAD standards are necessary if engineers are to exchange and share geometry data. STEP (Standard for Transfer and Exchange of Product Data) is beginning to address some industry concerns in this area.

Many of the aerospace companies we visited feel that too many standards are being proposed and developed. Some of these are overlapping, others inconsistent. Aerospace companies are facing difficult economic times and cannot afford to track and support all of these standards. The result is that they are being more selective in the standards they support.

D.1.6.8 Technology

Technology was not considered by any of the aerospace companies we visited to be constraint for enterprise integration. The aerospace companies we visited believe that the technology to support enterprise integration exists today.

The cost of deploying that technology at the lower-level tiers in the enterprise is still prohibitively high in some cases. This essentially makes that technology unavailable to those team members, and thus limits their participation in enterprise integration.

D.2 AEROSPACE INDUSTRY 2001

In this section we describe the state of the aerospace industry in 2001. The four characteristics, technology, competition, teaming, and long-lived systems and safety concerns, used to describe the aerospace industry in 1993, will be used in this discussion.

Technology continues to drive the industry. Composites and other materials research advances have changed the way aircraft and their component parts are designed and manufactured. Digital mock up and stereolithography are used to the exclusion of traditional model shops and full-scale mock-ups.

Advances in the technologies supporting enterprise integration, such as network access, product data models and exchange formats, and other technologies such as object bases, and CAD, CAM, and CASE tools, have meant a heavier reliance on electronic interactions supporting a more decentralized business with dispersed partners and players. A leaner marketplace requires a careful investment in these infrastructure technologies. However, the benefits of these investments are evident: saving time, money, and allowing concurrent engineering, leading to higher quality products and a more competitive company.

By 2001, the number of companies in the aerospace business have been significantly reduced. This reduction mirrors the shrinking traditional market. However, government regulations which previously hampered sales to foreign markets have been eased somewhat. However, competition with foreign aerospace companies receiving subsidies continues to be a concern to the domestic aerospace industry.

Teaming continues to be the norm in the aerospace industry in 2001. Some former team members are no longer in business however. In some cases this was due to mergers. New types of partnerships have been possible, including arrangements with government agencies, foreign governments, and new foreign investors.

The nature of the new structure has taken many different forms, the least radical being (1) the merger of several companies resulting in a fewer prime and subcontractors, (2) considerable cross-teaming to capitalize on scarce and distributed technical capabilities, and (3) some multi-national teaming. This structure is responding to a more intelligent DoD whose needs are for even more diverse weapons that are far more cost effective and can be readily moved and efficient in a wide range of conflicts.

Long-lived systems and safety are still concerns in the aerospace industry. New information systems have improved the tracability of all data associated with a product, however.

D.2.1 THE VISION

Even with the future structure not well defined, there is general consensus on the process through which enterprise integration has been implemented and the results of that implementation.

Companies have fully implemented the concepts of just-in-time (JIT), concurrent engineering, TQM, CALS, and PDES. IPD teams are used throughout the organizations to ensure the best available talent address particular design and process problems and they interface in the most cost-effective manner. Interactions among potentially geographically dispersed team members are supported by electronic networks.

There is a common implementation of open systems and distributed computer architectures throughout each company. Since many elements of a company are widely dispersed, networks capable of carrying large amounts of text and graphics have been installed and are operational. All organizational elements, including research, engineering development, production, logistic/support, administration, finance, human resources, and other groups, have appropriate access to the same set of object bases. This interconnection permits all elements to have their information integrated. To reach this capability the associated interface standards have been established to permit effective access to the system with a wide variety of hardware and software. This access has been coupled with the recognition that each organizational element has made large investments in computers and associated equipment (the legacy system). By having an open architecture, the company has eased many interfacing problems.

With the increased need to team with competitors to effectively respond to Requests for Proposals (RFPs), an Internet capability has been established to tie nearly all of the prime contractors, major subcontractors, and appropriate DoD offices, including the SPOs and Air Logistics Centers (ALCs). Similar to the internal information system described above, there is an acceptable security system which will limit access to proprietary information. Although text and graphical information is of great proprietary importance, the key concern is still the exchange of critical process information which may or may not be in that format.

With a system of networks established, the effectiveness of the manufacturing floor has been tremendous improved with advent of paperless or less paper fabrication and assembly. With relative small assembly rates needed for most DoD systems, considerable organizational and assembly consolidation has taken place so more cost-effective production of diverse items occurs. Surge capabilities will exist in limited places.

With effective three-dimensional CAD, including animation to ensure proper fit and operation among multiple parts, and CAM systems tied directly to part fabrication machines, the "old" model shops will have long ago been absorbed within production, i.e., the fabrication of parts for a new prototype system will be manufactured along with existing production items through truly flexible manufacturing centers.

D.2.2 FUTURE INFORMATION INFRASTRUCTURES

Nearly all of the technology required to support an integrated enterprise is available in 1993. Between 1993 and 2001 most of the changes we anticipate are in the use of this existing technology.

As described in the section on Future Information Infrastructures for the electronics industry, Appendix B.2.2, the enabling technologies for information infrastructures include distributed computing and Open System Interconnection (OSI) networks, and object-oriented management and tool services. The technologies required in the electronics industry are the same as those required in the aerospace industry.

Computer networks will expand, providing greater coverage and higher-speed access to all parts of nation and globe. This will allow greater connectivity among companies interested in participating in enterprises. Companies providing network access and services will become more competitive in the types of services provided as well as the cost of these services. This will allow smaller companies or individuals to join electronic partnerships.

Data management systems will include more object-oriented databases in addition to the legacy relational databases that currently exist and will continue to be developed.

Integrated development environments will mature as vendors begin to market "framework" products. These frameworks may be designed as frameworks of frameworks if standards fail to emerge. The development of these systems will be facilitated by maturing standards in the area of open systems, object management, CAD and other tool interfaces, and data exchange formats. Integrated development environments will provide increasing support for collaborative work through the concepts associated with groupware.

Computer hardware will continue to evolve. The move away from mainframe computers will continue in the aerospace industry. Standards will increase the interoperability among the heterogenous mix of workstations and servers configured across the enterprise.

D.3 ISSUES AND BARRIERS

The most significant inhibitor to the implementation of enterprise integration in the aerospace industry is the requirement for changes in culture within the various companies. This finding was unanimous among the companies we visited, and was cited during both the 1991 and 1993 visits. This finding was also echoed in the electronics and automotive industries.

The critical cultural changes identified by the aerospace companies we visited centered on several issues. One issue is that of information exchange and sharing. The type of information, including the amount of detail, that must be exchanged among various parts within an organization and with outside subcontractors, suppliers, and customers, is an area of disagreement. This issue reflects the openness a company is prepared to establish regarding its data. Company data is a valuable asset. A balance between protecting this asset and enabling a more efficient business process must be established.

Teaming, or establishing partnerships with other aerospace vendors, is widely recognized by members of the aerospace industry as vital to their success in competing for major contracts. However, although practiced for many years already, teaming continues to be an area of concern in the industry. The concern centers on the use of technologies and practices to support an integrated enterprise approach, and the sharing of information and practices with companies that were previously competitors.

Progress measurements and the visibility these provide represent another cultural issue creating barriers to enterprise integration. The "old" ways of doing business were comfortable and unless there were significant reasons such as financial, there was reluctance to accept the changes.

To implement the needed culture changes, the companies we visited identified various strategies and approaches. The first was the commitment and direct involvement of the top executives in establishing new business goals and objectives and the processes by which these were to be attained. Using teams from all areas of the company, corresponding changes in policies, procedures, and organizations were identified through modeling and analyses of the work activities and processes.

Training to improve the needed personnel skills was identified, scheduled, and implemented.

Metrics were found to measure the improvements within *all* effected areas; these areas included engineering, management, and support staff as well as manufacturing.

Leadership from *all* levels of the organization was needed to initiate such action as team building, instilling trust among all segments of the organization, encouraging open self-appraisal, and instituting continuous quality improvement.

One of the biggest problems is standards: too many standards exist or are being developed for any single company to track and support. These standards are often conflicting and extremely slow to evolve. Generally, aerospace companies find that they cannot wait for a standard to be developed or officially released. Instead they must proceed with whatever is available to help them get their job done.

The issue of proliferation or lack of standards arises when information sharing or exchange must occur within or between aerospace companies. As noted earlier, the tendency is to grow enterprise integration from a company's CAD system. Unfortunately, not all aerospace firms (including their subcontractors and suppliers) use the same CAD system. Some use commercially available products, others use in-house developed CAD systems.

Even where the CAD system may be the same, application software such as analysis tools may be different. Versions of the same CAD system may not be directly compatible.

CATIA was found in this study to be the system in widest use; the second most used was Unigraphics. In most cases the Initial Graphics Exchange Specification (IGES) was used as the exchange format.

This study also found that most CAD application software is developed by each aerospace company to suit its own unique design needs and approaches. In most cases, design application software is considered proprietary and can only be exploited when used with a company's design data bases.

Another major hinderance was legacy systems such as computers, communications, and management controls. These were found to be not readily changeable due to high cost, time, or technical constraints. Common ways around such barriers were development of bridges between the legacy systems (interfaces), building around them, maintaining them but initiating new systems for the future, and maintaining maximum flexibility within product and process design and implementation.

Proprietary information is a major concern among aerospace companies who may be currently teamed with a future competitor. Security mechanisms and procedures will need to be developed and proven before many companies feel comfortable with inter-enterprise integration.

The size of most aerospace companies, as well as the complexity and cost of their products, requires that any effort to integrate the enterprise be done in a phased approach. It is not possible to integrate thousands of workers overnight.

The size of many subcontractors and suppliers prohibits the substantial investments in an infrastructure necessary to support enterprise integration. These companies are often unable to invest in equipment and software licenses to enable participation in electronic data exchange with the prime and first-tier aerospace contractors.

D.4 RECOMMENDATIONS

Companies indicated there were several constraints which could be eased by changes in DoD policy, regulations, and/or procedures.

With the significant increase in the development and exchange of electronic design and maintenance information, corresponding changes need to occur in how the DoD requires receipt, review, and storage of that data. Specifically, Federal Acquisition Regulations (FARs) should be changed so they no longer limit the ability of the SPOs and other units to procure needed computer equipment to send and receive the data. One option is for the contractors to place terminals within a DoD office using contract funds. This has been demonstrated on the F-22 project.

With the increased complexity of most weapon systems, it has become almost impossible to fully describe parts and their interconnections on normal two-dimensional paper representations. Requirements should be changed to permit the exchange of data among the procuring and developing organizations. A key aspect is that the DoD needs to commonly accept receipt of design and design interface data electronically.

Control of data from a normal DoD security aspect has required separate data lines to be installed and maintained. That poses considerable added cost to the teaming organizations. With the addition of special access requirements in addition to the normal DoD classifications of confidential, secret and top secret, there are further limits to effective information exchange.

With the potential for large cost savings being attained by using enterprise integration systems, corresponding changes are needed within various cost-benefit models used by DoD organizations to evaluate and assess companies' proposals and development efforts. Such updates need to include revised ways in which data is being exchanged and used.

The Environmental Protection Agency (EPA) and Occupational Safety and Health Administration (OSHA) requirements of identifying and tracking hazardous material are placing an increased burden on the aviation industry and aircraft operators and owners. Various forms of aluminium or pieces of scrap have been determined to be hazardous; the additional costs to track each appropriate sized part, although quite large for the aircraft manufacturer, will be even greater for the Services. Proper systems to handle this information need to be acquired soon.

Since most aircraft companies produce products for both domestic and foreign airlines as well as for the DoD, there is room for improved efficiency if the DoD, FAA, Airline Transportation Association, and foreign regulating organizations were able to minimize their unique data requirements.

D.5 LIST OF COMPANIES VISITED

- Digital Equipment Corporation
- Enterprise Integration Technology (EIT)
- Hughes Aircraft Corporation
- International Business Machines Corporation (IBM)
- Intel Corporation
- Motorola Cellular Subscriber Group
- Motorola Corporate
- Motorola Paging Products Group
- National Semiconductor
- NeXT Computers
- Tektronix, Inc.
- Texas Instruments
- Westinghouse Electronic Systems Group
- Allison Gas Turbine, Division of GM
- CDI/Modern Engineering
- The Cross Company
- Ford Motor Company of North America
- General Motors, Chief Information Officer
- Ryobi Die Casting (USA), Inc.
- SATURN
- University of Michigan: Director/Office for the Study of Automotive Transportation (OSAT)
- General Electric Aircraft Engines
- Lockheed Aeronautical Systems Company (LASC)
- Martin Marietta Missile Systems
- Northrop Corporation
- United Technologies - Pratt and Whitney

APPENDIX E. COMPANY REPORTS

E.1 DIGITAL EQUIPMENT CORPORATION (DEC)

Description of the Business:

Designer and manufacturer of computer platforms and operating system, networking, and application software.

Industry 1991:

Business Strategy:

DEC's approach to enterprise integration has been motivated primarily by Time-to-Market (TTM) and economic concerns. However, DEC does not make most integration decisions based on formal cost-benefit analyses. Rather DEC will estimate the savings after the fact. They tend to plan and implement changes to decrease time-to-market (TTM), increase competitiveness, or because there was no other way to do it.

State of Integration:

DEC initiated a project three years ago to make product development information a shared resource throughout the corporation. A major component of the project, which builds on the existing D-Bus Architecture, is the BRIDGE system.

Engineering product data and metadata were the initial focus of this integration effort. However, as the system concept evolved, it grew to include engineering processes, and further, to include manufacturing.

The BRIDGE system was designed with internal engineers and manufacturing groups reviewing the requirements and goals for the product development information management system. The group developed a data model for the information the system would need to support to fulfill the goals. The model contains both product and process-based data. The system addresses a hierarchy of objects including projects, parts (and sub-parts), products, generic file (types), file (instances), processes (and subprocesses), and tools.

The BRIDGE system provides various services to different classes of users such as tracing a history of transactions on data objects, configuration management, and version control. Due to the constantly evolving product designs, configuration management and version control are vital services.

BRIDGE provides several different user interfaces ranging from menus to command line input. Remote access is provided through the use of a client-server paradigm.

Files may be held locally for performance reasons or stored remotely due to capacity limitations. The BRIDGE project makes use of existing software packages developed at DEC. The KEEP system is an object-oriented database providing a wide range of data management services.

The BRIDGE system has been operational at a major DEC division for the last 14 months, providing access to product development information to over 150 users daily. Roughly 600 to 800 transactions per day are logged. The current implementation manages over 1.5 gigabytes of design data contained in roughly 6,000 files.

Before this project was begun, there was always verbal/manual coordination between manufacturing and engineering. Now files are viewed and shared in both domains. DEC is fighting a cultural barrier, however, in trying to get manufacturing not to physically remove files. Manufacturing feels the need to have a tangible set of drawings and other data. Feedback between engineering and manufacturing on issues of manufacturability and reliability can now occur on-line. System-wide notification of design changes is provided via BRIDGE. This notification is in the form of electronic mail (e-mail).

The next phase of the project will provide the same functionality but use new technology. Specifically, an improved data model will be integrated with the Atherton Software Backplane approach, and greater use will be made of object-oriented programming and database features to enhance system extensibility.

DEC is not yet considering adding an on-line ordering capability to the system. For this next phase, management vision will play a much more minor role and they will have to justify the cost of eliminating the legacy system. To do this, they will model the process visually and highlight bottlenecks.

Service centers can log into BRIDGE for diagnostic information. This was not part of the original plan, but once the information was there people made use of it. Service manuals are not yet on BRIDGE. There is still a concern that pre-release information will be used too early (prior to approval) and inappropriately. One application of BRIDGE is that the drill and die information is now pulled off and processed into machine software that is then loaded back on to BRIDGE.

Before BRIDGE it took 12 to 15 coordinators to manage the data. Even more coordination was required for the DEC 9000 project. With the new system, two and one half data coordinators are required.

As evidence of the savings afforded by Bridge, it now takes 2 hours for a mask information change to be released (20 minutes best case). That is, after a design originating in engineering in Massachusetts is transferred to California and fabricated, and tested to uncover errors, the error report is transferred back to engineering and the file is changed in 20 minutes. This process used to take a minimum of 21 days.

The enterprise integration and EDI (Electronic Data Interchange) effort attempted with the BRIDGE system was undertaken on the DEC 9000 project to improve upon the approach that had been used for the DEC 8600 project. The results have been outstanding, and the approach will now be spreading it to other projects.

On the 8600 project, engineering, manufacturing, delivery and all the other functional entities were housed in a single building. On the 9000 project the team was nationally and internationally distributed. They are now building on the success of the 9000 to get the DEC 6000 project out.

On the 9000 DEC saved six months in delivery time. On the 9000 they saved three to five months by eliminating paper. They saved 60 days in part ordering by having an on-line database.

Another integration effort at DEC is the integrated part and document system (IPDS). This project involves the management of metadata associated with the parts process. The old system was called DOCS. It tracked document numbers and parts.

IPDS is an object locator. It is being accessed 20 hours per day, 6 days per week. There are 450,000 unique object locations. The average number of users at any time is 20. IPDS has 1.2 million records, and over 50 users. IPDS feeds the manufacturing process, supports the release process, supports technical publications, provides international access to information, and provides contact information (change control, rework, etc.).

ERICA, another part of the integration effort, replaced microfiche distribution and maintenance. It has saved $675,000 per year. This figure does not include "tub" maintenance. It provides 24-hour turnaround with view and print capabilities. The funding for this project is spread across projects.

Integration Strategies:

DEC had to get second-level managers involved. On the 9000 project they had high- and low-level managers involved. No middle managers were involved. There were pockets of resistance that tended to change as the project progressed.

The decisions on the integration effort were program driven. Both bottom-up (Program Manager) and top-down (Vice President) were required. In the end, an edict from the Vice President made it succeed. Without him the cultural aspects of the company would have caused a failure. Instead of automating existing processes, he directed a reengineering of the processes. They had to plan for organizational and cultural changes.

Previously, islands of automation existed. This caused major problems because people were using out of date information. Integration allowed DEC to save time and money (decreased its information inventory), and saved people (to manage the information). Further DEC used the opportunity to get its documentation on-line.

Selling the new system to management has meant "glorifying" all the things it could do for them. To sell it to the engineers, however, in order not to scare them, they had to identify their particular problem and show the how the system would fix it. People are skeptical and their trust must be gained. The strategy was to solve small problems first, then grow the solution.

Information Infrastructures:

Unigraphics and ComputerVision (CV) are used for mechanical CAD (computer-aided design).

The technology that has been the hardest for DEC is the database technology. They have developed an internal object-oriented database (KEEP). DEC is monitoring commercial database products. The applications on top of the database have not been all that hard.

Issues and Barriers:

Cultural barriers are the greatest problem foe enterprise integration. The technical barriers are always temporary and/or short lived.

It turned out that system availability was most important to users. Performance was also critical.

On the 9000 project vendors did not have on-line access to information. There were legal issues of net access. They used a trusted intermediary (an IBM personal computer) between DEC and their subcontractor's Motorola.

E.2 ENTERPRISE INTEGRATION TECHNOLOGIES (EIT)

Description of the Business:

EIT is a new research and development (R&D) and consulting organization aimed at increasing enterprise productivity. That is, increase the rate at which a manufacturing enterprise can develop and implement changes to its operation to meet the needs of quickly changing markets. EIT is approximately one year[1] old, with revenues of $1.2 million.

Industry 1991:

Business Strategy:

EIT is concentrating on bringing applications supporting concurrent engineering, integrated manufacturing, and electronic commerce to specific industry sectors such as semiconductor, aerospace, computer, and system houses using an integration framework and a set of tools.

Two Small Business Innovative Researches (SBIRs) have been proposed by EIT. The first is a feasibility plan to move the Manufacturing Knowledge System (MKS) out of the university into practise. The second is a communication framework for mechanical CAD, using hypertext and a concept of "shared notebooks."

State of Integration:

The focus of the work at EIT is on integration frameworks and tools to facilitate information sharing and coordinate decision making. The view at EIT is that a great deal of integration work is going on. Each effort is taking a slightly different vector, however. For instance, many efforts are centered around developing a computer-integrated manufacturing (CIM) architecture. In some cases these efforts are undertaken by groups better suited to provide specific services rather than specify the entire architecture

The Center for Integrated Systems (CIS) at Stanford University is similar to the CIM-OSA (Computer-Integrated Manufacturing—Open System Architecture (European)) effort except that at Stanford the result has been the development of a real prototype. This prototype focuses only on a single semiconductor process, however. The prototype is used to develop a model of a real-world factory where simulations can be played out. In this way, the prototype represents a virtual factory. The prototype can also be used to program a factory floor. This capability has been demonstrated using a 10,000 ft.^{2} research facility at Stanford University.

[1] As of the fall of 1991.

Integration Strategies:

Researchers at CIS are looking at a five-year time frame to transfer some of these concepts to private industry.

Information Infrastructure:

The CIS prototype uses existing databases of information relating to the factory being described, and several separate applications (tools). The prototype provides interfaces for the attachment of tools, an internal object-oriented database, and notification services.

Lessons Learned:

The goal of any enterprise integration effort should be to understand the business thoroughly and streamline the processes before attempting to automate those processes.

The use of simulation lags behind simulation technology significantly.

E.3 HUGHES AIRCRAFT CORPORATION

Description of the Business:

Designer and developer of commercial and military avionics.

Industry 1991:

Business Strategy:

Hughes Aircraft Corporation was motivated by competition and economics to begin to implement enterprise integration. The corporate culture of operating group autonomy has made enterprise integration difficult. For example, the acquisition strategy associated with the integration effort has sometimes conflicted with the autonomy of an operating group's acquisition strategy.

Hughes has strong technology steering groups and is working to establish a strong process focus as well. Investments are based upon business strategies, and technology investments must support these strategies, such as time-to-market, concurrent engineering, and so forth.

Integration Strategies:

Implementation of the Corporate CAD/CAM integration program is six months old. The program was first proposed in a 1989 plan motivated by budgetary concerns. That plan identified that Hughes could realize significant savings by standardizing and integrating its CAD/CAM systems. Standardization would also reduce the amount of heterogeneity in their current CAD/CAM environment.

Phase 1 of the Information Systems Study Team (ISST) Strategic Information System Planning (SISP) effort was the development of the vision for enterprise integration. During this phase the study team worked Hughes business goals and objectives into an integration strategy. Phase 2 of the plan includes the development of a detailed business model and an assessment of that model. During this phase changes in Hughes business processes will be implemented. Phases 1 and 2 will be a one-year effort. During Phase 3 the study team will identify implementation risks and options, develop a migration plan from existing systems, and develop technology, application, and organization architectures. This three to five year effort incorporates top-down planning and bottom-up design of the solution. The Information Engineering Workbench (IEW) tool will be used to capture information during each phase of the effort. Enterprise integration will be a cross-corporation effort. This is notable as it is very different from the way things are normally done at Hughes. Typically, groups within Hughes have complete project independence.

The Space and Communications Group (S&CG) at Hughes began an enterprise integration effort in May 1990. Before that they had three unsuccessful attempts at enterprise integration. It was a learning experience. Hughes executives were taught courses on information management. The effort was motivated by business information needs and driven at the operating division managers level. The support and full time commitment to the project of an executive-level champion are the reason it has succeeded.

The S&CG enterprise integration plan outlined a roadmap for proceeding with implementation. The first step was to address data exchange standards and electronic mail. The electronic mail systems will be the first area to be integrated, followed by the data systems. In the first one to three years, S&CG hopes to decrease time-to-market by 30% by integrating its operations with both customers and suppliers. In the next 3 to 10 years, they hope to decrease time-to-market by 50% (from the original baseline).

The company Information Systems Architecture (ISA) Team laid out a multi-phase project for enterprise integration. The project centered around the development of a process model. They have an Information Systems Executive Council (ISEC). This group is looking at an integrated information system to exchange data across the seven operating groups at Hughes. The ISEC is also sponsoring an effort to integrate existing systems, identify common Hughes business processes, and meld the technology aspects of IS with the business process aspect of IS. These two were traditionally separate with an emphasis on technology. In linking IS to business process improvement the project begins by identifying who the executive level process owner is. Until there is an identified process owner, there is natural ownership of the business information.

The project is using CASE tools and business area analysis to model their business processes. They are developing a process model that will be reviewed by the executives to ensure a high level buy-in, and will be validated by approximately 150 experts from across the corporation. The model does not include group- or sector-specific information.

The suggested data architecture for the model is based on the S&CG's 60 data classes. The group dropped one data class, added three, and provided descriptions of data and processes for the communications sector. It developed a matrix using a technique called CRUD (created, read, updated, deleted) for the data classes and processes. Now it believes that it is ready to do a roadmap for systems integration and management as they move toward enterprise integration at Hughes.

The Missile Systems Group (MSG) began a product data management system project. This project was found to be strategic to the company and MSG was asked to form a multi-group activity. The Ground Systems Group had a framework initiative looking at engineering workflow management and a CAD framework. These two efforts were combined to become a company-wide CAD/CAM Integration Plan (CCIP) initiative. This initiative will address both the product development process and the information systems needed to support it.

The S&CG is working toward a heterogenous, distributed, client-server model as the basis for its enterprise integration. The goal is for everything to be mediated by the data. The focus is on three big payoffs: engineering data management, integrated resource management, and integrated cost and schedule, although they are still investigating activity-based costing. S&CG clearly wants integration back at the data source, but that would take five to six years. So it is focusing on quick payoffs.

S&CG bought into the Donavon Process Development Method and are now planning to integrate existing systems into it. This integration should take six months. S&CG currently has IDMS on an IBM mainframe, a contract cost system, a program scheduling system, and an earned value utility. These applications exist in SNA. They are in the process of bridging from SNA to Unix (POSIX) and will include 110 users in 4 divisions. Users on PCs and Macintoshes will also be included. The new system will give the appearance of integration with the bridges existing in the background.

There is currently an EDI effort, motivated by the ATF contract award, to connect customers. But Hughes is concentrating on both internal integration and external EDI. The company has recently initiated a project to establish a common Manufacturing, Material, and Acquisition System (MMAS) to support its aerospace activities.

Information Infrastructure:

At Hughes the Groups have assessed their existing systems against their needs. They built a matrix of business processes and data. It showed them how data is used and by whom.

The components of the enterprise integration project include a common data model, product data management, and common parts definition and libraries. It is too early to say how these components will be implemented. Hughes is considering buying and integrating and then tailoring various products.

An object-oriented data base (OODB) may be of interest later. Right now, Hughes is concentrating on the process.

Currently the vision at Hughes is that it will be eliminating all existing legacy systems with open systems over the next five years.

Hughes strongly supports the notion of a national standardization initiative that would tie networking and product data standards together. It sees OSF (Open Software Forum) as a model of standardization effort effectiveness. Hughes also participates in the PDES standardization efforts.

E.4 INTEL CORPORATION

Description of the Business:

Designer and manufacturer of microprocessors.

Industry 1991:

Business Strategy:

Business strategies at Intel are driven by four characteristics: a constantly changing organization (in response to rapidly changing market needs), the geographic dispersal of its operating units, a culture of bottom-up consensus building, and a very strong "people" network.

The decision making process at Intel is not always based on the results of elaborate cost-benefit analyses, especially when providing a quantifiable cost-benefit analysis is very difficult. Rather, employees develop compelling arguments in support of a position and convince the relevant groups. The arguments are often based on intuition and experience, which are supported by hard data as appropriate. Arguments may be driven, for example, by market trends or by what competitors are doing. In the pursuit of enterprise integration, Intel sees this not as an investment issue, but rather a consensus and competition issue.

To be competitive, Intel recognizes that the technology processes will be revised frequently, possibly every two or three years. Thus, the very large investments required to develop new processes and build new wafer fab facilities need little additional justification for senior management. However, within a given technology process window, the decision to build a specific product or product set requires substantial justification, especially when demand exceeds process capacity.

Intel believes that the costs associated with producing a product are in materials, capital and facilities, people, and transportation. Issues of critical importance to Intel from the cost standpoint are yield and time-to-market. The primary cost driver in any product is yield or possible units shipped. The secondary cost driver is time-to-market. In this area, Intel has implemented some aspects of concurrent engineering to help reduce time-to-market.

Enabling technologies such as integrated CAD tools, engineering workstations, analysis software, fibre optic communications links, and shop floor control systems will support the concurrent engineering strategy. Beginning in the 1980s Intel invested heavily in these technologies with the goal of cutting one year off product development time. The common CAD system has been extensively modified, but is being used throughout the corporation.

As an indication of the divisional and geographical independence at Intel, there are 5 design facilities, 8 fabrication plants, 3 assembly plants and 15 test groups. The initial logic for this distribution was for fabrication to be done in the United States since it was capital intensive, assembly was to be done off shore as it was labor intensive, and testing was to be done in the United States as it needed to be closely monitored by the U.S.-based engineers. There is a move to migrate operations out of Santa Clara, California, due to rising costs and environmental concerns. As a result of the geographical dispersion, logistics are fairly complex but are not supported by very sophisticated systems.

State of Integration:

Enterprise integration is a recognized issue at Intel. Management believes that it needs higher level, coherent direction to solve its integration problems. It feels that the first step in integrating the enterprise is for someone to model the enterprise and how the business is to be run. A senior management decision on how integrate must then be made. An area of concern is that middle management cannot get the attention of anyone higher up who is willing to take this first step. An additional concern is that the effort to develop a solution would require the commitment of some of Intel's best people, all coming from different organizations. People and divisions are fairly independent within Intel and do not often work as a team toward global (corporate) benefits. Intel has just recently started to share information within a "team" and with industry.

Marketing, manufacturing, and logistics are attempting to develop an integrated sales order entry system. The incentive for this integration is to improve performance to the customer. Management at Intel estimates that it will be one and one-half years to get consensus on this effort, however. Implementation will then take an additional two to four years. No one has asked what the cost savings will be as a result of this system—the benefits seem intuitive and hard to quantify. They feel it is "customer justified."

Management at Intel recognizes that control of material is the one of the biggest problems to be solved. It has developed several loosely connected material control systems. However, the bottom-up culture of consensus building means that until all the groups indicate that this is a major concern, Intel Corporate will not impose a centralized approach. The corporate view now is that if they can still get a product out in a profitable manner, why impose a centralized system that requires resources now being utilized in delivering products to customers?

At Intel products tend to be designed by a small (20 engineers), well-integrated group, working with process development groups. Not very much manufacturing data are integrated between product and process development and manufacturing groups. On the factory floor, shop floor control data are relatively available, as are engineering data, in somewhat integrated systems. There are many, many translators and interfaces to these systems. Intel is currently building larger islands of automation out of many smaller ones.

EDI has been set up with Intel customers. Intel is starting to put its smaller vendors on EDI. In general, Intel is working to decrease the number of vendors—and working to tighten and/or improve its relationships with those vendors. Sales order entry is being replaced by modularizing a former monolithic system. The goal is that this will help later attempts to integrate it with the manufacturing systems.

Product nomenclature is not standardized. There are 10 to 13 major product nomenclature inconsistencies Intel is willing to live with for the time being.

Integration Strategies:

The strategy at Intel is to encourage a bottom up, consensus-driven approach to decision making. Islands of automation or integration grow bottom-up for a while until they gain the attention of senior management. At that point a decision to integrate or consolidate comes from the appropriate division or corporate management.

Approximately 100 companies make up the key accounts at Intel. These companies represent about one-half of the dollar volume of sales. Intel has started to encourage greater customer involvement, especially when the customer seeks product changes. In one instance, response time was shortened from five months to one month. In general, however, management at Intel feels that response time is poor.

Information Infrastructure:

Intel has no cross-divisional database. Marketing has the closest thing to a corporate-wide database. Divisions and Groups use their own data representations. Translators between formats do not always exist. For example, 10 to 13 major different product nomenclatures exist within the semiconductor group. Maybe as many as another 100 minor ones exist as well. No standard formats exist.

Engineers are strongly encouraged to solve their own problems (bottom-up). This may be because the company grew up as a result of a strong entrepreneurial spirit and is related to the strong people culture at Intel.

There is an integrated CAD tool environment into which the mask fabrication system is tied. Product and process quality data is available on-line (as a result of recent internal demand).

Intel has numerous electronic mail systems which do not communicate well—if at all. Low-level managers and engineers complained about this situation (to no avail). Then Corporate ran into problems associated with having so many non-communicating systems—and the systems were better bridged and the number of systems reduced. Consequently, Intel has accepted the separate islands and are now trying to combine them in a coherent fashion.

Lessons Learned:

There is a great deal of concern over the attitude of U.S. vendors. Vendors are seen as not being as responsive as the Japanese vendors. U. S. industries have maintained a too near-term vision.

Intel follows a five-year plan. Ten to fifteen is too far in the future. It does track developments in key universities, schools specializing in specific areas, or universities close to their facilities.

The recent push toward quality improvement, including the Baldridge award, has seemed to help. Improved benchmarking has also had a positive effect.

Industry 2001:

Issues and Barriers:

Intel views the standards world as being a massive quagmire. Order is needed but it is not clear how that order shall be provided.

E.5 INTERNATIONAL BUSINESS MACHINES (IBM) CORPORATION

Description of Business:

IBM is a computer maker, software developer, systems integrator, networking specialist, service company, and more—a federation of businesses dedicated to helping customers work smarter, faster, and better.

Since IBM is a federation of autonomous businesses, each business unit visited presented only its own integration practices. In this report we cover the CIM Integration, IBM Engineering Framework, AD/Cycle[2], and Systems Object Management portions of IBM's business. This does not purport to address all of IBM's integration practices and strategies.

Industry 1993:

Business Strategy:

The world-wide computer industry is being reshaped by fundamental changes, including trends towards smaller computers and open systems. Customers place increasing value on software, services, and integration skills. In 1991, responding to these changes, IBM revised its business structure to create more autonomous and responsive business units. It is reallocating resources to growth business, reducing costs, and increasing the autonomy of IBM business units.

IBM's Marketing and Services businesses are increasingly focusing on consulting, systems integration and related services. Growth areas include client-server computing, networking, RISC technology and multimedia, together with essential software.

Marketplace demand for world-class quality at competitive prices is driving cost and manufacturing capacity reductions. Clear focus and speed to market are essential for competitiveness. Increasingly, each IBM business is shaping itself to its own marketplace disciplines.

CIM Integration:

Business Strategy:

IBM's CIM Integration Center provides consulting and integration services for both internal and external customers. The CIM Integration Initiative supports a partnership between the Industrial Sector Division (ISD) and customers. Feedback and guidance is pro-

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[2] The AD/Cycle information is from a visit to IBM's Santa Teresa Laboratory in 1991. The remainder of the information is from visits in 1993.

vided through the CIM Steering Committee, the Executive Steering Committee (VP-level participation), and the Integration Project Group (three external customers and one internal customer). They also maintain a dialogue with major customers world-wide.

CIM is moving to providing solutions and services via consulting arrangements, in addition to via announced products. IBM can't support a product forever. Nor can it just build a product and put it out there. *Partnering* is a key strategy.

The goal of partnering is to provide a solution now, not a product in two years. Solutions need not be products (which must go through the product-approval process). Partners participate in defining the potential product (the solution), sh[illegible]k of the project, and obtain the solution before the product is announced. The C[illegible]gration Center may prototype a solution, but they don't build deliverables unless some customers are involved as partners.

The driving force is ensuring the implementation of the IBM CIM architecture as an open, integrated set of ISD and key business partner CIM Advantage offerings. This architecture will provide integrated environment and support services, integrated validation, integrated requirements definition, and development of selected integrated software.

CIM Application Consulting Services (CACS) is a six-person team, formed in May 1992, to work on what it takes to deliver integration and to identify gaps and overlaps between hardware and software products. CACS integrates ISD applications in manufacturing industries and performs integration studies.

State of Integration:

IBM has the same integration problems as everyone else. The CIM Demonstration Lab has a configuration of heterogeneous hardware and software; for example, hardware ranges from a 3090 mainframe to data collection equipment. By integrating products in a realistic business scenario, the staff builds expertise and broad experience providing integration services. The scenario shown to the IDA electronics team demonstrated a product revision under engineering change control. (IBM stated that most customers acknowledge that change management is a serious issue.) The scenario was developed with the Integration Project Group, and involved IBM and non-IBM hardware and software. The scenario uses a data model driven approach. The "target" enterprise provides the model. Obtaining a consensus data model is difficult.

Bridging among network systems is non-trivial. In the Distributed Application Environment (DAE), users can send and receive messages across heterogeneous networks.

Messages can be sent from applications to users, users to applications, and even to devices to handle an event. The CIM Integration Center uses DAE as the heart of its distributed capability.

Integration Strategies:

The CIM Integration Center is in the infrastructure business, as an integrator of IBM and non-IBM environments.

Information Infrastructure:

Team Integration Environment (TIE) is a collection of services used by IBM for CIM integration. TIE services include Common Data Facility (CDF), Distributed Application Environment, Concurrent Engineering (CE), Services Access Interface (SAI), User Interface (UI), and Information Server SAI.

SAI uses "adaptors" to encapsulate applications to the standard interface. Current adaptors are focused to existing applications. The strategy is to make the adaptors generic. If future applications are written to object-oriented standards, adaptors will be easier to write.

DAE is a messaging system with queuing capability and system alerts. It provides portability for communications services, data services, user services, and device services; DAE takes care of network, time, threads, and messaging. DAE is presently a proprietary implementation but will evolve towards a distributed computing environment (DCE).

UI targets "integration at the glass," point-and-click integration. By encapsulating applications via adaptors, engineering management information can be extracted from each application and presented to the user with common look and feel, including some mouse-based functions. (Note: *this common look and feel is supported in a separate, TIE UI window*, and does not imply that the application running in its own window conforms to the TIE UI.)

In the CIM Integration Lab demo, the Long Data Reference Option (LDRO) from Product Manager is used for engineering management of data from encapsulated applications. KI-Shell is used to follow the demo's engineering change methodology. This is a process model driven system, but the user provides the model. Designing this model is the hard part.

IBM is the largest CATIA user in the world, and is probably the largest CADAM user in the world as well.

The CIM Integration Center is supporting PDES/STEP.

Electronic CAD:

Business Strategy:

Technology Products' CAD Systems Solutions and Frameworks Program provides electrical CAD tools and the IBM Engineering Framework (IEF), and supports electrical CAD tool integration for IBM divisions.

State of Integration:

IBM's Electronic Design Application (EDA) environment (in the mid-1980's) ran on mainframes under the MVS operating system. As divisions began buying more outside parts, they also started to acquire outside CAD software. The CAD group saw a breakdown of its large, established (internal) customer base. Although the MVS system, which executed as a sequence of batch steps, appeared integrated to its users, it comprised over 100 programs and file formats, and was difficult to integrate with outside software. The MVS system involved over three million lines of code written in proprietary languages.

The CAD group decided to implement a platform independent system written in standard languages (C or C++). It tried to move to centralized database approach, an integrated system around an integrated data model. This proved to be somewhat unwieldy, so it followed the tack of integrating multiple tools into multiple frameworks, and using the tools' databases as views on a composite virtual repository. Now the CAD Group is integrating point tools into frameworks, and integrating frameworks into the IBM Engineering Framework.

Integration Strategies:

IBM has extensive direct involvement in the CAD Framework Initiative (CFI) working groups, to generate interest within CFI in concurrent engineering and to influence CFI to work with other standards bodies. The IEF is compliant with the CFI's Standards Release 1.0 for Inter-Tool Communication (ITC), Computing Environment Services, and Tool Encapsulation Specification (TES).

IBM has a corporate culture to use division-specific "standard" design methodologies within a design group, but does not dictate corporate-wide IBM-standard methodologies. However, many IBM sites are not using a single design methodology and tool suite.

IBM will go through ISO 9000 certification; several groups have already. IBM has many European Labs and European customers, so they have followed ISO 9000 as it emerged. IBM's rationale for conformance is to sell products in Europe (IBM Europe companies are European; 95% of what is sold in Europe is made in Europe.) The biggest effect of ISO9000 will be on engineering change procedures, but overall it will not require much change for IBM.

Information Infrastructure:

Ten years ago, IBM's EDA environment ran on mainframes under the MVS operating system. Some of these tools continue in use today. In addition divisions are using outside CAD software. Suites of point tools that are used together are integrated into workbenches. There are CASE workbenches, ECAD front-end workbenches, and so forth. The CASE workbench might be integrated through a PCTE framework, while an EDA workbench might be IBM internal tools under IEF, Cadence tools under Design Framework II, or Mentor Graphics tools under Falcon Framework. Workbenches (and their domain-oriented, proprietary frameworks) are integrated as clients under the IEF server.

IBM has developed a VHDL-oriented workbench of EDA front-end tools (under IEF). It has added a "desktop" interface that presents design status, process control, session status, and an error browser. The error browser runs in a standard window that is used by all tools for error reporting.

IBM connects to suppliers by the IBM Information Network Services. Security is not an issue because a rigorous security methodology is in place.

Application Development:

Business Strategy:

AD/Cycle is IBM's Application Development strategy for Systems Application Architecture (SAA). SAA crosses mainframe (System/370), AS/400 and PS/2 computers under MVS and VM, OS/400, and OS/2 operating systems, respectively. They are becoming interested in extending AD/Cycle to support AIX (Unix) machines.

IBM has established a customer advisory council on AD/Cycle. The members have two representatives on the council: one at the CIO level and one at the technical level. The CIO level council members advise on strategy.

State of Integration:

AD/Cycle is characterized as a repository manager plus tools, supporting multiple languages and providing a knowledge-based system. The architecture diagram for AD/Cycle is depicted in Figure E-1.

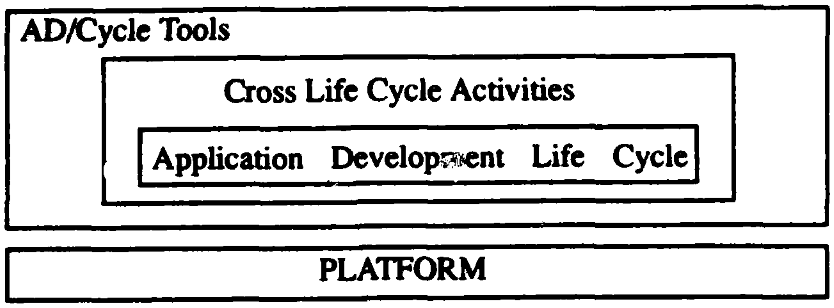

Figure E-1. AD/Cycle Architecture Diagram

AD/Cycle enables developers to apply clean room methods to application development.

The platform component of the architecture includes the Repository Manager (e.g., RM/MVS) and library services of the Software Configuration and Library Manager (SCLM). Both of these work with the AD Information Model which is an Entity-Relationship-Attribute + Constraints model that provides a predefined extendible base model for AD/Cycle developed applications.

An example of Cross Life Cycle services is process control from the Application Development Project Support (ADPS) program.

An example of an Application Development Cross Life Cycle tools is an SA/SD (Structured Analysis/Structured Design) dataflow tool. Some of the AD Cross Life Cycle tools are provided by third-party partners, such as Knowledgeware (Application Development Workbench, ADW), Bachman Information Systems, and Intersolv (Excelerator products).

ADW/MVS REF (or ADW/REF) Repository Enablement Facility is an application to the Repository Manager. ADW/REF adheres to the AD information model. ADW/REF interfaces ADW's entity aggregations to RM repository objects. Repository objects provide a flat interface to various media, such as optical disks and libraries.

Integration Strategies:

AD/Cycle is a collection of software tools that provide an Application Development environment that address the entire life cycle. AD/Cycle-developed applications execute in the context of many other software systems, such as CIM, AIX/CASE, System View, Image+, and Office View. In developing the architecture for AD/Cycle, a goal was to identify integration services that serve all of these application areas, for example, the RM.

Information Infrastructure:

The AD/Cycle information model has three levels of models: Enterprise model, Technology model, and Global model.

The Enterprise model deals with process, information flow, entity relationship, and so forth.

The Technology model deals with business modeling and application modeling. It follows John Zachman's framework model. Views include:

- DRC, Database Relational Common
- DRM, a DB2 unique extension of DRC (M denotes MVS)
- DL1, for IMS (Information Management System)
- High-level language (HLL) Cobol, for Cobol data structures
- APT, Application Programming Technology

APT is library oriented, dealing with parsed source code, denormalization, and data definition language. The Global model is a data dictionary with descriptive text. It describes entities at the level of an RM object. Relationships are possible across layers of the information model, for example, to support object-oriented analysis and design. Conformance to the information model is enforced at three levels, depending on the level of integration: Common User Access (for external users), Tool-to-Tool Control Flow and Data Integration.

The RM is a system for managing specifications. For the specification domain, RM uses a three-level data architecture with conceptual, storage, and logical views. For the run-time domain, RM provides data services, user services, and systems services.

Data services support reading and writing entities, relationships and attributes through a tool's logical data view. User services supports automatic mapping from RM template fields to Dialog Manager panel fields and other services in the logical view for Dialog Manager I/O operations.

System Services support RM functions. This includes binding functions and methods to templates, dynamically binding templates to entity sets, opening and closing functions, and invoking functions and methods. RM objects provide method inheritance, but not data inheritance. There are no persistent identifiers for RM objects.

Object Management:

Business Strategy:

System Object Management (SOM) provides portable, language-neutral object technology. The goal for SOM was to provide objects in OS/2 without an object-oriented programming language. Distributed SOM (DSOM) extends SOM objects to interoperate with objects located across a local or internet network. IBM is very open with SOM technology. They see DSOM as a ubiquitous part of the information infrastructure. They will port to certain non-IBM environments (e.g., DOS) and are willing to talk to everybody about making the technology widely available.

Information Infrastructure:

SOM provides portable, language neutral object management. SOM is portable in that for systems objects there will be a common API across DOS, OS/2, AIX, and Taligent. SOM is language neutral in that the methods for an object class can be written in any language (for which there are SOM bindings), even to the extent that each method can be implemented in a different language. To do this, IBM developed the SOM binding technology, which resolves linking (to a binary executable in a library) and solves the library compatibility problem.

SOM is a component of OS/2. SOM objects are defined using the Common Object Request Broker Architecture Interface Definition Language (CORBA IDL). SOM is the only object strategy that is not tied to a specific implementation language. Presently there are SOM language bindings for C, OO-Cobol, C++, and SmallTalk-V. For languages without SOM bindings, a SOM adaptor can be written for a non-SOM object so that its methods can also be invoked through SOM.

Distributed SOM (DSOM) allows invocation of object services (methods on a SOM object) anyplace in a network, in a location transparent manner. DSOM, which is CORBA compliant, is now based on sockets, but will evolve to DCE. IBM will submit DSOM to the Object Management Group (OMG) as a reference implementation of CORBA. Also, IBM and Hewlett-Packard are proposing extensions to CORBA that, if accepted by OMG, will ensure that CORBA-compliant objects can interoperate.

Lessons Learned:

- Business processes are changing faster than Information Systems can keep up.
- A company may be a supplier, a prime, and a competitor all at the same time.

- Nobody builds anything at only one place anymore.
- With respect to integration infrastructures, industrial sector vs. non-industrial sector is a marketing distinction, not a technological distinction.
- Islands of automation are no longer sufficient. Customers want information exchange between islands of automation; interfaces are required.
- There are problems in two places: networking and presentation. Messaging to/from functional servers and designing data models and databases to work in this environment are hard problems. Porting application interfaces is in hours and days; porting presentation is in weeks and months. The data model and structure affect performance.
- Standards dealing with data visibility, and data exchange are the most important to support integration. There is a need for standards progress on presentation.
- For integration infrastructures, 90% of the innovation is done. Only the implementation remains, which must be driven by users' priorities.
- The technologies required for integrated infrastructures are currently available. The challenge will be to develop a strategy for selecting from the wide variety of available technologies to ensure that the appropriate components, applications, and standards are used in implementing the integrated infrastructures.
- A key requirement is to work with existing legacy applications, allowing migration to new technologies. A legacy system is either (1) an older, existing system, or (2) any system where the data is integrated with the application. A "new" system could be a legacy system.
- Push/pull depends on an application's capability. A pull capability plus an appropriate message and user action approximates push.
- Object Management Systems are six to nine months out; object-oriented databases are not necessary to obtain the benefits of objects for integration. The CIM Integration Center group sees existing object management technology plugging in at departmental level, but feel that current object databases are not suitable for enterprise level solutions.
- CIM compliance with OMG's CORBA is a requirement (raised by heavy equipment manufacturers).

- Development of new high-speed components has the effect of blurring lines between validation, test, synthesis, design, etc., and of blurring the distinction between electrical and mechanical design. IBM had to develop better coupling between engineering and test, which required greater emphasis on Concurrent Engineering.
- Design engineers resist standard methodologies because they fear that standardization may take the "art" out of engineering (they want to keep the artistic part of design).
- Integration of point tools into large systems is difficult.
- It is impractical to believe that people will give up their point tools to move to standard tools. Engineers would rather have faster point tools than closer integration with other disciplines.
- It is impractical to believe that people will go to federated databases. An enterprise will probably retain many separate databases.
- IBM is doing less outsourcing of design work now, in part to keep people employed.
- One wants the enterprise's integrated data model to grow incrementally. An enterprise process model is the guide to consistent incremental growth. Don't push data models as standards; instead, pursue a process modeling standard.
- Change management is an application issue. The ability to communicate change in related pieces of data is within our grasp. Three facets of dealing with change are (1) to minimize the amount of change due to errors, (2) to recognize that external influences will cause change (some rapid, some controlled), and (3) that the dynamics of thousands of applications will require change.
- Right now, even developing shops aren't using their own frameworks; a test of success is when they do. Not everyone will be on one framework.
- Communicating information among applications is central to integration. CIM: DAE provides necessary communications services. EDA: Inter-Tool Communication is the center of a framework. And SOM: cut and paste are required in all applications.
- The functionality of frameworks is moving into operating systems.

- IBM has invested a lot in past standards work and has occasionally been burned (e.g., Jovial).
- SOM enables programmers to utilize their training, whether in C, Cobol, C++, or SmallTalk-V. There need be only a few specialized object designers, who might have to be retrained.
- Some CORBA-compliant products work well in a homogeneous environment but do not interoperate well with objects in a different CORBA environment. CORBA is necessary but not sufficient.

Industry 2001:

Vision:

IBM is pursuing a concurrent engineering vision for 1997.

Application families must be commodity items. We need a structured approach for integrating inconsistent environments. There must be (application family specific) standard interfaces so that the applications remain modular within an integrated system. An IBM PC VP was quoted as having said that "the time will come when IBM will only purchase software that meets standards."

In 2001, systems will contain a mix of relational and object-oriented databases. They will also have a mixture of procedural and object-oriented applications. An integration framework or reference integration architecture is necessary to handle it all.

In the future you will have "some of everything" and you must have an information technology structure that lets you evolve. A parametric services workbench could put parameters under engineering management, providing levels of authorization, lock, controls, and so forth.

There are levels of integration: workbench integration integrates tools into workbenches, discipline integration integrates workbenches into disciplines, and enterprise integration integrates disciplines into the enterprise.

Object technology in the infrastructure will enable existing technology to plug in and use the infrastructure to expand to the enterprise level. Business processes will also be represented as objects.

A "framework" as the integration of multiple applications frameworks tied together with standard message scheme (according to CFI) is a feasible way to build an engineering framework.

Future Information Infrastructures:

For portability, TIE is targeting DCE which takes care of a lot of necessary system-level services (backup, security, etc.).

Requirements for Structured Architectural Approach include:

- client/server
- heterogeneous data
- open system environment
- full API at application
- high-level/stable API
- large objects[3]
- complex objects
- network transparency
- *information directory*

The functionality of frameworks is moving into operating systems.

DSOM will be a ubiquitous component of the information infrastructure, providing portable object services across all the popular computing platforms.

Applications will be developed as specializations of "application frameworks." An application framework[4] is an application that is designed to be extended by subclasses. It includes a library of classes plus a sample application that uses the library. That is, an application framework includes user interface, file housekeeping, cut and paste, networking, links, plus "the algorithm."

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[3] IBM referred to experience with a 345 Megabyte object at one customer.

[4] The Application Framework approach is being developed by Taligent, a joint venture between IBM and Apple Computer. Taligent will be providing a rich set of frameworks and objects; currently 24 frameworks, 2,000 objects.

Issues and Barriers:

There is a need to reach agreement on meta-models and communications; a meta-standard would help to consistently harmonize competing standards.

Recommendations:

Industry:

The IEF group is heavily involved in standards. It has been active in the CFI since 1989, and is working with the electrical side of PDES. The IEF Group see that these standards are beginning to overlap. IBM proposes that where there are similar concerns, the different standards efforts collaborate on joint pilot projects.

CFI needs to focus on integrating engineering activities (concurrent engineering) rather than just focus on integrating tools.

IBM would like to see things better in the standards arena. Suppliers must get together and be collaboratively involved in standards development to prevent losing their technical autonomy to the bigger customers.

Government:

Scalability is the key to moving complex software (e.g., CAD tools) onto smaller computers. The Advanced Research Projects Agency (ARPA) has a role in studying technology support for scalability.

Large companies cannot solve all the country's problems—government must push standards and business practices all the way down to suppliers, where it is in the country's best interest. Government should insist on standards or refuse to buy non-compliant products.

E.6 MOTOROLA CELLULAR SUBSCRIBER GROUP

Description of the Business:

This division of Motorola designs and manufacturers a line of cellular phone products.

Industry 1991:

Business Strategy:

The Management of Information Systems (MIS) group put together the plan (in excess of $1 million) to develop a Material Control System (MCS) system. It is unclear whether a cost-benefit analysis was performed prior to implementation. However, initial results indicate that it will result in significant savings.

State of Integration:

The manufacturing resource planning (MRP) or material control system (MCS) has 42 modules and is hosted on an IBM mainframe. Motorola Cellular Subscriber Group (MCSG) is in the process of moving it to a distributed Unix system. All the legacy databases will be moved to a relational database. The material control system portion of the system should be converted in six to eight months. The new MCS will have greatly increased functionality.

Electronic EDI is now in place. It has resulted in major cycle time reductions. For instance, five to six weeks' worth of work is now compressed into one week. Engineering teams are organized by market orientation. They are taught to "live and breath" the market place. This has had a major impact on efficiency at MCSG. EDI is now being pursued with customers and suppliers.

Supplier EDI will include inventory, inventory requirements, and orders. However, the semiconductor group within Motorola has a different EDI system. Motorola Cellular prefers to continue to use its own system. Printed circuit board (PCB) information, the largest component of the engineering effort at Cellular Subscriber Group, is shared electronically with the supplier.

MCSG is decreasing the number of its suppliers. This number currently stands at 50 to 75 key vendors. MCSG is tending to drive its EDI. However, due to an overlap in their markets some suppliers are being driven by automotive EDI. Cellular Subscriber Group is very interested in pursuing EDI with customers. However, it is not yet in place.

MCSG is continuing to automate its manufacturing. Component placement information is electronically supplied at the assembly site. A physical model of how a product is built has been replaced by on-line build information including a screen image of the product and assembly instructions. Motorola Cellular is implementing a factory control system (FCS). The goal is to speed up new product introduction by decreasing the time from product design to factory programming. This system is part of the MCS and uses the same database. MCSG uses Motorola platforms and writes its own software for the manufacturing FCS. The system is Unix based. Not all of its CASE tools are ported to the Motorola platforms. Therefore, many CASE tools are not available. The result of MCSG efforts thus far is a decrease in the cycle time from five weeks to one week.

The machine programs controlling the production lines on the factory floor can be changed in hours. MCSG production lines are set up for producing 250 different kinds of boards in lot sizes of 10. They are able to produce 600 to 800 boards per day using 2 shifts.

MCSG uses a Contracting Book. This is a document of contracting specifications that includes ordering, manufacturing, and delivery agreements. Once the details of the agreement have been negotiated and settled, the terms serve as a contract for all the players, both internal and external. The Contracting Book will be converted to electronic format.

Cellular Subscriber Group uses simulations to optimize manufacturing. By identifying machines that were not needed, the simulations have saved millions of dollars. This has resulted in a 10% improvement in operations on the manufacturing floor.

Information Infrastructure:

The legacy database currently in use at MCSG is being moved to a relational database.

Issues and Barriers:

CAD tool integration has been a problem. The issue is whether the tool is Unix or IBM based.

The next step in the vision is to somehow solve the problem of rapidly changing operating systems and platforms. MCSC spends 40 to 50% of its operating budget to keep up with rapidly changing technologies.

When the Cellular Subscriber Group was started as an independent operation, it was directed to use Motorola products in the cellular phone product. Since Motorola divisions operate autonomously, dealing with other divisions in the company sometimes resembles dealing with an outside company.

E.7 MOTOROLA CORPORATE

Description of the Business:

Motorola Corporation is a leading provider of electronic equipment, systems, components and services for world-wide markets. Products include two-way radios, pagers, cellular telephone systems, semiconductors, defense and aerospace electronics, automotive and industrial electronic equipment, computers, data communications, and information processing and handling equipment.

This visit concentrated on the views of Motorola Corporate Headquarters regarding enterprise integration company wide.

Industry 1991:

Business Strategy:

Divisions within Motorola are very autonomous with regard to both their management and direction, as well as their finances. The belief is that smaller groups can be more responsive to changing markets and technologies.

The feeling at Motorola Corporate is that historically Motorola did not need to integrate. The business was generating a profit and seemed responsive to changing markets. The payback for the investment required for enterprise integration was not clear. The payback is now clear however. By implementing enterprise integration, greater economies of scale can be achieved. Previously, the Semiconductor Products Sector Group and Corporate Staff were pursuing integration as separate entities, whereas now they collaborate.

The integration of the electronic mail systems was proposed to save money. Motorola did not know how much it would save, but they were confident the savings would be significant. It now looks like it is saving more than they expected.

State of Integration:

Currently four separate customer order fulfillment (COF) projects are ongoing at Motorola Corporate. This is because everyone thinks their problem is unique. Corporate currently supports 19 to 21 major platforms.

An electronic mail application is the first enterprise integration project to be attempted at Motorola Corporate. Electronic mail is currently running as an enterprise utility. The goal is to move from a centralized "post" system to a distributed system. The entire electronic mail problem stems from the divisional autonomy. Motorola has teamed with two customers/suppliers (DEC and IBM) to complete the electronic mail project. DEC will provide the platforms.

The Information Technology Management Group is also planning a roadmap for enterprise integration. The plan is not fully in place yet. But with a goal of a wall-less work space, the group is beginning with office data and documents (e.g., spreadsheets). It is not yet considering engineering information at all, as it is believed to be a much harder problem.

Motorola has data and a case history showing decreased costs and a 50% decrease in cycle time resulting from enterprise integration. These figures all relate to integrated circuit production.

Motorola has reduced the time required to produce sales catalogs from two weeks to being able to produce them in real time.

Integration Strategies:

The electronic mail system is inappropriate for the transfer of engineering data to manufacturing. Electronic mail has a size limit of one to two megabytes. Therefore, EDI will be used to move large files. A translation system will make application-to-application communication possible. A process model for the approval process is proposed. Data will reside in a data warehouse or knowledge repository. The entire system will move from a mainframe to smaller computers.

The Motorola Corporate vision is a "wall-less work space" where desk-to-desk video conferencing and co-development among engineers is supported. It is moving toward this vision of enterprise integration with a five-year plan.

The Corporate view of information communication is a global one that includes vendors and suppliers. The exact percentage of its parts that are outsourced was not specified, but 80% of those parts are produced by 20% of its vendors. Motorola wants to establish lifetime relationships with its vendors. This relationship includes the extension of the Corporate philosophy of Six Sigma quality goals to include the vendors. Motorola outsources primarily for production rather than for engineering work.

The enterprise integration strategy at Motorola Corporate Headquarters is to provide corporate leadership in the form of a seven-member team to coordinate information sharing. The view is that Motorola Corporate Staff can not afford to do small projects, that it must leverage off existing work and undertake major projects. However, this perception is not supported by the current approach to integration. For example, the four small COF projects would appear to contradict this.

Information Infrastructures:

The enterprise integration work is process model based. Tables are used to drive the code. Motorola has incorporated an object-oriented paradigm due to a belief that it will support change more readily. Unfortunately, the code being developed by subcontractors and consultants embeds the model and will be expensive to change should the model change

Motorola is running many different CAD systems, primarily due to the different platforms they support. A data warehouse is used by engineers and management currently. EDI is supported.

MOTOROLA PAGING PRODUCTS GROUP

Des iption of the Business:

This division of Motorola designs and manufactures a line of pager devices.

Industry 1991:

State of Integration:

Management at Motorola Paging Products Group of the Motorola Paging Division (MPD) believes that enterprise integration will support its goal of Six Sigma Quality. Integration has allowed them to begin tracking errors using bar codes. Thus, they have eliminated some of the paper previously associated with the manufacturing process. Information integration now supports a more advanced approach to controlling the production process. The goal is total defect elimination in all its factory and office processes. Shipping, ordering, manufacturing, and invoicing are all included in the integrated process plan. Motorola Paging Products Group is asking its preferred suppliers to make a commitment to quality and cycle time performance to support their objectives.

The Bandit product line was started six years ago. Speedy is a rebirth of Bandit. On the Speedy product line, a significant amount of software, hardware, and people were reused, resulting in a very steep learning curve. Significant decreases in the cycle time were achieved.

Some suppliers have been included with EDI. This is a test program, however. Some customers who provide a substantial volume are connected on-line with systems in-house for direct order capability.

EDI is critical to strengthen U.S. industry. The EDI effort at Motorola Paging Products Group is on schedule. MPD purchases a service from GE to translate EDI between Motorola Paging Products Group and its suppliers.

Currently all the divisions contribute to "schedule sharing." In this system, electronic schedules are passed up to corporate. The schedule is very detailed, including information to the supplier level. Schedule sharing gives you an average schedule. Some suppliers however prefer exact MRP data. The system gives suppliers 26-week visibility on orders.

Integration Strategies:

The ultimate goal at Motorola Paging Products Group is to be able to build any product on any line. Integrating design with CIM is currently the weakest link at MPD. They are hoping to integrate these two areas within one year.

In a move toward enterprise integration, the Management of Information Systems (MIS) and Software Engineering (SE) groups were combined. Previously, MIS had provided the business system support, and SE had provided the software tools and support. Enterprise integration would require a significant amount of new software bridging existing applications, replacing existing applications and adding new ones. The expertise of both groups would be needed. This reorganization created a culture clash that eventually sorted itself out primarily through attrition.

Motorola Paging Products Group places a great emphasis on partnerships with suppliers. A goal of a 50% decrease in the supplier base was set in 1987. The Group would like to receive daily shipments from the suppliers. The factory currently runs at seven turns per year. The goal is 30 turns per year.

Two engineers are currently assigned to coordinate with the suppliers. Eventually, the goal is to co-locate people.—that is, a supplier on site or an MPD engineer at the supplier site.

CIM data is collected and used on the production line. The philosophy is that only "useful, timely" data be available on the factory floor. Not necessarily all data is useful in real time. Statistical Process Control (SPC) data is on line and available in real-time.

Warranty data comes in every two weeks. It is provided to engineering and is coupled to defects per unit (DPU) data. Engineering and manufacturing would prefer to simply use DPU; however, several types of errors would not be caught this way.

Information Infrastructure:

All integration applications are built in-house. Integrating commercial-off-the-shelf (COTS) products is seen as too expensive and too much work. However, statistical analysis tools have been bought and are now being integrated.

MRP still exists in a legacy database at Motorola Paging Products Group. It will phase out legacy databases by migrating to a new relational database over time.

Industry 2001:

Issues and Barriers:

Every product off the production line is unique. This presents unique problems for automation and information integration. In addition, some customers change the information provided to Motorola Paging Division, such as the order, ship date, or ship location, frequently and often at the last minute.

Managers at the MPD do not see technology as the barrier to enterprise integration. The barrier is the lack of widely accepted standards around which to architect their systems. As a customer, they feel it is difficult to pressure vendors to provide the right products.

A high-level visionary within Motorola presented the goal of a lights-out factory to the CEO. The company tried it. That experience has taught it a great deal. For the current information integration effort, Motorola did not begin with a lengthy statistics collection process. The feeling was that you never know enough up front to justify a goal or vision of the future, so you must just proceed.

Motorola has a Model Factory Project. It came out of the CEO office at Corporate. Cooperation would increase as a result. However, Corporate sees autonomous divisions as being important entrepreneurs and has not pushed this concept.

Cultural resistance to enterprise integration was great at first. The pockets of resistance changed as the integration process has progressed. The goal is to simplify, automate, and decrease costs, using the savings to push the process forward.

Motorola Paging Products Group does technology roadmaps to monitor emerging technologies. This should enhance the results of an integration effort.

E.9 NATIONAL SEMICONDUCTOR

Description of the Business:

National Semiconductor designs, manufactures, and markets high-performance semiconductor products. Headquartered in Santa Clara, California, the company's major market focuses include analog-intensive and communication-intensive products.

Industry 1991:

Business Strategy:

National Semiconductor has instituted a restructuring plan that will allow the company to consolidate its underutilized manufacturing capacity while it upgrades its continuing operations and improves their utilization. These changes are beginning to have an effect. The company anticipates relatively slow revenue growth over the next few years, but sees further operating advances helping to build a lean manufacturing base.

National Semiconductor's investment plans include investing in technologies and tools that will support its enterprise integration efforts. In the resulting environment, transaction-based activities will be highly automated (almost rule based). National Semiconductor hopes to decrease costs and increase productivity by automating the mechanics of doing business and simplifying the strategic controls of the business.

Service objectives are the primary goal of National Semiconductor. The motto is "service second to none." National Semiconductor wants to provide on-line, real-time delivery schedules. The goal is not an manufacturing resource planning (MRP) approach but rather to monitor the process in real-time, with re-planning done every day.

State of Integration:

In 1984 service problems peaked, and management information system (MIS) was not perceived as part of the solution. Representatives from MIS met with Planning to convince them that MIS would improve the service level. With focus from the Director level, a cross-functional group was assembled to implement the plan.

The ASPC project (Automated Semiconductor Planning and Control System) represents an effort to improve the planning phase of the chip manufacturing process. The goal is to optimize the manufacturing schedule based on major order placement. The schedule would be confirmed continuously. The foundation of the system is implemented.

About 7% of the items in their inventory are currently automatically scheduled for loading to the factory floor. Fifty percent of the components in special products are automatically loaded to the factory floor. By doing automated factory loading, costs are decreased.

The normal cycle time for a product is 26 weeks. This includes wafer fabrication, electrical test, sort, assembly, and final test. However, the assembly and final test are conducted in southeast Asia. A major management review of the process flow of 24 chips led to a 20 to 30% reduction in cycle time.

Automation and integration of manufacturing processes requires predictability. The fabrication and sort phases of the process are never predictable, but the assembly and test portions are. Therefore, the assembly and test phases are currently integrated. The fabrication and sort phases are only in the very early stages of automation. This integration effort is succeeding due to a high-level champion. Success of this project has meant having to align the factory CIM (computer-integrated manufacturing) goals with the rest of the company.

ASPC 2.0 has continued to build on the initial results of the ASPC project. Upper management was committed to the effort. The engineering level and operations in the factory were working the problem. However, the middle managers saw themselves as being "challenged." Their goals needed to be realigned and their jobs changed to make the project successful. Planning against future resources was automated. In the pilot implementation, this resulted in seven million pre-planned resources, with 1,000 manufacturing orders, two million die starts, and on-time performance of 98% (and 100% for target accounts). On-time performance was 80 to 85% before the implementation of the system. Previously, material was loaded to the factory two weeks too early, resulting in an inventory build-up. Now even loading occurs. Early loading can be planned, however, on specific orders when this is desirable.

The process of planning and scheduling the orders at the factory is unpopular for automation. There is concern that inventory will build up. Instead, the preferred approach is to dump the automated order data to a report and get a human in the loop to review the report and tweak the factory by placing orders manually. This manual ordering was found to have only a slight negative effect on automated ordering.

PDS (Product Definition System) is a Bill of Materials (BOM) for parts produced at National Semiconductor. PDS supplies an assembly document and a routing structure which describes the set of manufacturing steps for each part. One of the problems encountered at National Semiconductor was a lack of a common nomenclature for the parts produced.

Integration Strategies:

There is a corporate strategy and consensus on the systems integration element of the enterprise integration process. Initially, the *not invented here* (NIH) syndrome was strong. The mechanism found to succeed is to engage the assistance of a power champion. Corporate culture is changing, requiring many of the same changes that are required for the Non-Stop Quality effort. The goal is to drive power and decision making down in the corporation. The business group presidents are driving the effort. The executive vice presidents own the major processes. In some cases time-to-market has been reduced from two years to nine months.

National Semiconductor sees a management commitment and alignment of goals and objectives as being critical to project success. Upper management support is required to implement change.

It sees major changes required in communications, data management, processes, metrics gathering, and implementation activities to achieve enterprise integration.

Sales and marketing integration is driven by corporate-level customer service. Planning integration is driven by the head of Planning (via APCS with PDS). Factory integration is driven by the Vice President of Manufacturing. In some cases the changes have been motivated by quantitative goals, but in other cases they have been motivated by intuitive appeal.

National Semiconductor produces parts that are more complex than parts produced for the commercial sector. Further, the processes involved in manufacturing these parts are slightly different.

Information Infrastructure:

National Semiconductor is currently using CVS (Central Version System) which runs IDMS. With the acquisition of Fairchild Semiconductor, there are legacy systems that will have to be addressed during the integration of the enterprise.

National Semiconductor is on the American National Standards Institute Electronic Data Interchange (ANSI EDI) committee. Sixty to seventy percent of its orders come in EDI.

Industry 2001:

Issues and Barriers:

A unique problem facing National Semiconductor is the world-wide factory distribution problem. National Semiconductor must have a "cutoff" to synchronize the factories around the world. It must get the other factories to stop at the end of a California workday to do backups and synchronize planning for the next day.

E.10 NeXT COMPUTER, INC.

Description of the Business:

Designs and manufactures workstations and their operating and application software.

Industry 1991:

Business Strategy:

NeXT Computer, Inc., believes that the cost drivers in the workstation market are time-to-market, quality, and flexibility. It has placed greater emphasis on optimizing these factors throughout its organization. However, automated manufacturing was identified as playing a key role in achieving a competitive advantage.

In examining the manufacturing phase of the product development cycle, NeXT estimated that offshore manufacturing causes a three- to six-month delay in time-to-market. To eliminate this delay, NeXT built its manufacturing facility next to the research and development (R&D) center.

A strong emphasis was placed on retaining highly qualified workers. As a result, 70% of NeXT CIM (computer-integrated manufacturing) and management staff have advanced degrees. Increased factory floor automation has meant that fewer people are required to run the production line. Currently six to eight people run the entire line. The eventual goal is two shifts (12 to 14 people). These individuals are fully cross-trained to operate other stations on the line.

State of Integration:

NeXT currently supports integrated manufacturing. It operates a continuous manufacturing process. That is, once manufacturing starts and parts go down the line, the production line is not stopped. It currently takes 20 minutes to build a board with approximately 1,400 to 1,500 components on the line. It takes one hour to build the entire workstation product.

Board assembly defect rates are very low due to continuous process control. At one competitor the yield or surface mount defect rate is 800 per million. At NeXT the yield is 40 per million.

Inventory storage and transportation costs can be high. This fact motivates NeXT to maintain an exceptionally low inventory. The manufacturing facility then serves as the warehouse for the inventory.

As an example of the success of this approach to product development, Next was able to go from concept to shipping in 11 months, beating the next best competitor by 5 months.

NeXT believes that enterprise integration provides significant savings over the typical "islands of automation" approach to product development. NeXT projects a factor of 15 to 20 improvement in productivity, measured in sales per manufacturing touch labor, versus the benchmark of a typical manufacturer.

Integration Strategies:

NeXT developed a strategy for CIM by surveying the leading domestic electronic and computer manufacturers. The strategy was based on the following:

- Strive for a single-layer architecture.
- Create object-oriented software tools to eliminate non-value-added CIM work.
- Develop quality control systems based on real-time access to all data.

NeXT stresses flexibility. Hardware designers participate during manufacturing start-up. They observe and participate in tweaking the process. Manufacturing engineers provide feedback to design engineers on manufacturability and part reliability and availability.

One strategy that NeXT uses to ensure manufacturability is an "approved parts list." Designers select from that list to assure quality, reliability, and that the package is consistent with the manufacturing process. Manufacturing is responsible for developing the parts list, based on knowledge from the factory floor. Manufacturing also monitors designs for compliance. During the design of the first product, manufacturing vetoed 35 components selected by designers.

Rapid prototyping is done on the factory floor using the production line rather than in a lab. Thus, R&D must come to the factory to watch the design being built. In this way design engineers work with manufacturing engineers to develop the product and the manufacturing process.

Information Infrastructure:

All corporate information, including inventory, orders, and manufacturing and design data, is integrated and available world-wide to any user on any computer. The data may take the form of text, graphics, audio, or applications.

A heterogenous mix of systems has been integrated where appropriate. The management information system (MIS) databases are hosted on a Sequent Unix-based machine that is optimized for database transactions. Printed circuit boards (PCB) computer-aided design (CAD) is done on Apollo workstations. Mechanical CAD is done on Hewlett-Packard (HP) workstations. The CIM users work from NeXT workstations.

NeXT uses a CAD system for not only design but also to control and program the factory robots. An example of the integration between R&D and manufacturing, an application called MENTRANS (MENTOR CAD Translator), is used to convert PCB files on a CAD system to optimized programs for the inspection and pick-and-place machines on the manufacturing floor. This application can convert a one megabyte file of CAD data to a machine program in a few seconds. The programs are then optimized for placement cycle time and machine wear within three or four minutes.

E.11 TEKTRONIX, INC.

Description of the Business:

Tektronix, Inc., initially established its reputation in oscilloscopes. The company diversified into new products and markets in the early 1970s. Today, Tektronix has three primary product categories: Test & Measurement, Television Systems, and Computer Graphics.

Industry 1991:

State of Integration:

About 10 years ago a study was done of the product design processes of Tek's customers. The goal was to understand an expanded role for oscilloscopes in computer engineering. The surprising conclusion was that the computer companies were more integrated than Tektronix in their own engineering and manufacturing. Momentum for the CAX Center emerged from the study (CAX = Computer Aided everything, X is a variable).

Tek's strategy has been to replace paper transfer with translators and electronic file transfer. In the past each Division or Group has made its own acquisition decisions and there was a tremendous diversity of adoptions. The CAX Center has built translators and so forth to enable integration with multiple diverse tools. The first level of integration is represented by the following stream model for mechanical design (Figure E-2).

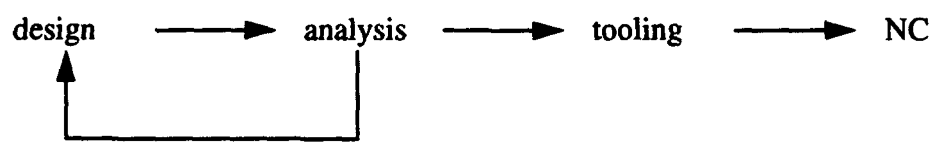

Figure E-2. Mechanical Design Stream Model

Tektronix is at this level of integration today in all disciplines. The same stream model exists for each discipline (mechanical, documentation, software, circuit, printed circuit board (PCB)), but there is very little crosstalk between the disciplines. PCB has both geometry and electrical, and it transfers geometry via IGES (Initial Graphics Exchange Specification). Documentation is the biggest opportunity for crosstalk, and it may succeed because of the CALS (Computer-Aided Acquisition and Logistics Support) model.

The Mechanical Computer-Aided Engineering (MCAE) program integrated the MCAE tools with the model shops, largely by replacing paper drawings with electronic drawings and automating prototyping operations. The program reduced cycle time from design to prototype with no increased operating expense.

The Computer-Aided Design - Computer-Aided Manufacturing (CAD-CAM) Link deals with PCB design translations. There is potentially a sequence of target machines, for example, depending on whether the PCB is through hole or surface mount, or because specific component part numbers may be allocated to specific machines. In addition, the component insertion sequence (the snake path) must be prepared for each board. This was first automated with a point-and-click interface, but now it is algorithmic.

The system uses an intermediate format with one translator from each PCB design system to the intermediate format and one translator from the intermediate format to each type of NC (numerical control) machine. The system also deals with documentation and a color report display for operators. In a procedural, operational system, the human aspect must be tended to.

The Engineering Master System stores the parts information, including geometry of footprints, for all Tek parts. The master copy of the parts database is kept in a relational database in the CAX center. ASCII files containing the data are exported to every Division within the company. Every day that there is a change or addition to the database, new ASCII files are downloaded automatically overnight. ASCII is the exported form because it retains the file format of the predecessor legacy system. Some groups now re-import the ASCII data into relational databases of their own, such as SQL/DB and FoxBase.

The Test and Measurement Documentation system does printing on demand for all manuals. The manual set to accompany an order is printed from the order's BOM (bill of materials) by selecting chapters that reflect exactly the options ordered. Printing the parts catalogue extracts data from databases so that each time a catalogue is printed, it is "automatically" up to date.

Engineering Change Order (ECO) processing and support are divisionalized. The ECO process is relatively paper based. There is an Interleaf add-on that writes into the ECO database when an ECO document is created.

At one time there existed a Reliability Information Systems Group. Failing boards were shipped to the central board repair facility and records of component failure were placed into a database. The Field Service Operation was one of the last to be divisionalized. The reliability database was sliced up. Some data was transferred to the Test & Measurement Group, and some was lost.

Integration Strategies:

Tektronix is poised to adopt common CAD/CAM throughout the corporation. It will adopt a single system for each of PCB, CAM, Software Engineering, Technical Documentation, and Product Data Management.

The initiative is coming from the CEO who feels that the benefits of uniform tools, including reduced training and support expenses, outweigh the costs of displacing legacy systems.

Common platforms and tools ease integration. Tek is going to pick one preferred platform, or at least one for each discipline. Sun is preferred for CASE (computer-aided software engineering). Tek will select a few preferred vendors, striving to minimize porting and diversity overhead. Tek will standardize on one operating system and on one interface (X windows).

The current stream integration model will be superceded. The second level of integration is to establish a common database used by all tools in a design discipline (Figure E-3):

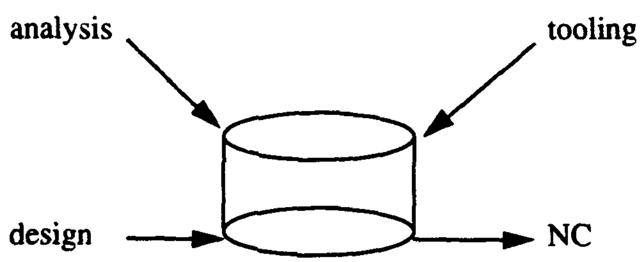

Figure E-3. Common Database

The database would provide multiple views of the data including shadowed data, hidden data, and orthographic data.

For legacy systems, Tek is following a displacement strategy. It is being done on a product line by product line basis to avoid using both a legacy system and a new system in a single product, thus minimizing the integration problem. To satisfy maintainability requirements, Tek will keep "one of" each legacy system in the CAX center or in the using division.

The Engineering Master System will be replaced by a data warehouse. Tek will convert the parts data first and then build a catalog system.

Information Infrastructure:

A coherent network is helpful. Tek uses TCP/IP (Transmission Control Protocol/Internet Protocol) and DECNet; the IBM mainframe is the last bastion of hard-to-access data.

Tek uses relational databases although they are less used than they could be. The databases used in the company for product information range from Paradox DB on personal computers to SQL/DB on the IBM mainframe.

Standard formats are needed. IGES is used in mechanical, from design to fab. IGES cannot transfer 100% of the design data, but the important stuff gets through.

For the CAD-CAM Link, Tek chose to use Mitron's IDF (Integrated Data Format) as a neutral drafting format. The IDF data only contains connectivity and XY placement information. The geometry for parts is added from the parts database.

Lessons Learned:

Top-down sponsorship is needed to succeed; otherwise there is too much resistance at the operational level.

In the mid-1980s there existed about a half-dozen little integration groups in Divisions. After two or three years those groups didn't persist (due to budget reductions or personnel transfers). Without support, the systems disappeared. This approach was not general enough. The CAX Center has prospered because it was a general corporate approach to the problem with continuity of personnel and management support.

Tool specialists are needed to do integration and tool support staff. The support person provides the user point-of-view and feedback. This make a good combination and has been highly productive.

The availability of formats from CAD vendors (whether supported standards or open proprietary formats) eases integration. Data from the successful CAD companies are more available than the data from the less successful companies.

It is crucial to train and/or recruit local people (in the operating divisions) to support the integrated system. When installed where there were zero local owners, problems occurred and band-aids were needed. When installed where there were at least two local owners, there was always a success story

Regarding object-oriented technology: object-oriented databases do not have a common data model (as relational systems do). Tek has used Smalltalk internally to develop some analog tools. They were developed very fast and have acceptable performance.

There were some integrity problems with the Engineering Master System in the past. One problem was the lack of common spelling for certain attribute values. Originally the attributes were character strings. One problem was that values would be entered with spelling or typing errors and would not match correct retrieval keys. Another problem was that incorrect values would be entered. The solution was to replace strings with enumerated attributes (such as *enum RAM, ROM*, etc.). This ensured that values were valid members of the domain into which they were being entered since only identifiers in the enumerated list were accepted. However, there is a need for parametric attributes (e.g., 8-bit, 16-bit, 32-bit BUS, or 1 Mbyte, 4 Mbyte, or 16 Mbyte RAM). The enum work has not been extended to parametric attributes.

Industry 2001:

Future Information Infrastructure:

TV products have so many options that each product is almost a custom product. Tek is developing a downstream tracking system by serial number that will reflect the as-built configuration of each unit. This future system will support field maintenance by giving module replacement compatibility with new modules.

E.12 TEXAS INSTRUMENTS (TI)

Description of the Business:

Designer and manufacturer of semiconductor products and devices using those products.

Industry 1991:

Business Strategy:

TI used a combination of various business case justifications for its enterprise integration plan. These justifications included cost-benefit analyses and an approximate return-on-investment (ROI) calculation. Changing to a client server model will be critical in driving down business costs. The percentage of expenditures required to provide services drives the business case for enterprise integration. TI will attempt to merge this with information on technology costs. But managers at Texas Instruments acknowledge that these analyses were not rigorous and that the justification was based at least partially on intuition and gut level feeling that enterprise integration was the right thing to do.

State of Integration:

The Information Systems and Services Group within the Information Technology group has been responsible for centralizing corporate-level services like electronic mail. The electronic mail system uses X.400 to provide external connectivity and handles 250,000 messages per day.

Information Engineering Facility (IEF) is being used for business applications. It is a fully integrated computer-aided software engineering (CASE) tool based on the James Martin methodology.The premise is that all the information generated in the life cycle of a product will be maintained in the IEF Encyclopedia. IEF provides several integrated tools including the following:

- Planning Toolset for top-level managers
- Analysis Toolset for end-users
- Design Toolset for end-users and data processing professionals
- Construction Toolset that produces machine code

IEF runs DB2 -based business applications. Interfacing with non-DB2 applications is difficult. The goal is for Texas Instruments to increase the number of business applications on IEF from 9 to 60%. The plans do not call for TI to move away from the information management system (IMS) completely, and to support an object-oriented environment with IEF in five years.

Currently, electronic data interchange (EDI) occurs with approximately 40 to 50% of the customers for the semiconductor group. All the electronic order and payment information migrates to a mainframe. A human picks up the order information and plans and schedules the manufacture of the product. Currently, some information must be manually re-entered. TI recognizes that these islands of automation are inefficient and costly.

TI is working on just-in-time (JIT) delivery from suppliers. The enterprise integration plan includes JIT for their production lines.

TI has an electronic payment scenario using DECASS.

TI is trying to develop a programmable factory. Today, almost no process control is done. Operators are not trained how to use the data from the machines for Statistical Process Control (SPC). Only after the fact analysis is done. One problem is that multiple translations are required due to the use of mainframes, operator consoles, and machine controllers. TI is working to implement automatic process machine control. The system will include a dynamic scheduler that will monitor work in progress and advise the operators.

Integration Strategies:

TI has a goal of enterprise integration within the next three to five years. The enterprise integration plans include transitioning from an IBM mainframe-based Data Vault to a client-server architecture. After removing all local site mainframes, the business applications will be hosted on a "mega center." All the sites will be connected as clients. TI is currently in the process of deciding which applications will be located at the mega center and which will be located at client nodes. The concept of "brilliant machines" where there is interaction and feedback between a machine and its schedule is being pursued.

The Microelectronics Science and Technology (MMST) project will develop a factory architecture applicable to "mega fabs," allowing queues of up to 200 lots and not just "mini fabs" allowing low-volume ASIC (application-specific integrated circuit) production. The work will center around integrating commercial equipment, building only what cannot be purchased and conforming to standards. The project will use a fully distributed, object-oriented database.

TI is developing an order entry system, TIES (Tooling and Information System), that will allow a customer and mask vendor to exchange information electronically. This should save $380,000 in labor costs. TIES will also decrease the number of errors generated during order entry. TI estimates that errors cost $100,000 each.

TIES will include both IMS and CAD (computer-aided design) data. Until now, the trend has been to move CAD data into IMS. However, engineers prefer to work on workstations. So by moving the CAD data out of IMS, TI will eliminate the need for a host mainframe computer. The goal is to network several separate systems. TI has not attempted to distribute the database. Instead, a single centralized database accessible world-wide will be used. This makes the communication network critical. This is still an area of concern for TI. The Data Archival and Retrieval (DART) component of TIES will provide the data storage facilities.

TIES will be implemented in three phases:

- Phase 1 will include an Oracle database with DART indexes to access archival data. Falcon will be used for the user interface and data collection.
- Phase 2 will use an Oracle database for TIES indexes. This database will provide pointers to data stored in DART as well as pointers to internal data. The DART storage system and database will be used for all other data.
- Phase 3 will provide a unified database with file, relation, and object-oriented database capabilities for both TIES and DART.

Some of the benefits of the DART system include permanent storage of mask and reticle instructions and graphics. The system will eliminate the need for paper processing and will help eliminate order errors.

TI has selected the Falcon as the user interface and for data collection for TIES. It is now developing a standard format for purchase and mask orders. One benefit of electronic order formats will be that Japanese customers will be able to convert the information to and from Kanji more readily than when the information was exchanged in paper form. TI is now developing a first cut at the user interface for the order forms. Eighty percent of the orders received by TI are simply modifications of previous orders. One goal for the new system is introduce the use of electronic signature for approval. The system will check for this electronic sign-off before allowing wafer fabrication to proceed.

The Product Drawing Control System (PDCS) project is a prototype system to support on-line creation, editing, sign-off, and distribution of engineering drawings. Ninety percent of the engineering drawings produced at TI are in a CAD system. Over 4,000 drawings exist. This prototype supports Autocad, CV, CAD System Development (a native CAD file), and plot files. However, sign-off still requires a paper copy. Another utility allows engineers to red line drawings electronically by annotating plot files. TI is experimenting with putting a plotter and workstation at subcontractor sites and electronically sharing engineering data. Of the 1,000 vendors working with TI, less than 10 vendors currently have such a capability in place. However, this system is raising many issues associated with having a softcopy system. For instance, are the available personal computer graphics systems adequate for inspectors on the factory floor, and does the zoom capability (D-size drawings are unreadable) lose the context? The question is, is PCDS an effective mechanism for drawing distribution? The system does decrease the time to copy and the time to drawing release.

TI would like to provide a hypertext information system with archival capabilities to vendors. Such a system will go into beta test in March 1992.

TI recognizes the need for electronic data book and terminology standards. Suppliers of components do not want to provide electronic data files. The cost is too high. EDI is has become too expensive because the workers who provided the services pre-EDI have been retained. Currently, data books cost $10 million per year to produce. The books may contain 30,000 pages and 18 different product families. They provide software support guides, hardware development guides, user guides, and training materials. Electronic data books could save a significant amount of money.

TI is attempting to decrease the number of business models in use. It currently has between 70 and 120 models, 25 or 30 of which are foundational models. The goal is to reduce the number to 12 to 14 models. They are working to put the foundational pieces, those common to customers, employees and the organization, in place. The rest of the system will be built on top of these pieces.

There are currently 95 applications that assess the customer IMS. This would have required 95 models. Instead, a shared model will be developed. The IEF reporting capability has allowed TI to uncover duplication and redundancies like this.

Another example of the model redundancy is the part number system. Several separate systems currently exist within the company. By reducing this to a single model, TI will also change the way it does business. TI is seeking to encourage data stewardship rather than data ownership. First-level managers with profit and loss responsibility have been the most reluctant so far.

TI will be CALS (Computer-Aided Acquisition and Logistics Support) compliant, but is not looking to be a leader in this area. In the past TI has automated everything, sometimes resulting in being able to do the wrong things faster. Now it is re-engineering processes before considering automating them.

Information Infrastructure:

An IBM mainframe is currently used to control planning, shipping, and marketing information. Information about the fabrication process is saved in lot log points for work in progress tracking.

TI considers frameworks to be a major opportunity in integrating the enterprise. The DART system has selected Falcon. However, Falcon is not Motif based. This conflicts with other system decisions that have been made. Since TI has found it very difficult to integrate existing databases, it requires a framework that supports both relational and object-oriented databases. Further, the framework must be platform independent and support X Windows as well.

Industry 2001:

Issues and Barriers:

TI sees too many competing standards and consortia efforts. It is supporting IRDS (the Information Resource System Dictionary) and OSF (Open Software Forum).

TI does not see technology as being a barrier to enterprise integration. Rather, the cultural issues tend to be a bigger problem. TI has typically encouraged individualism and innovation. Now very capable engineers are being asked to allow someone else to make major decisions regarding how the new system will work and how the engineers will do their jobs. TI found that because of this, developing grass roots support and winning over the engineers were critical to the success of the integration effort. A common vision is necessary to arrive at a solution.

Within TI, individual business units have a great deal of operational autonomy in that they may have their own legal, computer, or other services. Thus, corporate groups providing central services have to become the "vendor of choice" to the rest of the company. This provides tremendous incentives for optimizing the operation.

The current automated environment is so integrated that they cannot respond to changes. TI management sees the goal of decentralizing the topology as one solution to this problem. The vice president of the ICS group is driving the decentralization effort. This high-level support should facilitate and speed the process.

Technology turnover is occurring very fast. TI finds it very hard to optimize their manufacturing practices to any degree. TI has focused on developing a new stable process flow for manufacturing. Time-to-market (TTM) is critical. Eighty percent of the profits are made in the first twelve months a product is on the market. Companies who enter the market after that merely supply products—they do not make a profit.

E.13 WESTINGHOUSE ELECTRONIC SYSTEMS GROUP

Description of the Business:

Westinghouse Electric Corporation focuses on seven basic business segments: Environmental Systems, The Knoll Group (furniture), Electronic Systems, Power Systems, Industries, Broadcasting and Financial Services. The Electronic Systems Group (ESG) supplies advanced electronic systems to the Department of Defense (DoD) and markets related commercial products. ESG products range from radar to electric vehicles.

Industry 1991:

Business Strategy:

ESG is moving to expand in commercial markets that are complementary to its defense business base, markets such as air traffic control, home security, aircraft power generation, and drug traffic interdiction. The defense market segment will be flat or down for the first half of the 1990s, but non-DoD markets are expected to grow 15 to 20% a year. About 33% of ESG products are commercial.

Westinghouse is seeking to leverage ManTech and IMIP funding to achieve a computer-integrated enterprise (CIE). It is also trying to get Westinghouse partners to adopt its view.

State of Integration:

An ESG process model has been developed. ESG critical success factors were used to set the context for process modeling. The modeling effort reports to a high-level steering committee; this committee checks the process modeling reports for consistency with filter-up information.

In the modeling process, people from the affected areas contributed, including customers and suppliers. The activity proceeded from identifying functions to subfunctions to processes. In manufacturing 504 processes were identified. All told, the effort identified 998 processes in 260 systems. There were 356 information entities, of which 218 occurred redundantly.

From the process model they applied affinity analysis to determine subjects; each subject had a single source of data in enterprise databases. ESG is using the Information Engineering Facility (IEF) which captures third normal form data and constraints as "design objects." The process enables ESG to model data components. Constraints add behavior. A process may have to launch another process.

The Westinghouse Integrated Systems Environment (WISE) manages the life cycle for Parts. The electronic vault satisfies CALS (Computer-Aided Acquisition and Logistics Support). During design, the responsible designer controls the design data; upon release, the vault controls the data. WISE provides recognition of the source of documents and control of documents, including paper.

The Electronic Assembly Plant in College Station, Texas, has been in operation since 1983. The CIM (computer-integrated manufacturing) system acquires design data and transforms it into machine control data. A Standard Electronic Assembly System (SEAS) controls a workcell consisting of an component insertion robot, an inspection station, and a computer-aided miscellaneous operations station (where SEAS directs operator assembly of components not suited for automated assembly).

Integration Strategies:

ESG began an enterprise integration project in 1986. The major steps are to develop the "as is" process model, to combine the process model with business directions and develop a future enterprise process model, and then define the implementation roadmap to achieve this target. In this process ESG will develop an Enterprise Business Model, an Enterprise Information Model, and an Operations System Blueprint.

Drivers for enterprise integration include competition, regulations, and initiatives. Competitive factors include time-to-market. Initiatives include concurrent engineering, CALS and ESG's Total Quality Strategy. ESG is trying to tie concurrent engineering and CALS together in a way that makes sense.

ESG is flattening the management tree. Top management is working more closely together. Interdependencies are stronger than had been with historical matrix management. A manager's span of control is increasing.

ESG's Total Quality Strategy addresses yield improvement, consolidation and standardization, coupling engineering and manufacturing, and strategic sourcing

Currently, about 1,000 companies contribute to an ESG product, but ESG is trying to reduce the number of suppliers. For example, formerly 400 machined parts suppliers have been reduced to 40. Consider both production and logistics (P&L) and investment strategies in out-sourcing decisions. Integrate at any site.

Enterprise integration will enable information to flow faster to places that can utilize it. Enterprise integration facilitates individuals working together, fostering communication over space and time. The implementation strategy includes a Unix client-server network connecting multiple computer platforms and an integrated CASE (computer-aided software engineering) development environment.

WISE provides the infrastructure for integration. In WISE there is no charge for Vault space. If there was, individual program offices might reject using the Vault because of cost.

The Advanced Quality Engineering System (AQES) is being developed to apply rule-based expert systems, process capability databases, voice data entry, computer vision-based solder joint inspection, and other technologies in an integrated strategy to improve non-manufacturing and manufacturing activities in the circuit card product life cycle.

Information Infrastructure:

In machining suppliers, ESG has set up equipment for digital data transfer (using electronic data interchange (EDI)) and has trained the vendors. These are vendors for whom ESG is the sole major customer, so they would accept ESG's operating procedures.

The Common Business Systems Library is a DB2 database and it will migrate to the IEF database over time. This will imply a transition from database design to object design. The IEF system generates code, leading to reduced maintenance.

WISE involves a distributed network, relational database, electronic vault, and imaging for advance documentation management. Cost data is presented as approximate costs based on a rolling average of actual costs.

There are five kinds of networks: (1) Apollo (TCP/IP, Transmission Control Protocol/Internet Protocol)), (2) Sun (TCP/IP), (3) NetBios, (4) SNA (Systems Network Architecture) and (5) DECNet.

The standard parts database is used in the parts selection process. The data on preferred parts include simulation models, cost to use, etc. There are over 10,000 standard parts, plus "per contract parts." No product can be released until non-approved parts are approved.

The Vault enforces policies at events: (1) some rules are in the database systems with triggers, and (2) some rules are implemented in code. The states are preliminary, released, and under revision. Everything in the Vault is "formatted" (i.e., data typed), including software used to generate digital data.

The controlling formats are "source" and translation (e.g., IGES, the Initial Graphics Exchange Specification). IGES translations are not good enough, nowhere near 100% of the data can be translated via IGES.

Advanced documentation handles engineering images.

AQES uses planning and rules in an expert system for manufacturing. It also saves feedback information on standard parts, such as fragility information or data about the effect of placement, and control and manufacturing data used to define interfaces needed to drive cell controller in its process capability databases.

Lesson Learned:

In target modeling sessions, stay away from the organization structure, and eliminate organization names so turf issues are minimized. In modeling meetings, stay away from technology and focus on business.

The justification for using the Vault is by the benefits it provides to programs that use it. Adoption is voluntary and is a little less than anticipated, although there are some individuals that use it beyond the release process. Most adoptions are by new programs at start-up time (rather than converting a program that is in progress). When WISE was started, Westinghouse was less sensitive to standards than today, so it just set Westinghouse standards. Critical and needed standards are parts characterization and flexible data exchange.

Westinghouse's experience with the Electronic Assembly Plant has been very positive, as shown in the following table (Table E-1):

Table E-1. Westinghouse Electronic Assembly Plant Results

	1981	1983	1985	1987	1989
Yields (first time through)	33	45	65	85	90
Cycle Time (weeks)	12	8	5	3	2
Relative Cost	100%	92%	56%	45%	33%

Industry 2001:

Issues and Barriers:

There is an issue of urgency with respect to standards, so Westinghouse is not waiting for PDES (Product Data Exchange Specification), but is using whatever is needed now. This may create a legacy issue.

A big investment will be required for the cost of moving legacy systems. Standard names for a PDES data dictionary and for EDI would help.

E.14 ALLISON GAS TURBINE, DIVISION OF GENERAL MOTORS (GM)

Description of the Business:

Develops and produces gas turbine engines for commercial and military aircraft and power generation for co-generation and gas compression applications.

Industry 1993:

Business Strategy:

Allison's sales have been about equally generated between military and commercial applications. These percentages are drastically changing as a result of the significant reductions in world-wide military expenditures. Consequently, Allison has been re-engineering its business structure to pursue and exploit new commercial market opportunities and to respond to the lower military volumes and programs. This new strategy requires a significantly different cost structure than has been in place over the past years of government-funded efforts. To successfully compete in the 1990s, considerable change is required.

Fundamentally, Allison is demassifying its business into smaller product-focused business units focusing on product lines. This new structure is essentially a "federation of business units," with each business motivated to become a word class competitor within its market sector. This new business architecture is key in meeting the degrees of scalability and flexibility that ensuing business requirements will require.

State of Integration:

The information technology support at Allison must also change to support this new business form. The centralized data center/common systems approach is no longer capable of reacting to the dynamics of a collection of collaborating business units. A new approach is also required in delivering information-related services. The new approach treats the delivery mechanism as an "information utility" through which services are delivered in a common manner to each of the separate business units. With these services, each business unit can create its own "workflow" or business processes that best meet its competitive requirements. This utility concept is currently being implemented at Allison.

Information Infrastructure:

Allison is preparing to engage in "electronic commerce" with its trading partners throughout the world. To successfully participate in the aerospace business today, extensive and capable use of information technology is imperative. Current and future business will be performed as collaborative efforts called "virtual enterprises." These new business forms exist for the duration of the particular product that is being jointly developed and produced by the coalition. They are bounded together, through value-added communications networks, into a single cohesive enterprise. Cooperative product design, development, and production among multiple enterprises will be the normal means for producing aerospace products into the 21st century.

A departure from the hierarchically organized infrastructure is required to achieve the flexibility and scalability to meet the new architectural requirements. Mainframe-based data centers are being replaced with client-server architectures. Highly capable workstations connected to high capacity networks are replacing centralized applications. Allison is installing this environment as part of its re-engineering effort. Servers designed to provide specific data, communications, and application services are integrated into the network, replacing general purpose computers that have historically been used. Allison's philosophy emphasizes that services be delivered to each business unit in a manner conducive to developing innovative business processes that lead to competitive advantage.

Lessons Learned:

- Creative and intelligent use of information technology is required to achieve world class levels of competitive electronic commerce
- The dynamics of rapid change is forcing new approaches to both the business architecture and the information technology architecture which supports the business.
- Aerospace business will be conducted via electronic commerce in the 1990s and into the next century.
- Collaborative business arrangements called "virtual enterprises" will be the normal way of designing, developing, and producing both commercial and military products throughout the 1990s and beyond.

Issues and Barriers:

- Products conforming to international interoperability standards are not available to fully implement electronic commerce.
- Redesigning the enterprise from a military-oriented process to a market-driven, commercially oriented enterprise is complex and time consuming. This transition requires capital investment in both plant and equipment, and also, more

importantly, into the retraining of the human resources. Obtaining the necessary capital to complete this migration in a reasonable time frame is a problem.

Recommendations:

Government

- The government should promote high technology demonstration projects.
- There is need for a high speed, high capability industrial "data highway" similar in concept to the interstate highway system.
- There is need to emphasize the agreement and acceptance for international interoperability standards and the near-term delivery of products built to these standards.
- The Federal taxation system should provide incentives for aerospace companies to invest in re-engineering their enterprises to full participation in electronic commerce.

E.15 CDI/MODERN ENGINEERING

Description of the Business:

The world's largest independent supplier of engineering design services to the automotive industry. Three types of contracted design services are provided:

- Contract design engineers as part of an OEM (original equipment manufacturer) team at the OEM site.
- OEM Manager who is responsible for the project using Modern Engineering engineers and facilities.
- Modern Engineering projects with their manager and engineers being totally responsible for the project. Modern Engineering has total engineering facilities for automotive design and concept development, including clay modeling and prototype development.

Industry 1991:

Business Strategy:

Modern Engineering is doing limited work for Ford because of its limited number of Prime work stations. It currently has 20 Prime work stations out of a total of 600 work stations. Modern Engineering is currently working on the Ford Mustang. The dies for this effort are being made by a Japanese company. Ford dies for exterior panels are made primarily by offshore companies. Currently there are five companies that make dies for Ford, four offshore, and one domestic who is filing for bankruptcy. While Modern Engineering follows the design process of the specific project OEMs it supports, it is analyzing the feasibility of having its own design process. However, it is quite concerned about what system it should use when it gets heavily into solids modeling. Modern Engineering feels it is in a difficult situation with its major customer, GM, who demands the use of the CGS system on its projects, and EDS who controls the price of using the CGS system.

State of Integration:

The state of integration within Modern Engineering is complicated by the demands of the OEMs that Modern Engineering use the OEM's CAD (computer-aided design) system when engaging in product design for that OEM. Modern Engineering currently owns and runs 16 different design systems in order to support its automotive industry clients. This is further compounded when it performs its finite element model analyses. Modern Engineering feels that upper management in the Big Three wants a higher level of information integration but middle managers always find a way to block standardization efforts that would lead to this. Suppliers of hardware and software also show no interest in standards. Modern Engineering estimates that this lack of integration costs about 20% in project inefficiencies because of designer training, re-startup learning curves, and basic inefficiencies in the CAD systems whose use is dictated by the Big Three. The European auto industry is CATIA based. Toyota, Nissan, and Mazda each has its own CAD systems. Modern Engineering's system of choice is CATIA. It does as much work as possible on CATIA and then translates between CATIA and the other OEM systems, where possible, using IGES (Initial Graphics Exchange Specification).

Lessons Learned:

- Suppliers to the U.S. OEMs find it impossible to truly integrate their internal design operations because of the systems use demands made by the OEMs. It is estimated that the resulting design staff inefficiency adds 20% to the cost of design programs.
- Suppliers normally supply 60 to 70% of the value to a U.S. vehicle program.
- Suppliers are not big enough or are unwilling to form a power base to push standards.
- Auto supplier industry is too fragmented to tell a large automotive company what to do.
- Detroit's Big Three are increasing their use of concurrent engineering contracts.

E.16 THE CROSS COMPANY

Description of the Business:

Cross is a medium-size manufacturer of special high-speed production equipment (high-speed transfer machines). It has operations in the United States, Canada, Europe and Japan. Cross products are constructed from one-third standard (off-the-shelf) components, one-third semi-standard components (components tailored to Cross specifications by other manufacturers), and one-third clean sheet design.

Industry 1991:

Business Strategy:

Cross has cost justified an integrated set of business and engineering systems by comparing new systems against existing legacies. The Vice President of Business Operations had to obtain approval of the Cross and Trecker Board to go ahead with a new system design for enterprise integration. The issues of integration were determined to be over 50% organizational, cultural, and procedural. Significant levels of training were conducted for all affected personnel. EDS functioned as the systems integrator. Cross not only supplies machinery to the Big Three automotive companies and it major suppliers, but also to European automotive manufacturers as well as cultivating business among the Japanese-U.S. transplants. Cross was in the process of building two piston-turning transfer machines for Muskovich (a then-Soviet engine manufacturer).

State of Integration:

Cross has just installed a highly integrated set of business systems and procedures across all domestic plants. Most legacy systems were discarded during this process. Cross is currently running a single computer-aided design (CAD) system. Because it is a job shop operation, the center of its business systems is a commercial MRP-II system (manufacturing resources planning). The design, evaluation, training, and implementation of these systems was accomplished during a three-year period. Training of all personnel, including top management, was considered to be crucial to the success of this implementation. Cross is on-line with the major automotive manufacturers to whom it supplies production machinery. More and more of this machinery is being designed under concurrent engineering contracts (Cross is part of the product design team which permits them to optimize their machinery design).

Lessons Learned:

The cost analysis developed by Cross to justify a complete new system design for enterprise integration, including scraping its legacy systems, showed that the existing (legacy) system could be economically replaced within a reasonable time, and would generate an internal rate of return of 30%.

Issues and Barriers:

Barriers were primarily considered to be nontechnical.

Internal standards were developed with the help of EDS, the system integrator.

Recommendations:

Industry:

Cross felt that the best chance for workable standards would be to get the major companies behind the efforts of organizations like the Automotive Industry Action Group (AIAG). However, at the rate that companies are integrating, there will probably be a set of *de facto* standards.

Government:

When asked about the role that the government should play, the comment was that there are sufficient systems available for industry to choose from to accomplish enterprise integration. It would probably be best if the government just stepped back and let industry do what it has to do. The government should not try to impose *de facto* standards of its own.

E.17 FORD MOTOR COMPANY OF NORTH AMERICA

Description of the Business:

Major world automotive manufacturer.

Industry 1991:

Business Strategy:

Ford's business strategy is to maintain a competitive edge through the use of its proprietary Prime computer-aided design (CAD) system. It considers Prime to be better than anything else and requires its use by key suppliers if they wish to sell to Ford. The CAD system is bought by users from Prime. Ford has about 100 engineers maintaining their CAD system at a cost of over $10 million per year. However, it feels that this is necessary to maintain a competitive advantage. Ford did admit that it ran the risk of not maintaining a competitive lead, especially if there was a lot of software support for systems other than Prime. This is one of the reasons for the need to incur the system maintenance cost cited above.

Ford's corporate vision for improvement is based on achieving quality, time-to-market, and cost improvements. Ford monitors outside technology developments for those it thinks will be winners, implementing them as soon as possible. This creates a problem in the use of standards. It claims that most good standards take four to five years to develop. Because it feels its current system gives it a competitive edge, Ford does not see the need to take a leadership role in the development of standards. However, it is monitoring the progress being made on standards and if something comes of the effort, it will use them. As for now, Ford feels it is big enough to require its vendors to use the technology and standards Ford needs. It is trying to reduce the number of physical models it develops from 20 to 2. It is also trying to implement CAD to milling clay, with the master-math model staying in the computer. It currently takes them three years to completely develop a new model.

State of Integration:

Ford North America has integrated its automotive design process: two CAD systems, a single release system, and common platforms and software across functional groups. One CAD system is for body panels and structure while the other is for components. All critical exterior panels are designed on its Prime proprietary CAD system. This is true even if the part is designed for them by General Motors (GM). (Case in point: GM does design and manufacture some body parts for Ford North America, and had to purchase a Prime system to do so.) There are currently about 1,000 copies of Ford's Prime CAD system running outside of Ford, primarily by suppliers to Ford. Ford makes the distinction of who must use Prime, based on a parts classification process:

- Class 1: Very critical and must be designed on Prime.
- Class 2: Moderately critical. The Initial Graphics Exchange Specification (IGES) can be used for data translation for different CAD systems.
- Class 3: Not critical and anything goes.

While Ford Europe uses the same CAD (Prime) and parts release systems as Ford North America, there is little or no transatlantic electronic transfer (integration) of design data.

There does not appear to be a common vision for corporate integration. The strategy appears to be based on the use of common platforms and standards. Most standards followed today are Ford standards, although Ford admitted to wanting international standards so that Ford North America and Europe could be integrated. Ford is now working on establishing (defining) common data elements and common business practices. It is also interested in re-engineering this business procedures with an eye towards corporate integration. Ford spent one year analyzing its clay to sheet metal process and reduced the time by 15%, cost by 10 to 15%, and improved quality.

Ford said that the links between its product design data, CAD, and computer-aided engineering (CAE) tools were not as good as it would like to see. One reason for improving this linkage is to do a better job, electronically, of crash analysis. The alternative is model crash testing to satisfy federal requirements.

Information Infrastructure:

Two CAD systems:

- A single release systems
- IBM, DEC, Apollo and Sun engineering work stations
- A Texas Instruments dealer system which is going toward Unix
- Component plants run HP floor systems
- Powertrain plants run DEC

Lessons Learned:

- If PDES (Product Data Exchange Specification) was available, Ford might use it.
- Product data should be separate from infrastructure.
- They cannot easily tie alphanumeric information to CAD surfaces.
- There was a major study four years ago. A team of 10 to 15 people spent a year benchmarking the process of going from clay to tools.
- Ford is reluctant to make major changes to current system.
- Supplier of Ford surfaces must use its Prime CAD system.
- Supplier integration is fairly good.
- Ford is following PDES efforts and could be very active if necessary, but there is no current interest in helping to define standards.
- Ford has been using stick figures in design for 15 years.
- It has a proprietary computerized crash system.
- It is now developing a solid modelling package.
- Open systems are gaining in Ford, e.g., its Dealer system was a Texas Instruments system but is now becoming more open (i.e., Unix based).
- It is moving to one system for office automation.
- Ford Europe is moving to OSI (Open System Interconnection).
- AIAG (Automotive Industry Action Group) is looking for standard commonality but not moving fast enough.
- Systems should assist globalization.
- Government pushes technology.
- The Computer-Aided Acquisition and Logistics System (CALS) seems to be using the technique of implementation through military specifications.
- The National Institute of Standards and Technologies (NIST) needs help from international companies to establish standards.

Recommendations:

Industry:

AIAG should move faster towards standards in CAD and electronic data interchange (EDI).

Government

The government should get involved in standards setting, but it is questionable how far it should go.

E.18 GENERAL MOTORS / CHIEF INFORMATION OFFICER

Description of the Business:

World-wide manufacturer of transportation vehicles and systems.

Industry 1991:

Business Strategy:

For enterprise integration to be successful, all stakeholders and their needs must be identified and balanced. The following model was suggested:

Stakeholders/Needs

- Customers (quality, price, availability, lead time)
- Employees (pleasant work environment, informed, creative tasks)
- Suppliers (stability in demand, easy information exchange)
- Stockholders (return on investment)
- Managers (easily digested current information)

Information plays a key role in satisfying each stakeholder and there should be a strategy to satisfy each one. Management's role is to determine these strategies and satisfy (balance) the stakeholders. *Interconnectivity* and *interoperability* in and across corporate boundaries are critical. If standards do not exist, complexity and duplication results. When companies come to apply information technology they find a myriad of solutions to satisfy basic functions. The more solutions in use by a company, the more people and training is required. Enterprise integration needs standards. No company alone can influence enough of the outside world to standardize the systems offerings. Standards that are currently in place are mostly industrially based. Within the automotive enterprise AIAG (Automotive Industry Action Group) is attempting to set integration standards in several areas but it is moving too slowly.

State of Integration:

Because of the history of General Motors (GM), independently information systems were developed and operated within its many operating divisions. This resulted in GM running as many as 10 different CAD systems and many sets of business systems. It now has a single corporate vision for corporate integration and all divisions will work toward the implementation of this vision. According to an AIAG report, the GM C-4 program[5] for product engineering will reduce the number of CAD systems to four, including the Corporate Graphics System (CGS), CADAM and Unigraphics.

Information Infrastructure:

Information infrastructure comprises hardware, operating systems, programming languages, and communications, but not applications. The government has a role in establishing infrastructure standards that would aid interoperability and connectivity. It has a lesser role in application standards.

Issues and Barriers:

GM is very active in activities such as CALS (Computer-Aided Acquisition and Logistics Support). It is also very active in industrial cooperative efforts such as AIAG, the National Center for Manufacturing Sciences (NCMS), the Microelectronics and Computer Technologies Corporation (MCC), the Corporation of Open Systems (COS) and SOS.

Recommendations:

The government has a role in pushing standards for integration infrastructures but not applications. Most companies would also welcome government intervention in setting standards for both Japan and Europe.

[5] C4 = Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), Computer-Aided Engineering (CAE), Computer-Integrated Manufacturing (CIM).

E.19 RYOBI DIE CASTING (USA), INC.

Description of the Business:

Ryobi Die Casting (USA), Inc., is a wholly owned U.S. subsidiary of a Japanese firm (Ryobi, Ltd.) that has grown, world-wide, by selectively procuring companies that could be vertically integrated into its primary line of business, i.e., producers of die cast components. Ryobi Die Cast produces precision die cast parts for the automotive industry, both commercial and farm vehicles. Its biggest customer is Ford.

Industry 1991:

Business Strategy:

Ryobi is trying to reduce dependency on automotive business. It feels that pressure from the automotive industry to reduce cost is putting unreasonable burden on the supplier community. Ford is currently asking it for a 4% reduction each year with little relief in design specifications. The result is that there is insufficient profit remaining for productivity investment. Ryobi is also operating a small transfer line operation for Ford. The equipment and the processing belong to Ford but the people and the daily operation are managed by Ryobi. Die and advanced processing development for the Ryobi plant is currently being done in Japan at its corporate tech center. Part data is sent to Japan via tape. Ryobi USA does intend to be on-line with Ryobi Japan for business reporting.

Working with General Motors (GM) on computer-aided design/computer-aided manufacturing (CAD/CAM) projects is expensive because GM's CGS (Corporate Graphics System) is not as efficient as other CAD systems. (Comments offered by Mr. Fant based on his experience while working at Modern.)

Ryobi has had some problems with integration because of its customers having different standards and different CAD systems. However, CATIA is becoming the prevalent CAD system across its customer base. It feels there is a need for enterprise integration standards in the automotive enterprise, but the Big Three are not dedicated to having a single oversee system for integration with their suppliers. The Automotive Industry Action Group (AIAG) is a good organization working towards standards for integration but it is not getting the top management support it needs.

State of Integration:

Ryobi is experiencing more use of concurrent engineering contracts, and as a result, is installing workstations to be able to communicate on-line with Ford and probably GM. They plan to use IGES (the Initial Graphics Exchange Specification) as a translator.

Lessons Learned:

- Automotive suppliers are actively looking for other industries to supply outside of the automotive industry. Ryobi's management was under the impression that this was a general trend within the automotive supplier base.
- U.S. subsidiaries of Japanese firms are still doing most of their product engineering and process development in Japan for their U.S. operations. There does not appear to be an overwhelming rush to change this.

Recommendations:

Government:

The government should ease some trade regulations.

E.20 SATURN

Description of the Business:

SATURN is a new division of General Motors (GM) which was established to compete with the Japanese in the manufacture and sales of small cars. SATURN's advanced engineering and business functions are located in Troy, Michigan. Its manufacturing facilities are located in Spring Hill, Tennessee.

Industry 1991:

Business Strategy:

The mission statement includes the integration of people, technology, and business systems. Business partners were selected on their ability and willingness to become part of the enterprise. This includes both engineering services as well as parts suppliers. Partnership includes sharing of both risk and reward. SATURN is a partnership with the UAW (United Auto Workers), and, as such, all manufacturing people and cultural issues associated with integration were jointly addressed and resolved before the plant and system design was initiated.

State of Integration:

SATURN has achieved broad internal integration across all information functions of the company: business, engineering, and manufacturing. This is clearly indicated by part of the mission statement: "The integration of people, technology, and business systems." Very few legacy systems were brought in from GM. The design of the new system was based on the following:

- Single computer-aided design (CAD) system
- Single logical data base
- Standard communication protocols
- Reusable software applications across business functions
- Common hardware platforms
- Distributed architecture

SATURN business partners have access to all information and people needed to integrate their products and process into the SATURN business. The physical manufacturing complex has integrated all major components made in Spring Hill as well as off-site parts shipped in just-in-time (JIT). The complex was designed to facilitate a JIT inventory control. Extremely low levels of inventory are maintained in the plant (e.g., 30 minutes for built-up engine blocks).

Information Infrastructure:

SATURN selected CATIA as its single CAD system. Because of the timing of the product design, GM's CGS (Corporate Graphics System), CADAM, and CATIA were initially used. After the selection of CATIA, all new designs have migrated to CATIA. SATURN feels that a single CAD system for all design gives it a strategic advantage. It appears to be very close to a single logical data base. Data elements which are used by multiple business functions are in one data base, with elements specific to one business function being in individual functional data bases. All plant systems are run on DEC platforms with common applications running in all manufacturing operations. Their common applications are based on the GEF Complicity software enablers. Standards for all plant floor systems were given to all equipment suppliers before they designed the software specific to their equipment. ITI coordinated the design and necessary education for these standards. The standards included the following:

- Communications
- Software enablers
- Man-machine interface
- Platforms
- Software design
- Architecture

The plant complex now runs four interconnected Manufacturing Automation Protocol (MAP) 3.0 networks, with critical information on inventory, scheduling, and equipment status accessible across the total complex.

Data models, information flow models, and existing reference models were all used in the design of the information systems. Other programs used to improve product design, quality, and time-to-market, such as Total Quality Management (TQM), Design for Assembly (DFA), Quality Function Deployment (QFD), Continuous Improvement (CI), and concurrent engineering, are in use at SATURN.

Lessons Learned:

Manufacturing lessons

- Standards are essential.
- Make use of strategic partners.
- Focus on applications rather than development.
- A wide variety of the business can use common software.
- Linking between floor devices is of primary importance.
- Manufacturing should be responsible for plant systems.
- MAP network direction was correct.
- Distributed processing is correct for manufacturing.
- Workers need to be involved in plant systems.
- Existing plants can implement integrated systems in phases.

Product Engineering Lessons

- Data ownership becomes data administration.
- Determining the value of intelligent numbers to the organization is critical.
- Change management for highly integrated information systems requires a high degree of coordination.

Powertrain lessons

- DNC is not practical for high volume production.
- Integration of manufacturing has high payoff in lowering inventory and increasing equipment utilization.
- People will use real-time information if it is provided to the production floor.

Issues and Barriers:

Plant floor standards were developed by ITI for SATURN, using existing national, international, and GM standards.

Without the people issues first being addressed at SATURN, the demonstrated level of integration would not have been possible.

E.21 UNIVERSITY OF MICHIGAN: DIRECTOR/OFFICE FOR THE STUDY OF AUTOMOTIVE TRANSPORTATION

Description of the Business:

The University of Michigan's Office for the Study of Automotive Transportation (OSAT) was established to analyze the automotive industry, world-wide. The following report is a summary of OSAT's conclusions concerning the enterprise integration of the industry. All of its comments are documented under the lessons and conclusions section.

Industry 1991:

Lessons Learned:

Technology and systems are the least important part of the integration problem in the automotive industry. People's resistance to change and cultures is the basis for most of the problems. Most of the current managers in the automotive industry grew up under the Taylor Philosophy where team play was not rewarded. Automotive companies are using short-term mentalities when it comes to measurements and rewards. The Automotive Industry Action Group (AIAG) is currently working on computer-aided design/computer-aided manufacturing (CAD/CAM) standards. This work needs to be speeded up but there is a lack of strategic understanding of the CAD/CAM technical and integration issues at the upper management level in the original equipment manufacturers (OEMs).

Strategic partners are treated very differently at different companies and divisions within companies. Chrysler is treating its suppliers more like strategic partners than anyone else. GM's 3-2-2 cost reduction program is not timed or coordinated properly with its manufacturing and engineering activities. These activities are very reluctant to change part specifications or costly practices which would help the parts suppliers reduce cost. Some level of integration is taking place at the powertrain, body and assembly, and electronics systems level. The OEMs cannot afford to continue duplication in these systems. They are undertaking several cooperative research programs such as electric batteries for their electric car programs. The federal government has been known as a regulator and its image must change to become an effective partner.

During the last several years, experiments have been taking place in the automotive industry from which we will now begin to harvest the results. The 1980s was the decade of understanding. the 1990s will be the decade of execution, and the 2000s will be management of knowledge. There will be comprehensive corporate data bases and their management will be key. The three-day car will be a reality but not with custom skins. Cars will be revitalized or updated at 50,000 mile intervals with new electronics, graphics, and safety features. Transportation will have to be provided to the "have nots" of society through revitalized vehicles. More flexibility will be needed in all parts of the production cycle. The 24-hour, 3-crew plant will become more common to increase the utilization of our capital. Fewer strategic partners will be providing more of the vehicle as total systems. More cars produced with a fewer number of parts will be the norm in the future. e.g., more common parts will be used across car lines. These concepts will require a whole new dimension of information tracking down to the part level.

E.22 GENERAL ELECTRIC AIRCRAFT ENGINES

Description of Business

General Electric Aircraft Engines (GEAE) is one of two U.S. manufacturers of gas turbine engines for both commercial and military use, and along with Rolls Royce and Pratt and Whitney, is one of the three major gas turbine engine producers in the world. GEAE's large gas turbine engines are designed and manufactured in Cincinnati, Ohio. Smaller gas turbine engines are produced by the GEAE division in Lynn, Massachusetts.Our enterprise integration interviews were with the large engine division in Cincinnati.

GEAE has been a leader in developing, producing, and supplying gas turbine engines to the worldwide airline market since the advent of commercial jet aircraft. The commercial product line was an outgrowth of its military engine line, GEAE being the first U.S. company to develop and produce a turbojet engine early in the 1940s.

Industry 1993:

Business Strategy:

GEAE is dedicated to having enterprise integration in place throughout the company as quickly as possible. As part of the process, the company has set a 1995 target of having enterprise integration fully deployed throughout engineering and manufacturing. The justification for enterprise integration is the return on investment benefits. To this end, GEAE has been collecting some metrics and has stated its intent to do so in a more aggressive manner on the basis that the need to justify such investment is more critical during the recent downturn in overall aviation business.

Enterprise integration will be deployed both externally as well as internally. GEAE has started to link itself with its primary suppliers and will continue the process. The company acknowledges that as they go deeper into their supplier network, companies tend to get smaller in size. Unfortunately, some of the suppliers are not large enough to justify or see the need to link electronically. The decision whether or not to stay with these small companies has yet to be made. Over the past three years, GEAE has reduced its number of suppliers to some extent. During the recent downturn in business, GEAE found that it had to hold the line on prices in order to retain market share. And, in turn, GEAE expects its suppliers also to reduce their costs wherever possible.

Status of Integration:

In the late 1980s, GEAE began to focus around the process of an engine development cycle from early conception of concepts and technology through customer product requirements, product design, manufacture, delivery, and field support. Two parallel master plans were defined (Engineering and Manufacturing Computations Master Plans). These plans focused on limiting the number of hardware platforms and operating systems to ensure compatibility of engineering and manufacturing applications to maximize process efficiency across functions instead of previously suboptimizing functional applications with too little regard for functional interoperability.

Both master plans focused on a strategic selection of a software vendor to provide common product geometric definition from design/analysis through drafting, manufacturing planning, and inspection automation. Unigraphics was selected as that supplier in 1990. By 1996, Unigraphics will provide this basis for common geometric master models across turbo-machinery for all product lines. Unigraphics currently penetrates about 25% of its planned implementation level; several component design scenarios have adopted the concurrent engineering process based on the common geometry approach and have demonstrated significant improvements in both speed and quality (design/manufacturing release cycle reduced an average of 30% while improving quality by more than doubling the analytical iterations and concurrently preparing the manufacturing process).

While attempting to move to internal standards for process efficiency, GEAE recognizes the need to concurrently integrate its propulsion system designs with the customer. Since 1987, GEAE has been working towards the capability of digitally exchanging the propulsion system geometric representation in the concept-to-design evolution with its customer (Boeing on the new 777 aircraft). This Digital Pre-Assembly (DPA) and Digital Mock Up (DMU) process is utilized to evolve the configuration design of the externals of the engine concurrently with the turbo machinery design instead of the sequential process that historically had been applied.

A comparison of the new GE90 engine design process as compared to the CF6-80C engine development about a decade earlier: The CF6-80C2 engine, which went to test in March of 1984, had 455 tubes and brackets on the first engine to test. By the time that engine was delivered to test, 1,056 tubes and brackets had been designed and released. Approximately 50% of that excess was in hardware by the time it was found that they had interferences with other hardware or no longer met the design intent or customer compatibility.

On the other hand, the GE90 engine first to test had four minor tube rework and first time hardware assembly with no interferences. This process now allows GEAE to design configurations of engines with the customer while no longer using physical mock-ups for design resolution.

The DPA/DMU process is currently being applied to the F18 E/F - F414 engine development program using Unigraphics to perform the customer design concurrency with McDonnell Douglas and Northrop.

GEAE's future DPA/DMU process will be applied to new development programs on a CAD system that was selected for customer compatibility until standards for CAD system exchange of geometry (like STEP, the Standard for the Transfer and Exchange of Product data) are robust enough to accommodate an inter-CAD system concurrency of design.

More historically, GEAE began an initiative in 1984 to accommodate digital creation, modification, retention, and distribution of engineering drawings regardless of the drawing source (CAD system, drafting board). ADSRS (Automated Drawing Storage and Retrieval System) reached its production critical mass in 1986 and was digitally integrated with a Raster CAD system for drawing revision and issuance in 1988. There are currently 1.7 million drawing images in the system which are digitally accessible from GEAE sites across the United States.

In 1988, a three-month measured comparison of the digital change incorporation process (using FORMTEK) to the manual process of drawing change incorporation was performed. The process of incorporating changes on the drawing by the draftsmen averaged eight man-hours per change on the board; the digital change incorporation on a Raster drawing averaged four hours. (This does not include the efficiency of avoiding plotting, manual handling of the tracing, and manual transfer of documents.) These savings map into about 80,000 man-hours a year (averaging 20,000 drawing changes each year).

This digital drawing system has been directly interfaced with the Air Force EDCARS system; the first digital data buy out was delivered to EDCARS in 1991. This reduced the cycle for complete technical data delivery on the F110-100 engine from previous cycles of over 1 year to about 10 weeks. The current 10-week cycle could be further reduced pending input capacity of EDCARS.

On the CF680CX wide chord fan blade engine, GEAE was able to reduce the cycle time from design start to manufacturing design release by 40% over the previous engine design program, with time to do three complete design iterations.

GEAE has completed the process of identifying its core business and is now identifying the data required to support its core business. After standardizing at this level, the data system that finally emerges will work outward from the core business.

As part of the enterprise integration deployment process, GEAE documented its business processes, along with the data requirements for each business process. GEAE has now undertaken a program to re-engineer its business process under a program that calls for continual business process improvement.

From a data management program point of view, GEAE is placing its enterprise integration efforts on Integrated Management System 90 (IMS 90). There are four levels of data control.

Table E-2. Levels of Data Control

Level 4:	Corporate Host	Finance, Administration, Purchasing, Master Schedule, etc.
Level 3:	Plant Host	Production Schedule, Maintenance Inventory Control
Level 2:	Workstation Controller	QA (Quality Assurance) Management, Cell Coordination
Level 1:	Direct Control	CNC (Computer Numeric Control), CMM Coordinate Measuring Machine), Robotics

After reviewing the problem internally, GEAE found that software and data are always being recreated within the Company. By integrating the data management system, this represents an opportunity for big savings. GEAE is picking IRDS (Information Resource Dictionary System) as the data modeling standard (because it exists). Knowledgeware is being used to model the data and processes within GEAE.

Barriers:

The greatest barrier to enterprise integration is lack of standards. Without them, geometry is not sharable. STEP, in part, addresses configuration management across the design process, whereas other standards do not. The need for standards is very apparent in the case of companies like GEAE whose interfacing requirements outside of the company are international in scope. GEAE's CAD preference is Unigraphics. On the other hand, Boeing requires the use of CATIA. Snecma and Airbus also require CATIA but they are also using STEP. GEAE has found IGES (the Initial Graphics Exchange Specification) to be no solution. As an example, for one of the engines, GEAE designs the compressor fan blades. The design is passed to Snecma for production. In turn, Snecma designs the compressor blades, whose design is passed to GEAE for production.

GEAE firmly believes that in order to incorporate STEP in a CAD supplier's software, government funding will play a key role and should be made available to the industry as soon as possible. This initiative will deliver immense benefits to both defense and commercial sectors.

A second barrier to be faced by enterprise integration is the handling of proprietary information. In the case of GEAE, for example, its programs bring it into contact with proprietary data from Boeing, Airbus, Snecma, McDonnell-Douglas, Canadair, Northrop, Lockheed, and other airframers. The legalities of properly handling another company's data can approach those associated with handling government classified data.

A third barrier is the readiness and/or willingness of outside companies (suppliers and customers) to be enterprise integration compatible with GEAE. And it is not only the intent of becoming compatible, but also a matter of timing. A small company that GEAE is dependent upon but whose financials will not permit it to become enterprise integration compatible with GEAE until many years after GEAE is up and running with most of its suppliers/customers, will force GEAE into operating a dual (old and new) communication system long after GEAE has totally deployed enterprise integration internally.

When asked about legacy systems, GEAE admitted that they are a problem but less of a problem when compared to the "soft issues" of culture and management. Within engineering and manufacturing, data bases are being converted as needed. Where interfaces exist or can be easily developed to avoid conversion, they are being used. Like airframe manufacturers, many data bases must be saved in their original format to satisfy legal requirements should warrantee or safety-of-flight issues arise many years after an engine has been produced. To begin to fix the problem, GEAE has identified three levels of required systems and services: (1) Enterprise databases (MVS, DB2, IDMS—hold 90% of the data); (2) Work group data bases (VMS/Ingres, UNIX/Ingres, Novell Oracle); and (3) personal data bases. The goal is to have a standard, open, scaleable system which will be accessible across the enterprise. To start, GEAE picked the minimal interface protocols (Network File System (NFS), Transmission Control Protocol/Internet Protocol (TCP/IP)) to accomplish this.

Industry 2001:

GEAE's intent is to be totally paperless where it makes good business sense. Certainly within engineering and manufacturing, there will be a seamless operation that supports a true concurrent engineering environment. The target of 1995 for the fully integrated engineering and manufacturing environment appears to be a reality, given the progress made to date. The issue of integrated data management remains to be worked out, however.

Steps are well under way to be electronically integrated externally as well as internally. GEAE is in the position of having pressure brought from both internal and external sources for enterprise integration. Its military customer is starting to demand electronic delivery of products as a contractual requirement. Many of its civil aviation customers are relying on electronic ordering to shorten the support pipeline and reduce spare parts inventories. GEAE, in re-engineering its business processes, is finding it more cost effective to be electronically integrated with its suppliers and is striving to accelerate the process of total enterprise integration.

The issue of when and where to make the enterprise integration investment is particularly critical today. Since GEAE recognizes that the enterprise integration investment is necessary to ensure competitiveness in the future, there is still the reality that the investment must come out of profit. During this time of business contraction, there is prioritizing of what will be done next. But all in all, GEAE is continuing towards its goal of being a 100% electronically integrated enterprise.

E.23 LOCKHEED AERONAUTICAL SYSTEMS COMPANY (LASC)

Industry 1993:

Business Strategy:

Having won, with Boeing and General Dynamics as teammates, the F-22 Advanced Tactical Fighter (ATF) contract in mid 1991, Lockheed has made significant progress in the development and implementation of several advanced information management systems. These efforts are driven primarily by program requirements, but are also for the general benefits of enterprise integration.

The Computer Integrated Systems, Technologies, and Resources (CISTAR) initiative at LASC is a company-wide systems modernization effort to bring integrated product development and total quality management techniques to bear on the functions of Engineering, Operations, Product Support, and Administration. These new system applications are being developed for use on the F-22 program and subsequently on other programs.

The CISTAR mission is to plan and implement the transition from traditional organizationally compartmentalized, and labor-intensive processes into a seamless set of highly automated systems. These systems will support the goals of (1) reduced product costs, (2) reduced product development schedules, (3) improved product quality, and (4) continuous process improvement (CPI). Most CISTAR projects were in response to F-22 contract requirements and a Total Quality Management (TQM) push within the company.

CISTAR, managed by a special office within the informations services and administration line organization, has been divided into five areas: integrated development systems, integrated production systems, integrated support systems, integrated management systems, and integrated information systems (Figure E-4).

State of Integration:

An information technology standards committee has been established within LASC and is chaired by the integrated information systems sector leader. This committee was established in response to high-level management frustration with the diversity and resulting conflicts among standards. The standards committee tracks all Department of Defense (DoD) standards applicable to programs at LASC, and generates a preferred product list to support those standards.

The products to be applied on the F-22 program participants have been mandated. A computer-aided software engineering (CASE) environment is being established for the

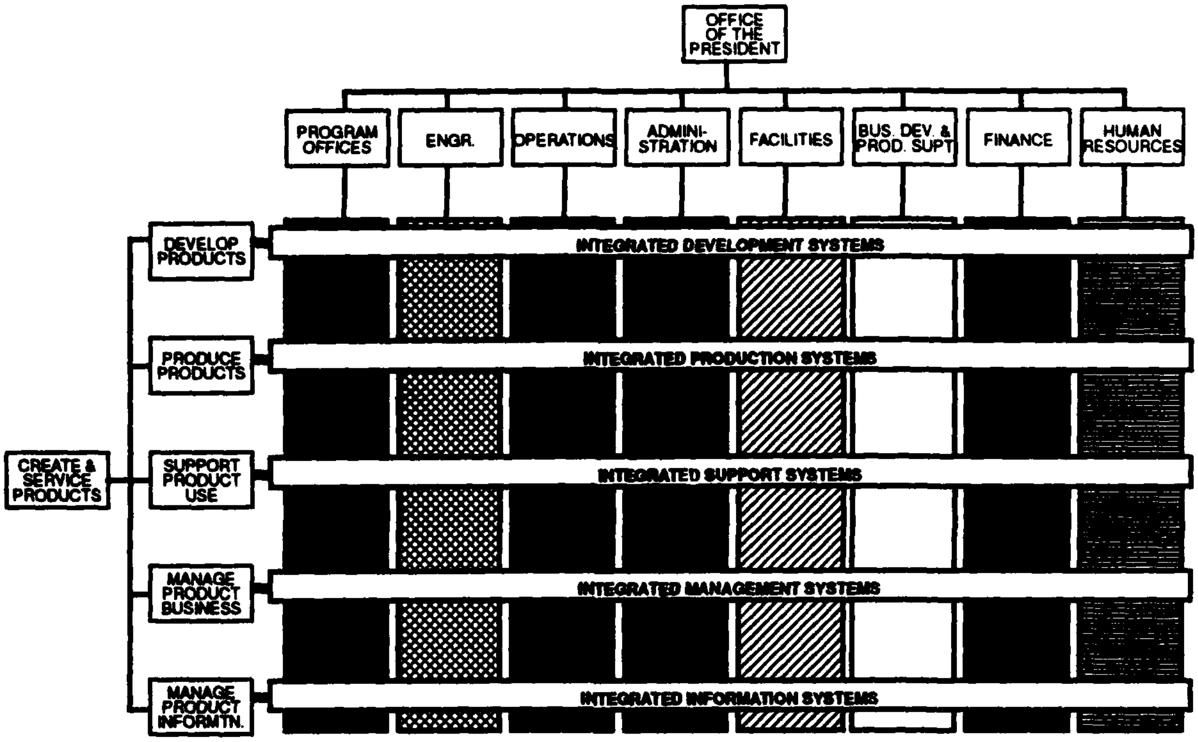

Figure E-4. CISTAR Architecture

development of general purpose software. This environment includes the Texas Instruments Information Engineering Facility (IEF) toolset, the James Martin Information Engineering methodology, and a mainframe encyclopedia for information sharing and management. By the end of 1993, this environment will support an IDEF (ICAM DEFinition Language) modeling capability.

Two pilot programs have shown success. The first is a materials database that automates the function of materials trade-offs during design. The second is an automated shop floor scheduler that integrates the many reports and sources of information previously used to manually generate those schedules. A third project, a logistics support provisioning tool, is planned for 1993.

The Integrated Weapons Systems Data Base (IWSDB), partially funded by the Advanced Research Projects Agency (ARPA), is primarily funded by the F-22 program. The function of this database will be to support the rapid solution of in-service problems by making key data available. The entire F-22 program team, including the subsystem program office (SPO) and ARPA, participated in the development of a reference model of the F-22, and identification of the data needed for the IWSDB.

One of the lessons learned during the first phase of the IWSDB project was that a paradigm shift is required when managing distributed program data on heterogenous systems. Problems are solved corroboratively by the program team members connected by electronic networks, and when data is being managed from a program-wide perspective.

The IWSDB will be used to manage both business and technical data. The IWSDB will provide SPO access to management and schedule data, logistics data, technical performance data, and some software engineering data. Most CDRL (contract data requirements list) data will be developed electronically. Training and technical manuals will also be available through the IWSDB.

Most of the design and analysis tools for use on the F-22 program are on-line and available team-wide. These tools include the following:

a. Methods Improvement Program (MIP) - an integrated computer-aided analysis package.

b. Mass Properties Estimation Procedures (MPEP) - an automated mass properties calculation and reporting package [not yet available through database]

c. Lockheed Advanced Wiring System (LAWS) - an electrical wiring system that incorporates engineering and manufacturing functions.

d. Three-Dimensional Electronic Mock-Up (3-D EMU) - a package that provides digital mock-up capability.

e. Design Support Database (DSD) - A database of standard parts, materials, and documents and specifications.

f. Direct Digital Load Control - a package to support static and fatigue testing using Direct Digital Control technology transferred from Rye Canyon.

g. Electronic CDRL Delivery System - electronic system to access and deliver CDRL data and provide access to SPO and team partners.

h. Electronic CDRL Tracking - electronic system to track CDRL data and provide access to SPO and team partners.

LASC does support EDI to its major suppliers. However, most suppliers still deliver hard copy engineering data which is scanned into the DSD. In some cases the reason for this is that suppliers are using different CAD systems than those used at Lockheed.

The integrated manufacturing system group is tailoring existing systems to provide an MRP-2 (manufacturing resources planning) like system. It has not yet automated the supplier delivery of parts. LASC will evaluate the General Dynamics acquisition system so that there are no overlaps or gaps between the two divisions. The General Dynamics tool for electronic sign-off will be used at LASC for the F-22.

Integration Strategies:

LASC is awaiting funding to proceed with the implementation of the IWSDB. LASC feels that efforts to integrate its information systems, processes and data across the enterprise for the F-22 program must be directly funded by the government.

LASC has decided not to re-engineer its legacy systems on a major scale, but instead encapsulate and interface these systems to the new IWSDB.

LASC may begin to re-engineer some of the older business applications based on a good business justification. The integrated information systems group has begun to identify re-engineering software and procedures as a precursor to establishing a re-engineering environment. Although little benchmarking has occurred to date, LASC plans to use metrics to perform trades among the options available.

Lessons Learned:

Several years ago a systems modernization initiative was outlined. Project managers assembled cost-benefit analyses based on the new applicable technologies. Company and Corporate management has difficulty accepting the cost justification. Finally the CEO stated: "...enough done, it's vitally needed, can't judge if it costs too much, we must have it." LASC is now collecting data on the cost savings it is realizing. Much of the savings thus far has been in the area of analysis.

A big concern in implementing this program is the cultural change required by both the company and its customers and suppliers.

The development of standards and process and product model descriptions (e.g., PDES, the Product Data Exchange Specification) is a major problem area. The current government and professional organizations involved in standards setting are moving much too slowly to meet Lockheed's schedules.

Technology is not a major constraint. Even though it would like to have the latest hardware (better distributed client-server systems, with mainframes to support CADAM/CATIA) and software, LASC can "get by" with what exists.

Process definition and any re-engineering of those processes must occur before any attempt to automate.

Minimal progress has been made integrating suppliers into the enterprise. Second and third-tier suppliers are often ignorant of Computer-Aided Acquisition and Logistics Support (CALS). As yet this has not been a problem on the F-22 program since these suppliers will only really become involved with the process well after a preliminary design review (PDR). However, very soon, this issue will have to be finalized. LASC managers noted that waiting until the last moment possible before informing suppliers about the data delivery requirements may not appear to be the best strategy, but data standards and practices are continuing to evolve. It is better to use the latest and best solutions.

Evolving, shifting system requirements has been a problem, contributed to be the turnover of personnel on the program. Good requirements documentation is essential.

Recommendations:

Industry:

Industry must share its experiences with the standardization committees if useful and timely standards are to result. Commercial products do not always support standards. In the case of the F-22, the team has some leverage in purchasing products to support its effort, but it has few choices.

Government:

A common data model is needed. LASC believes that a national standard is required and that ARPA should provide the funding for this. LASC has a concern that the numerous government and commercial data model initiatives will not be pulled into a common data model, further delaying efficient EDI.

E.24 MARTIN MARIETTA MISSILE SYSTEMS

Description of Business:

Development, production, and support to military missile systems.

Industry 1991:

Business Strategy:

Martin Marietta has a corporate strategy for enterprise integration and has a goal to have it in place by 1995. Each division is to address local issues and resolve them to the best of its ability while fulfilling the corporate requirements. At the Missile Systems Division, it has implemented several facets of Total Quality Management (TQM) and concurrent engineering and views these as initial steps toward a more complete enterprise integration implementation.

State of Integration:

The major enterprise integration application is the integration of the Mentor Graphics and HP (Apollo) computers into an electronic computer-aided design (ECAD) system which is electronically interconnected to greatly enhance concurrent engineering among "all" needed local and dispersed organizations. Mechanical CAD implementation has been slower, having recently converted from using CADAM to CATIA. The LANTIRN program is the first to make intensive use of these aspects of enterprise integration.

Information Infrastructure:

The information infrastructure of the Printed Circuit Board (PCB) ECAD system involves a network of over 100 work stations, with a fiber optic connection between facilities in Orlando, Florida, in which the design is produced and Ocala, Florida, where the PCBs are fabricated. On one project Martin Marietta electronically coupled PCB design data with Texas Instruments in Dallas, Texas. The system allowed several engineers to look at the same drawing at the same time. Electronic sign-off of the final design by all involved personnel is accomplished within this system.

Martin Marietta foresees the use of animation (currently using WAVEFRONT software) as one of the next major enhancements in the information interchange with the customers, suppliers, and peers.

With the implementation of inter-connected ECAD system, Martin Marietta has attained significant cost savings. These include savings due to a large decrease in the number of PCB drawing changes. Changes declined from an average of 5 per drawing in 1979 to 2.2 in 1990, with a goal of 1.9 within the next few years. The dollar saving can be calculated based on a $5,000 cost for each change multiplied by the 12,000 drawings created during 1990 and multiplied again the decreased average of 2.8 changes per drawing. This equals $168 million savings during 1990. Other benefits were as follows:

- The ECAD system reduced the number of design cycles it took to produce a PCB from 2.5 to 1.5.
- The mechanical CAD (MCAD) system helped reduce the number of engineering man hours to prepare the mock-up of the Patriot missile from 2100 hours to 900 hours.
- The selection of a better CAD support system helped reduce the number of CAD tool designers from 10 in 1984 to 4 in 1991.
- The use of stereo-lithography for preliminary modeling (mock-ups) of mechanical parts from plastic has permitted engineering and management to visualize the product more quickly and at a lower cost than when fabricated from wood or metal. No cost or time savings data was available.

A gross measurement of the improvement in effectiveness of the Martin Marietta work force is noted by the growth in total sales in 1979 from $.75 billion with 15,000 employees to a 1990 sales of $2.5 billion with 8,600 employees.

Lessons Learned:

Martin Marietta still does not fully understand how to best manage an open architecture system. It recognizes that distributed processing is the "wave of the future" and has a handful of pilot projects using the client-server architecture model.

The product description (PDES) activities are wonderful but not progressing fast enough.

E.25 NORTHROP CORPORATION

Description of Business:

Northrop is a leading U.S. aircraft company, most recently noted for its development of the world's first stealth bomber aircraft. In addition both commercial and fighter aircraft are produced at the Hawthorne facility. Northrop also develops and produces military electronic systems and operates an information services division. Our interviews (both the summer of 1991 and spring of 1993) were hosted by the Northrop Information Services Division (NISC).

Industry 1991 and 1993:

Business Strategy:

The responsibility for designing and implementing the company-wide enterprise integration efforts was given to the NISC Division. NISC management initiated, as an initial enterprise integration task, an effort to define the corporation's goals, culture, business interests, and best practices. As part of this process, Northrop's overall management also identified what it considers its core business and expertise. The corporate goals were used by the divisions to better define their own processes, information support requirements, technologies, and system concepts. In mid-1991, Northrop expected that its enterprise integration program would focus on the following implementation sequence: (1) selection of a common process, (2) automation of the common process, and (3) development of a "world-class" process. One goal of Northrop's enterprise integration program was to exchange design, manufacturing, and support information better between the various B-2 program participants. As part of the B-2 program, Northrop proposed establishing the Contractor Integrated Technical Information Service (CITIS).

A new Division was established for the B-2 program. This division brought engineers and managers from across industry, and new perspectives (not all from Northrop) together. Integrated Logistics Support (ILS), normally in engineering, and Quality Assurances (QA), normally in operations and manufacturing, were both raised to VP-level functions to be on a level with engineering.

State of Integration:

At the initiation of the B-2 program, Northrop had several non-integrated computer-aided design (CAD) systems in place. The B-2 program would involve many subcontractors, in addition to the two other major players, Boeing and Vought. Team members recognized that there were no standards in place, and no data release procedures among the participants, and that this would cause difficulties during the program. In addition, the complexity of the B-2 would provide severe manufacturing challenges due to the sculpted surfaces and low observable requirements. An effort was begun to facilitate information integration, sharing, and control among the B-2 team members.

The first step was the creation of a single release database to contain all CAD, part, and ordering information at Northrop. Duplicate systems were installed at Boeing and Vought.

A network with controlled access and encryption devices allowed communication and working data set exchange among Northrop, Boeing, and Vought. Security was a major concern. The major contractors installed secure voice, video teleconferencing, and data lines. Due to the costs of these measures, smaller subcontractors did not participate in graphics interchange. Customers were initially connected like small subcontractors, but will move toward connectivity more like the larger contractors.

The network reduced data redundancy, the primary cause of inconsistencies among engineers. All the information required to run the business was on-line. All engineering tools and models and many post-processors were also on-line.

The single release database permitted access to all design data prior to final release. All downstream functions, such as logistics, had veto power over all design releases.

Using the database and establishing a part-family-oriented design approach based on a significant modeling effort, the team developed an integrated manufacturing process. The part family approach provided greater consistency across designs and allowed greater use of automation in the manufacturing process.

Initially, the three contractors had attempted to get their CAD systems to work together. This effort was abandon in 1981. Instead, a common CAD system was installed at all three companies. This decision was driven by the complexity of the 2-D and 3-D design requirements. Mechanisms were established to provide nightly synchronization of data between the sites. Software was used to ensure consistency and data integrity between design changes at the sites.

A new hybrid job function was created, the data verification engineer. This position encapsulated the knowledge of a 2-D and 3- modeler, a manufacturing engineer, and a data modeler.

One goal for the B-2 program was to eliminate waste in tooling. The approach was to eliminate as much mock-up as possible, instead of driving tooling from models. The results were impressive. All tubing was done via models. The time savings were used to refine designs by permitting extra analyses.

Information Infrastructure:

The B-2 program has exploited electronic data integration between the engineering and manufacturing departments, between Northrop and the Air Force B-2 project office, and, in support of the CALS (Computer-Aided Acquisition and Logistics Support) requirement, between Northrop and the appropriate air logistic centers (ALCs). Within the program, Northrop utilizes Northrop's CAD system (NCAD), coupled to both secure and unclassified T-1 data lines for data transmission to numerous program contractors and Air Force organizations.

Utilizing NCAD, the B-2 team was able to design and prototype (digital prototype) many parts of the airframe and high-performance avionics subsystems, which led to a perfect fit on the initial-build vehicle. This success has led Northrop to adopt the goal of attaining 100% digital prototyping on future systems.

The B-2 contract was also amended to include the electronic delivery of eleven contract data requirements list (CDRL) items to the B-2 SPO and three ALCs. This eliminated the initial requirement for hard-copy delivery of the items. The electronic interchange has led to a much closer interaction of the parties involved in the B-2's development, and thus many of the problems that would not have surfaced until later in the program's life cycle surfaced early and were solved. Early problem resolution in this case is a clear but undocumented cost savings.

Unfortunately, the goal of the B-2 program was to build a unique, state-of-the-art bomber aircraft at the lowest possible cost, not to document the advantages of enterprise integration. However, one metric that was brought to light was that the use of enterprise integration reduced the time to get approval on a provisioning document from 6 months to 60 minutes. This was a result of both Northrop and Air Force personnel being electronically linked and interacting as the document was prepared.

B-2 CITIS

Due to the success and obvious savings resulting from the use of enterprise integration on the B-2 program (delivery of CDRLs, communicating with suppliers and the Air Force, communicating between facilities within Northrop), Northrop proposed to develop and implement a B-2 program-wide electronic information system, the CITIS. The B-2 SPO funded a business case feasibility study on CITIS whose results were published in August 1992. The study looked at a number of data-driven services and processes whose cycle time could be dramatically reduced, thus resulting in costs savings over the current business practice. Some of the savings, such as those associated with the storage of design data, were actual savings documented within the current B-2 program; others were estimates of future cost savings that could be realized if CITIS were implemented.

Estimated cost savings were developed for four levels of CITIS involvement (each level representing a broader application of electronic integration). Based on the Northrop-generated study, the potential cost savings (cost savings and cost avoidance) from CITIS on the B-2 programs ranged from a total of $537 million to $894 million over the life cycle of the initial B-2 buy depending upon the level of CITIS involvement. The analyses also included savings resulting from reduced acquisition time and shortened supply pipelines.

Lessons Learned:

Based on its B-2 experience, Northrop anticipates the greatest barriers to enterprise integration will be the internal resistance to cultural changes. On-line access to information proved to be a new way of doing business to some. Experience showed that it was best not to force people to go on-line if they resisted. Electronic sign-off was accepted by some groups and not others. For instance, the structural engineering group still wanted a paper sign-off.

Additionally, there is the cultural change that must also take place within the customer (Air Force) environment. While the Air Force SPO regarded the electronic interchange of data as a positive action, it also came to the realization that the required specified level of detail regarding protocols, format, and data was far more extensive than originally expected.

Significant procedural changes were also required for the B-2 program. A modelling guide was developed to define the rules for modeling parts to be included in the part family. A multi-discipline, on-line release and change process was established. This release process eliminated the problem of engineers developing finely detailed 3-D models before releasing them to the community for comment and feedback. Engineers now allow earlier sharing of design information.

Common systems were necessary to enable team interaction and cooperation. Software compatibility was required for data portability. Northrop is now trying to de-couple data from the NCAD tool used to create it. The goal is to move toward an open system in the future, eliminating the need to maintain a CAD tool for life.

Some of the benefits derived from the integration efforts on the B-2 program include the following:

- 6:1 form and fit error reduction.
- 17:1 error reduction in tubing. 97% yield in first time tubing.
- 5:1 improvement in producability change incorporation.
- 40% reduction in NC (numerical control) programming effort.
- 475,000 hours avoided in the last 24 months to perform mass updates of drawings and parts lists.
- $2.4 million in savings in travel costs due to teleconferencing.
- $20 million in costs avoided to date with on-line provisioning.
- Drawing cycle time reduced from 55 people days (pre-B-2 program) to 7 people days.
- Decreased shop floor paper and instructions 22,000 pages per vehicle with an on-line IMPCA (Integrated Manufacturing, Planning, Control, and Assembly) system with graphics.

Industry 2001:

Vision:

The B-2 experience has convinced Northrop that enterprise integration is the only practical way to go for the future. The technology exists for enterprise integration. Cultural and organizational changes are needed however. The extent that enterprise integration is implemented will be a function of its business environment, customer base, and the status of its internal business processes. Two areas that need additional attention are change management and configuration control.

Recommendations:

Government:

In order to exploit the benefits of enterprise integration, the SPO will have to be better prepared to receive, process, and act upon data in an electronic format. This include updating the electronic receiving and processing equipment, being prepared to process data electronically, and the training of SPO staff to function within the enterprise integration environment.

Federal Acquisition Regulations (FARS), including Defense (DARS), Navy (NARS), Air Force (AFARS), which restrict the use of program funds to upgrade SPO computer equipment should also be changed.

The questions of how to charge the government for information and the maintenance of the databases containing the information have been not resolved.

E.26 UNITED TECHNOLOGIES - PRATT AND WHITNEY

Description of Business

Pratt and Whitney is one of two U.S. manufacturers of large gas turbine engines. Its product line spans the commercial market's requirement for all large turbofan engines and the military's requirement for high performance turbojets through heavy lift cargo aircraft turbo fan engines and smaller high technology fighter aircraft engines.

Commercial engine development and production is centered in the Hartford, Connecticut, locale, and it is from here that its world-wide engine logistic support network for all commercial aircraft operators originates.

Pratt and Whitney's military aircraft development and production activities are centered in West Palm Beach, Florida. Pratt and Whitney designs and produces some of the most efficient and sophisticated large military fighter aircraft engines in the world. The separate military and commercial development facilities accommodates the need for addressing commercial and military contractual accounting requirements as well as enforcing DoD security requirements.

Industry 1993:

Business Strategy:

Pratt and Whitney made the decision that it was going to do whatever was necessary to enhance its image as a world class supplier of commercial aircraft engines to its worldwide customer base of commercial aircraft operators (about 350 airlines). An internal analysis of the company's business dealings with its customers as well as customer interviews revealed that Pratt and Whitney had developed a serious credibility problem with its customer base. Engine problems were taking too long to resolve, many problems were not being addressed because the problem did not peak somebody's interest, and, when problems were forced into the limelight by an engine user, solutions were tiger-teamed to the detriment of other ongoing problem solutions. The bottom line was that customer problem solving was preventing Pratt and Whitney from filling the world class supplier role it envisioned for itself.

State of Integration:

Pratt and Whitney's management recognized that it had developed a smokestack mentality to data management and flow when in reality a horizontal data flow was needed. Pratt and Whitney embarked upon an enterprise integration program which will eventually encompass all of the company's business activities, both internal and external. To support its enterprise integration activities, Pratt and Whitney undertook an extensive data management restructuring program entitled *Vision 2000*, to serve as the primary facilitator for all enterprise integration activities, data base conversions, updates, and distributed data management plans.

Pratt and Whitney's management established Integrated Product Management Teams (IPMT) composed of operational managers for each major product (e.g., the 4000 engine). These teams meet weekly to review and take action on major problems associated with their product (i.e., PW 4000). There are 10 to 12 Component Integrated Product Teams (CIPT) under each IPMT, one for each engine major subsystem or section (turbine, compressor, etc.). Membership includes the leaders of the various groups involved in the component area (engineering, manufacturing, quality, etc.). The CIPTs also meet weekly. Reporting to the CIPTs are about 100 Integrated Product Teams (IPTs), one for each Pratt and Whitney subcomponent or problem part found in the component (next higher assembly). IPTs are formed for each newly designed part or as problems arise, meet as necessary, and disband when their job is finished. If a problem occurs with their part in the future, the same people reconvene. The total framework of IPMT/CIPT/IPT makes up Pratt and Whitney's Integrated Product Development process or IPD. The enterprise integration data management system has been designed to support the IPD process.

At about the same time that the IPD process was being established, International Aero Engines (IAE), a joint venture between Pratt and Whitney, Rolls Royce, MTU (Motoren - und Turbinen-Union), Fiat, and Japan Aero Engine Company (JAEC) put an Request for Proposal (RFP) on the street to develop a problem-tracking system. The *Vision 2000* group bid and won the contract. The product, VECTORS (V2500 Engineering Change Tracking and Online Reporting System), built on top of IBM's Product Manager, served as the development vehicle for the IPD project. (VECTORS is an electronic folder system that incorporates all the data on a problem previously collected in paper format into a single electronic folder for each problem.)

IAE initiated the VECTORS project because it was spending \$1.5 million a year faxing problems, change orders, and configuration control documents around the world to its partners. Since VECTORS has been installed on-line, IAE costs for the same information control and transmittal has dropped to \$10,000 per month for CPU charges (\$120,000 per year). Program problems under the paper-fax system averaged 100 days from entry into the system until close-out. Under the VECTORS electronic folder control system, average time was reduced to less than 20 days.

Another interesting fact that emerged at IAE with the conversion from the paper tracking system to VECTORS was that only 1,250 active problem solving programs were identified whereas the paper tracking system showed about 1,700 problems being worked in-house. The reason was that under the paper tracking system, once problems were logged in, about 450 problems were never addressed and therefore were not picked up by VECTORS. VECTORS now tracks 100% of the customer and product problems at IAE.

With this experience, the VISION 2000 project office started the development of a series of electronic folders to support the IPD process.

The first product was the Common Problem/Task Report (CPTR) folder which came on-line in June 1992. The project started as a result of customer dissatisfaction with the way problems were solved. Its need was reinforced when Boeing insisted, contractually, that Pratt and Whitney have a problem tracking system in place for all 777 work; a second project, the CPTR folder, was conceived. It was originally thought that the PW2000 engine program would be the first Pratt and Whitney program to use and prove the CPTR folder concept. It is, however, actually being exploited by the PW4000 engine program (the 777 commercial engine program) which currently has about 1,000 problems under active tracking. An Integrated Product Team (IPT) folder is initiated at the IPT level to complete and track engineering change. This is done when the IPT is formed. Into it are recorded all data required to track actions taken by the IPT (problem definition, design changes, solution, owner of solution, etc.), and the folder serves as an up-to-date living electronic document. All folders are currently on a mainframe but the move is to switch from the main frame to a fully distributed system.

When a product problem is identified in test or in the field, a CPTR folder is established at the IMPT or CIPT level. This forces the establishment of an IP team to solve the problem and an IPT folder to record all actions taken. The CPTR becomes the controlling document for its respective IPT folder.

Pratt and Whitney's internal design system of choice is Unigraphics for all solids modeling because it lends itself to a distributed system. It is also going toward extensive use of Sun workstations. Boeing had insisted that Pratt and Whitney use CATIA for all 777 work. Pratt and Whitney resisted but did agree to develop a Unigraphics-CATIA translator with Unigraphic's assistance. It currently has about 2,400 workstations on-line in Pratt and

Whitney plus about 13,000 personal computers. In turn, Pratt and Whitney insisted that all Tier 1 suppliers deliver their designs in CATIA or Unigraphics. Pratt and Whitney is helping its suppliers move to a workstation environment by selling them Pratt and Whitney's old workstations and computers at discounted rates, assisting in the training of the people, and covering them under Pratt and Whitney's software site licenses. One of the payoffs is the ability (also a contractual requirement) to undertake electronic prototyping. In fact, Boeing has required that all 777 engine mock-ups be electronic.

Pratt and Whitney currently has 60,000 active design files. There are 500,000 old designs on file. The active files will be put onto Unix workstations. The old files will be installed when and if they are used: if conversion is justified and metadata is provided. The engineer will have the option of viewing the object in the system using FORMTEK, or by building a Unigraphics object-oriented file. This decision will be made on a case-by-case basis.

In parallel with the design automation process, Pratt and Whitney has reduced its supplier base by over 50%, from about 800 to about 300 suppliers. Pratt and Whitney would like to go to a single source for many of its items, but in turn would like to establish a shared-risk arrangement with its suppliers.

Pratt and Whitney is working on a Distributed Data Management (DDM) system. One of the goals is to ensure that all who are required to work with engineering or design data are working with the latest information. While not documented, Pratt and Whitney estimates that up to 10% of current engineering hours might be wasted hours because a solution or design change is generated by an engineer using his/her own outdated data base. When discovered, corrections are made, of course, but the fact is not made known. Pratt and Whitney has retrained all its engineers to use workstations and Unigraphics, but is still tied to the mainframe to manage all its data. The goal is to move to distributed servers and allow information sharing by maintaining only the metadata on the mainframe. By the fourth quarter of 1993, Pratt and Whitney will have all the drafting groups using shared data (having provided the metadata needed). This new way of doing business will ensure that anyone who requests information will always receive the most recent information available. Drawings will be released in one of several forms, paper (raster images), vector graphics, or solid models.

An interesting metric on the cost savings available when moving from a mainframe-based data management system to a distributed system is that Pratt and Whitney was able to reduce the backup costs from $105.00 per user per month to $18.00 per user on the distributed system.

Documenting the configuration of developmental engines is a serious problem. In the past, the commercial side of Pratt and Whitney exercised much less control over test engine configuration than the military side of the house. All configuration tracking was paper-based and would lag behind the engine build-up (and, unfortunately, frequently the teardown). Pratt and Whitney is going to DECMACS (Development Engine Change Management and Control System). As of February 1993, 85% of the software development was complete. DECMACS will be used initially on the F119 and PW4000 engine programs. As an example of how serious this problem can be, upwards of 600 engineering changes take place on each test engine. Under the current system, many minor changes go unrecorded. DECMACS is intended to change this by providing electronic change control as the engine is built.

Internally, Pratt and Whitney figures that it has about 28 bills of material (BOM) and between 75 to 80 change management systems. For example, each department has its own change management system for each Pratt and Whitney product. The tie-in required by the CPTR and IPT folders to a strong change and configuration management system will erode the feasibility for local (departmental) change management systems, thus forcing the phase-out of the local systems.

Issues and Barriers:

As elsewhere, the major impediment to change is found in the people. For some, it is the need to change a work culture, for others it is the need to accept the fact that what they have been doing for many years is no longer the best way, and in fact, may no longer be needed or wanted. The change in the way the business process is to be managed is also an impediment. New business processes and practices require new management processes. Fortunately, Pratt and Whitney's enterprise integration and data management changes are being championed from the top-down and implemented from the bottom-up.

Industry 2001:

Pratt and Whitney's goal is to strive for a paperless environment where it makes sense, both from a fiscal and practical point of view. Realistically, it knows this will not happen for quite some time due to the nature of its customer base. For example, Pratt and Whitney is currently on line electronically with United Air Lines. But there are many small airline carriers within the Pratt and Whitney customer base of 350 who will not be able to afford to go electronic for many years, and in some cases never.

There are also discussions of single point management of spares inventories between engine operators, overhaul centers, and Pratt and Whitney. Such information will allow major suppliers like Pratt and Whitney to plan production runs and supplier buys far enough in advance to optimize production quantities and schedules for cost breaks.

Is it worth the investment? Pratt and Whitney thinks so. For example, the CPTR and IPT folder concept alone is estimated to decrease product development and problem solution time by at least 10 to 15%. When fully implemented across Pratt and Whitney, this will translate into a $60 million per year savings. The *Vision 2000* project, IPT, CPTR, DECMACS, etc., is currently costing $6 million per year.

APPENDIX F. FRAMEWORKS

The word "framework" is in vogue, being used by organizations to refer to their respective approaches for enabling interoperation among software products. To provide some focus and precision for this study, we introduce the term "operational integration framework" and give its definition in Section F.1.

In particular, software makes up a very large and growing portion of engineered products, and of Department of Defense (DoD) acquisitions. Operational integration framework standards for software engineering environments will help control the costs of software products. In Section F.2, we describe activities in the software engineering community to develop Software Engineering (CASE, computer-assisted software engineering) Frameworks.

F.1 OPERATIONAL INTEGRATION FRAMEWORKS

"Framework" is used to describe many different concepts and kinds of things. In most cases, these descriptions are legitimate: they share some common basis reasonably attributable to the word. Unfortunately, these descriptions also differ in some very fundamental ways and the differences are often unstated, causing confusion. This section contains a proposal for defining a specific use of the word. To make the difference explicit, the term "operational integration framework" will be used.

F.1.1 DEFINITIONS

An operational integration framework (OIF) is a collection of executable software. The OIF is a skeletal part of an operational information and process management system, and provides a set of services and data types common across all information systems based on the OIF. The OIF is used by human users and other software (tools and agents) to structure and manage information, collections of software tools, and collections of external processes in an integrated fashion such that:

a. The actual information being managed may be inserted into the OIF but is not actually part of the framework;

b. The framework manages information and metadata about the *information*—*that* is, it manages the information model which the user organization defines;

c. The actual software tools (a broad term) being managed may be inserted into the OIF but are not actually part of the framework;

d. The framework manages metadata about the tools;

e. Models of processes to be managed are inserted into the OIF but are not actually part of the framework;

f. The framework provides process control mechanisms so that actions can be triggered on the occurrence of events defined in the process model;

g. The framework implements definitions of how information, tools, and models may be inserted into it and it provides mechanisms for controlling that insertion; and

h. The framework provides mechanisms for the enforcement of policies concerning information and tool use (perhaps a subset of item *f*), and mechanisms for the expression of such policies and insertion of them, but the policies themselves are defined by the user-organization.

Thus, the information and process management system that an organization uses will be made up of an OIF fil d in with tools, information and process models, information bases, and policies. Two systems operated by different organizations that are based on the same OIF might contain different kinds of tools and information, different tools or information of the same kind, or identical tools and information. Having the same OIF, they would have the same notion of "kind" and, therefore, they would be able to exchange information of the same kind and the systems would know that they are of the same kind (because of conventions on metadata). Furthermore, communities of interest would have a base, the OIF, in which to implement conventions on information representation, service interfaces, and kinds of policies (e.g., configuration management), and would know that these conventions were enforceable on their systems through the mechanisms of their common OIF. All these are intended to follow from the definition.

Note that there are desirable characteristics of OIFs not listed above. One example might be that the information structuring and metadata allowed must support strong abstract type mechanisms. Another might be that policies must be expressible as rules. It may well be that some of these desirables will be defined in any official standard OIF. For the purposes of understanding the concept and utility of OIF, they are not necessary. Note also that the definition could have been built by defining operational framework, then adding the characteristics having to do with integration support.

F.1.2 RELATIONSHIP TO "ARCHITECTURE"

The word "architecture" is commonly used in the information management community in at least three ways that derive from general use.

First and most basic, is the "architecture process": what architects do. Architects create designs or models of things to be built. In the information world, these may be models or designs that try to describe either functional or structural characteristics of the thing to be built.

Second, is the "product of the architecture process": architectures. These are, as indicated above, designs or models of things to be built. Since all proper models are abstracted from reality (where "proper" is in the set theoretic sense), they always leave out details. In information systems, architectures usually are designs that have significant numbers of significant details left abstract. These absent details are often called "implementation details." The failure of many system implementations gives rise to some speculation about this partitioning of the design problem: it must be done very carefully. On the other hand, a high-level design, or architecture, is often needed to understand the general shape of a system to be built and to make some general or high-level decisions about it. The presence of all the details might make this understanding impossible and their absence may make the decisions wrong. This is probably the fundamental problem of doing multi-level design.

The third meaning of architecture follows from the second and it has to do with the "high-level characteristics of designs." Thus, a system with a "client-server architecture" is one that has certain structures with certain behaviors and interrelationships—similarly, a "cyclically scheduled architecture" or, arguably, a "RISC architecture" (Reduced Instruction Set Computer).

In this third sense, one could describe some systems as having a "framework-based architecture." A system based on an OIF would be of this class. Thus, an OIF is an architectural entity because it is a fundamental and obvious structural entity within a system and would be described as such in the architecture (second meaning) of the system. The architect, doing architecture (first meaning), would have to decide early on that the system would be based on an OIF.

There is also an obvious connection between "architecture" and OIF in the other direction. An OIF is a thing to be built. It must be designed. It is complicated enough to require a high-level design, an architecture (second meaning). In fact, for the purposes of standardization, the architecture may be all that is needed. (It may be that the standardization will proceed at greater depth in some areas of the OIF design, though.)

F.1.3 OPPORTUNITY FOR STANDARDIZATION

The utility of OIF was expressed above in terms of community interactions. This community might be made up of organizations within a company or of organizations from several companies teaming to design and build a product. In either case, there is an economic payoff in having a standard OIF. There is a reasonable level of understanding of the concept in the community of potential suppliers of OIF products and of tool vendors who would build to OIF-specified interfaces. There is even reasonable understanding of how to deal with legacies. And there are some demonstration products. It happens that these products have some but not overwhelming market penetration, and, therefore, the interface specification situation has not yet gotten out of control. There is an opportunity now to start the standardization process in earnest. There will have to be continuing demonstrations of various approaches both to settle some issues and to demonstrate utility in real projects. These demonstrations will also educate the community on the necessary support structures. Nevertheless, the standardization process, focused on an OIF approach to integrated information and process management, is now feasible.

F.1.4 OPERATING SYSTEM OF THE FUTURE?

The similarities between OIF and the notion of operating system are pretty obvious. Operating systems manage memory, manage internal (computer) processes, manage input/output (I/O) resources, run the file system, and perhaps a few other things. Some of these functions can be modularized (operating systems used to be conceived as including the user interface). If the world began using OIF-based systems, eventually unneeded modules of what we now call operating systems would be cast away. A micro kernel might be all that is needed and would produce maximum performance. The OIF might be the operating system. Evidence of a trend in this direction can be found in the widespread use of Microsoft Windows, which provides inter-tool services to tools on a simulated desktop, similarly the Apple Macintosh operating system, and the reported work on joint development of an object-oriented operating system by Apple and IBM.

F.2 SOFTWARE ENGINEERING (CASE) FRAMEWORKS

The software engineering community is developing sophisticated operational frameworks for the integration of software engineering. This section describes some of the efforts in order to give the reader a feel for the kinds of activities happening in the development of potential standards for operational frameworks in one community.[1]

F.2.1 DEFINITIONS AND TERMS

The term "framework" has been used in several ways. For CASE environments, "framework" is generally accepted to refer to a set of common services, found in all environments, and callable by an *ad hoc* tool that is introduced to the environment. The National Institute of Standards and Technology (NIST) Reference Model,[2] based on earlier work done by the European Computer Manufacturers Association (ECMA), has been widely accepted throughout the CASE community. Its definition of "framework" is generally accepted as definitive:

> Current thinking in the area of CASE environments is that an environments consists of a (relatively) fixed set of core facilities which form the "Environment Framework," and a set of facilities, called "Tools," which are more specialized for particular environments and cannot be presumed to be available in all environments. Tools use the services provided by the environment framework to a large extent, and as integration mechanisms evolve over time, this will increase . . . Services in one part of the framework may use services in other parts of the framework.

The NIST Reference Model defines the following categories of framework services: Object Management, Task Management, Communication, User Interface, Tool Integration, Security, and Framework Administration/Configuration.

Central to most descriptions of a framework, including the NIST model, is the supposition that the framework is an integrating agent. Three forms of integration are commonly assumed: data integration, control integration, and presentation integration. In the NIST model, the first two are categorized as Object Management services and the third as a User Interface service. Differing strategies for Object Management services are a partial reason for the current lack of uniformity that now exists. In particular, divergent opinion as

[1] A more general baseline, summarized in Section 5 of this document, can be found in the Institute for Defense Analyses Document D-1386, *Current Standardization and Cooperative Efforts Related to Industrial Information Infrastructures.*

[2] *A Reference Model for Computer Assisted Software Engineering Environment Frameworks*, National Institute of Standards and Technology working draft, prepared by the NIST Integrated Software Engineering Environment (ISEE) Working Group, May 29, 1991.

to an object-oriented (OO) approach to information management has been and continues to be a barrier to widespread agreement on framework standards.

F.2.2 STANDARDS, PRODUCTS, AND INITIATIVES

There are many initiatives including government-sponsored projects, industry consortia, and proprietary programs working in various areas of CASE frameworks. Few of these initiatives are in direct competition; rather, each has targeted a particular subset of the frameworks domain. This makes comparisons difficult, since few programs are really comparable. Further, many ongoing initiatives not specific to CASE, or even software engineering, have significant overlap with others that are specifically in the CASE domain. As an example: CALS (DoD's Computer-Aided Acquisition and Logistics Support) embraces the Product Data Exchange Specification (PDES), a proposed standard for computer exchange of data, and will depend on SQL (a software standard for database queries) and the Information Resource Dictionary System (IRDS), a specification for a standard data dictionary system. While none of these areas (CALS, PDES, SQL, IRDS) is particularly *centered* in the domain of software engineering environments, all of these efforts and possible standards are *concerned* with software engineering; many CASE framework standards have relevance to these other areas as well.

Nonetheless, very general categories may be useful, even if only to organize our thinking. These categories are rooted in simple distinctions: whether the initiative is government-sponsored or industry; whether it is aiming to create an interface standard or a full product; whether it is developing a framework entity or an environmental one; whether the effort is software-centric or not. One other category, that cuts across these, is that of *profiles*. NB: It should be noted that the term "standard" is used loosely here, and may apply to existing, developing, or proposed standards.

F.2.2.1 General Software Tool Interface and Integration Standards

Most of these standards are commonly referred to as "frameworks," notwithstanding the fact that none of them supplies the entire set of services called out in the NIST Reference Model.

F.2.2.1.1 ATIS (A Tools Integration Standard)

ATIS is a developing OO framework standard that originated in a commercial product. As ATIS matured, it was subsumed into a consortium called CIS (CASE Integration Services) and was proposed to the American National Standards Institute (ANSI) as a formal working group. ANSI first rejected, then accepted the proposal; CIS is now ANSI/X3H6. ATIS is widely regarded as the most mature object-oriented framework standard, and is the basis for a commercial framework product (Atherton's Software Backplane), and a commercial CASE environment (Digital Equipment Corporation's Cohesion).

F.2.2.1.2 CAIS (DOD-STD 1838) (Common Ada Programming Support Environment (APSE) Interface Set)

CAIS is based on an entity-relation-attribute (ERA) node model; it originated in the early days of Ada, and was developed to provide tool portability and tool interoperability between different Ada environments. CAIS was superceded by CAIS-A (MIL-STD-1838A); this has to some extent been extended by the Portable Common Interface Set (PCIS) (*q.v.*) The CAIS program has been supported by the Ada Joint Program Office, which is now a major supporter of the PCIS program.

F.2.2.1.3 IRDS (Information Resource Dictionary System)

IRDS exists in two somewhat different versions, one an International Organization for Standardization (ISO) standard and one an ANSI standard. IRDS defines a model similar to a relational model based on SQL, and is aimed at data modeling in information systems. Information is stored at the definition and at the IRD level. The IRD level contains the application data. Schema information is available through tables that define entities, attributes, and relationships; an object in ISO/IRDS is actually the result of a join of two tables. There exist plans for an IRDS2, though it is not known what effect the existence of X3H6 will have on the development of IRDS2.

F.2.2.1.4 P1175/D6 (IEEE Reference Model for Interconnections Between Computing System Tools)

P1175 is targeted at "computing system tools"; omitted are such tools as graphical drawing packages and word processing; included are computer-assisted engineering (CAE) and both variants of CASE (i.e., "Software" and "System"). The standard is centered in the connections area; one notable element is the notion that tools are interconnected with such items as organizations, application domains, business information modeling. This standard was to have been submitted to the IEEE Computer Society's Task Force on Professional Tools. Balloting was scheduled to take place during the Fall of 1990; submission to the IEEE Standards Board was scheduled for February 1991.

F.2.2.1.5 PCTE (Portable Common Tool Environment)

PCTE, like CAIS, is an ERA system, and is available in a commercial implementation from Emeraude. There are apparently several other incipient commercial implementations, though none have yet been widely advertised. PCTE has been superceded by PCTE+ and also by ECMA/PCTE. Note that PCTE+ and ECMA PCTE overlap in most areas, but neither is a subset of the other. PCTE is also a major [illegible]nt in the PCIS program. It is the framework for at least two commercially availab[illegible]nments (EAST, Enterprise II). PCTE is expected to be submitted for ISO standardization in 1992.

F.2.2.1.6 PCIS (Portable Common Interface Set)

PCIS was originally planned as a merger between CAIS and PCTE, both of which are ERA systems, and between which there is significant overlap. PCIS is now broader in scope, and is planning to embrace OO concepts as well. PCIS has recently developed a set of requirements, and is currently refining them as well as defining the scope of the standard. The original target for a PCIS specification was 1994; that date is likely to change as the requirements for PCIS are refined.

NB: PCTE and ATIS are generally regarded as the foremost of the developing standards, and are also regarded as competitors. Numerous efforts are being made to find a rapprochement between them. The Software Technology for Adaptable, Reliable Systems (STARS) Program held a Frameworks Convergence Conference in January 1991,[3] for this purpose. The convergence is especially likely due to the explicit statement (in the proposal accepted by ANSI) that the eventual outcome of X3H6 (standardization of ATIS/CIS) must reconcile itself to and be implementable over PCTE. One potential route for this convergence may be the PCIS activity; there has been speculation that the goals of PCIS and the ANSI X3H6 working group will essentially converge.

F.2.2.2 Government-Sponsored Projects Developing Specific Software Engineering Environments

The following sections contain examples of many government projects developing software engineering environments.

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[3] Carney, D. and Belz, F., *Report on the Software Technology for Adaptable, Reliable Systems Conference on Frameworks Convergence*, IDA Document D-972, Institute for Defense Analyses, Alexandria, VA, 1991.

F.2.2.2.1 ESF: EUREKA Software Factory

The ESF project is a European research effort funded under the EUREKA program. It began in 1986 and is intended to last 10 years. The effort is aimed at producing a configurable software engineering environment; ESF has produced a reference architecture which standardizes interfaces between environment components. Particular characteristics of a "software factory" include interface uniformity, incremental interaction, support for diverse life-cycle paradigms, extensibility, tight integration of components, support for distribution, reuse and customization, portability, and heterogeneity. EUREKA contains the notion of a process model; those aspects of the environment driven by the process model are provided by a process programming language.

F.2.2.2.2 SIGMA (Software Industrialized Generator and Maintenance Aids)

SIGMA is a joint project of the Japanese government and some 50 commercial companies in Japan. The expected cost will be $200 million over a five-year development period. Sigma is seen as an all-embracing, national software activity. The nucleus of Sigma is the Sigma Center, located in Harumi near Tokyo. While the term "repository" is not used to describe the Sigma Center, its activities intersect with many of those envisioned in American repository efforts. A major component of Sigma is the Sigma Network, a Unix-based network that connects all Sigma sites. The network will transmit files, messages, and will permit target-machine access functions. The operating system for Sigma is a revision of Unix that includes functions for Japanese-language processing, graphics, windows, and database functions. Finally, Sigma will be populated with a large number of general-purpose tools (e.g., planners, requirements analysis tools, process-flow editors).

F.2.2.2.3 SLCSE (Software Life Cycle Support Environment)

SLCSE originally was a project sponsored by Rome Air Development Center. Development began in 1986; a final prototype was delivered in August 1989. Further work is in progress at this time. SLCSE is a DEC-VAX/VMS-based software development environment framework intended to present common and consistent user interfaces accessing a comprehensive set of tools that fully support MIL-STD-2167A. The data model is tailorable to support a variety of life cycle models. SLCSE distinguishes between a "Framework Database" and a "Project Database"; only the latter is specified as using an ER model. The Project Database is implemented on top of commercial relational databases supporting SQL; it uses a client-server architecture that supports integration of CASE tools resident on any platform configured as a DECnet node. The project continues to evolve; the original operational concept of SLCSE included material from the STARS Operational Concept document of 1985; the current Reference Model used to describe SLCSE is apparently based on the model from the NIST Reference Model. One particular future direction is inclusion of an object-oriented data model.

F.2.2.2.4 STARS (Software Technology for Adaptable Reliable Systems)

The STARS program is sponsoring three prime contractors (Boeing, IBM, Unisys) to develop environments based on a common architecture and a set of common standards. The program is also heavily aimed at bringing about a paradigm shift toward process-driven, reuse-based software development. The current set of common standards is very similar to the NIST Applications Portability Profile (*q.v.*). The STARS environments are scheduled to be put into use in late 1993. The three STARS environments are intended to be commercialized by the "commercial counterparts" of the prime contractors, which in the case of Boeing is the Digital Equipment Corporation.

F.2.2.3 Industrial Initiatives and Consortia

There are a very large number of commercial efforts, some of which are existing commercial products, others of which will soon be available. One class of these products is based on the developing ATIS standard, and includes Atherton's Software Backplane (a framework product) and Digital Equipment Corporation's Cohesion (a populated environment). Another class is based on PCTE, and includes Emeraude's implementation of PCTE (a framework product), and two environments from French companies (EAST from SFGL, and Enterprise II from Syseca). There are several other emerging products, about which little information has yet been released. Two environments from IBM, AD/Cycle and AIX/CASE, are expected to be based on PCTE. HP Softbench, from Hewlett-Packard, is also expected to be become a PCTE-based product.

Another set of efforts is less clearly commercial. This includes industrial consortia, sometimes with government support. The scope of these varies widely, for example, from development of a single standard data format to a broad set of agreements on standards and protocols.

F.2.2.3.1 CDIF (CASE Data Interchange Format)

The CDIF Technical Committee operates under the authority of the Electronic Industries Association (EIA), a voting member of ANSI. This effort appears to be a joint effort of several commercial participants, though CALS and P1175/IEEE representatives have attended CDIF meetings. The CDIF Charter is "To develop an ANSI standard (eventually to become an ISO standard) for the exchange of information between CASE environments." At the Plenary Session of CDIF in July 1990, representatives from CALS and P1175 were in attendance. In particular, there was a strong indication that members from various standard bodies would welcome cross-fertilization between and among efforts such as CDIF, PDES, CALS, and P1175. The schedule for public review of the CDIF standards was to occur throughout September and October 1990.

F.2.2.4 Related Efforts

The following efforts do not concentrate on CASE but are closely related enough to warrant attention.

F.2.2.4.1 EIS (Engineering Information Systems)

EIS was a government-sponsored effort led by Honeywell, Inc. The original concepts and requirements for EIS, published in 1986, were the result of a research effort by the Institute for Defense Analyses (IDA). EIS is a system embedded in an engineering environment, with components external to EIS itself; in essence, it is a framework, parameterized by an information model and described in a standard modeling technique. The model (and hence the EIS instance) is object based, i.e., with classes, relations. The program addresses heterogeneity of hardware and software platforms, data formats, tools, site-specific policies, and interfaces, all primarily oriented toward the computer-assisted engineering (CAE) domain. The approach consists of consolidating a broad set of functional requirements, standards, and guidelines for services that will enable and accelerate a trend toward uniform engineering environments and information exchange. EIS is conceptually a set of fundamental services (much like an operating system) and a series of specifications forming a baseline for communication and implementation. There are three basic parts: the Engineering Information Model (EIM), the EIS Framework, and the User Interface Management System (UIMS). The EIM contains electronic design information; it may be extended with site-specific semantic models that capture site-particular data. The EIM is implemented as a reference schema that establishes the functional interfaces to the EIS data. The EIS Framework consists of an Object Management System, an Application Object Model, and Engineering Services. The UIMS consists of guidelines and candidate standards for interfaces to a CAE system; it concentrates on interfaces for interactive applications and adaptations.

F.2.2.4.2 SEMATECH

SEMATECH is a government-industry consortium concentrating on the manufacture of semiconductor devices. It has a CASE environment project currently in requirements development.

F.2.2.5 Groups/Portfolios/Profiles of Standards

The following is a list of collections of standards relevant to CASE environments.

- NIST Application Portability Profile
- XPG3 (X Portability Guide, Version 3)
- STARS Standard Portfolio
- NGCR (Next Generation Computer Resources) (a Navy-led DoD activity).

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LIST OF ACRONYMS

2-D	Two Dimensional
3-D	Three Dimensional
3-D EMU	Three-Dimensional Electronic Mock-Up
ABC	Activity Based Costing
AD	Application Development
ADE	Advanced Development Environment
ADPS	Application Development Project Support
ADSRS	Automated Drawing Storage and Retrieval System
ADW	Application Development Workbench
AEP	Application Environment Profiles
AFARS	(U.S.) Air Force Acquisition Regulations
AFB	Air Force Base
AIAG	Automotive Industry Action Group
ALC	Air Logistics Center
AME	Association for Manufacturing Excellence
AMT	Advanced Manufacturing Technology; Association for Manufacturing Technology
ANSA	Advanced Network Systems Architecture
ANSI	American National Standards Institute
AP	Application Protocol
API	Application Programming Interfaces
APM	Architecture Projects Management
APP	Application Portability Profile
APSE	Ada Programming Support Environment
APT	Application Programming Technology
ARPA	Advanced Research Projects Agency
AQES	Advanced Quality Engineering System
ASIC	Application-Specific Integrated Circuit
ASPC	Automated Semiconductor Planning and Control System

ATA	Airline Transportation Agency
ATD	Advanced Technology Demonstration
ATF	Advanced Tactical Fighter
ATIS	A Tools Integration Standard
B&P	Bid and Proposal
BOM	Bill of Materials
C^3I	Command, Control, Communications, and Intelligence
CACS	Computer-Integrated Manufacturing (CIM) Application Consulting Services
CAFE	Corporate Average Fuel Economy
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAIS	Common Ada Programming Support Environment (APSE) Interface Set
CALS	Computer-Aided Acquisition and Logistics Support
CAM	Computer-Aided Manufacturing
CAM-I	Computer-Aided Manufacturing-International
CAMO	Computer-Aided Miscellaneous Operations
CAPP	Computer-Aided Production Planning
CASE	Computer-Aided Software Engineering
CAX	Computer Aided everything, X is a variable
CCIP	Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) Integration Plan
CCR	Commitment, Concurrency and Recovery Protocol
CCS	Common Communications Support
CDF	Common Data Facility
CDIF	Computer-Assisted Software Engineering (CASE) Data Interchange Format
CDM	Common Data Model
CDRL	Contract Data Requirements List
CE	Concurrent Engineering
CEO	Chief Executive Officer
CFI	Computer-Aided Design (CAD) Framework Initiative
CGM	Computer Graphics Metafile
CGS	Corporate Graphics System
CI	Continuous Improvement
CIE	Computer-Integrated Enterprise

CIM	Computer-Integrated Manufacturing
CIM-OSA	Computer-Integrated Manufacturing - Open System Architecture
CIO	Computer Integrated Operations
CIPT	Component Integrated Product Team
CIS	Center for Integrated Systems, Stanford University; Computer -Assisted Software Engineering (CASE) Integration Services
CISTAR	Computer Integrated Systems, Technologies, and Resources
CITIS	Contractor Integrated Technical Information Service
CLOS	Common LISP Object System
CMM	Coordinate Measuring Machine
CNC	Computer Numeric Control
CORBA	Common Object Request Broker Architecture
COF	Customer Order Fulfillment
COS	Corporation of Open Systems
COTS	Commercial-off-the-Shelf
CPI	Common Programming Interface; Continuous Process Improvement
CPTR	Common Problem Task Report
CPU	Central Processing Unit
CRUD	Created, Read, Updated, Deleted
CSRC	Computer-Aided Acquisition and Logistics System (CALS) Shared Resource Center
CUA	Common User Access
CV	Computer Vision
CVS	Central Version System
DAE	Distributed Application Environment
DARS	Defense Acquisitions Regulations
DART	Data Archival and Retrieval
DBMS	Data Base Management System
DCE	Distributed Computing Environment
DDM	Distributed Data Management
DDR&E	Director, Defense Research and Engineering
DEC	Digital Equipment Corporation
DECMACS	Development Engine Change Management and Control System
DEM/VAL	Demonstration/Validation
DES	Data Encryption Standard

DECMACS	Development Engine Change Management and Control System
DFA	Design for Assembly
DFM	Design for Manufacture
DME	Distributed Management Environment
DMU	Digital Mock Up
DoD	Department of Defense
DOMF	Distributed Object Management Facility
DPA	Digital Pre-Assembly
DPU	Defects Per Unit
DRC	Database Relational Common
DRM	DB2 unique extension of DRC (M denotes MVS)
DSD	Design Support Database
DSEG	Defense Systems and Electronics Group
DSOM	Distributed System Object Management
E-R	Entity-Relationship
EAP	Electronic Assembly Plant
ECAD	Electronic Computer-Aided Design
ECMA	European Computer Manufacturers Association
ECO	Engineering Change Order
EDA	Electronic Design Application
EDI	Electronic Data Interchange
EDIF	Electronic Data Interchange Format
EDS	Electronics Data Systems
EEI	External Environment Interface
EI	Enterprise Integration
EIA	Electronic Industries Association
EIM	Engineering Information Model
EIP	Enterprise Integration Program
EIS	Engineering Information Systems
EISWG	Engineering Information Systems Working Group
EIT	Enterprise Integration Technology
EMD	Engineering and Manufacturing Division; Engineering and Manufacturing Development
ENE	Enterprise Networking Event
EPA	Enhanced Performance Architecture; Environmental Protection Agency

ERA	Entity-Relation-Attribute
ESF	EUREKA Software Factory
ESG	Electronic Systems Group
FAA	Federal Aviation Administration
FARS	Federal Acquisition Regulations
FCS	Factory Control System
FDDI	Fiber Data Digital Interface
FIPS	Federal Information Processing Standard
FTAM	File Transfer, Access, and Management
GE	General Electric
GEAE	General Electric Aircraft Engines
GKS	Graphics Kernel System
GM	General Motors
GM-C4	General Motors - Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), Computer-Aided Engineering (CAE), Computer-Integrated Manufacturing (CIM)
GNMP	Government Network Management Profile
GOSIP	Government Open Systems Interconnection Profile
HLL	High-Level Language
HP	Hewlett-Packard
HPGL	Hewlett-Packard Graphics Language
I/O	Input/Output
IAE	International Aero Engines
IC	Integrated Circuit
ICAM-FoF	Integrated Computer-Aided Manufacturing Factory of the Future
IDA	Institute for Defense Analyses
IDE	Inspection Data Entry
IDEF	ICAM DEFinition Language
IDF	Integrated Data Format
IDL	Interface Definition Language
IDMS	Integrated Data Management System
IDS	Integrated Design Support System
IEEE	Institute of Electronics and Electrical Engineers, Inc.
IEF	Information Engineering Facility; IBM Engineering Framework
IEW	Information Engineering Workbench

IGES	Initial Graphics Exchange Specification
IIS	Integrating InfraStructure
IISS	Integrated Information Support System
ILS	Integrated Logistics Support
IMPCA	Integrated Manufacturing, Planning, Control, and Assembly
IMPT	Integrated Product Management Team
IMS	Information Management System
IP	Internet Protocol
IPD	Integrated Product Development
IPDS	Integrated Product Development System
IPMT	Integrated Product Management Team
IPO	Initial Graphics Exchange Specification - Product Data Exchange Specification (IGES-PDES) Organization
IPPD	Interacted Product/Process Development
IPT	Integrated Product Team
IR&D	Internal Research and Development
IRD	Information Resrouce Dictionary
IRDS	Information Resource Dictionary System
IRR	Internal Rate of Return
IS	Information Systems
ISA	Instruction Set Architecture; Information Systems Architecture (Hughes)
ISD	Industrial Sector Division (IBM)
ISEE	Integrated Software Engineering Environment
ISO	International Organization for Standardization
ISST	Information Systems Study Team
ITC	Inter-Tool Communication
IWSDB	Integrated Weapon Systems Data Base
JAEC	Japan Aero Engine Company
JIT	Just in Time
JV	Joint Venture
JSD	Jackson System Design
KBS	Knowledge-Based System
LAPI	Layered Application Program Interface
LASC	Lockheed Aeronautical Systems Company
LAWS	Lockheed Advanced Wiring System

LCM	Least Common Manager
LDRO	Long Data Reference Option
MAP	Manufacturing Automation Protocol
MBR	Model Based Reasoning
MCAD	Mechanical Computer-Aided Design
MCAE	Mechanical Computer-Aided Engineering
MCC	Microelectronics and Computer Technologies Corporation
MCO	Manufacturing Change Order
MCS	Material Control System
MCSG	Motorola Cellular Subscriber Group
MENTRANS	MENTOR Computer-Aided Design (CAD) Translator
MIP	Methods Improvement Program
MKS	Manufacturing Knowledge System
MMAS	Manufacturing, Material, and Acquisition System
MMS	Manufacturing Message Specification
MMST	Microelectronics Science and Technology
MPD	Motorola Paging Division
MPEP	Mass Properties Estimation Procedures
MRP	Manufacturing Resource Planning
MS&T	Manufacturing Science and Technology
MS-DOS	MicroSoft Disk Operating System
MSG	Missile Systems Group (Hughes)
NTMA	National Tooling and Machine Association
MTU	*Motoren - und Turbinen-Union*
NARS	(U.S.) Navy Acquisition Regulations
NAS	Network Application Support
NASA	National Aeronautics and Setbacks Administration
NC	Numerical Control
NCAD	Northrop Computer-Aided Design
NCAT	National Center for Advanced Technologies
NCS	Network Computing System
NCMS	National Center for Manufacturing Sciences
NCSL	National Computer Systems Laboratory
NDDL	Neutral Data Definition Language
NDML	Neutral Data Manipulation Language

NEMA	National Equipment Manufacturers Association
NFS	Network File System
NGC	Next Generation Controller
NGCR	Next Generaiton Computer Resources
NIH	Not Invented Here
NII	National Information Infrastructure
NISC	Northrop Information Services Division (Northrop)
NIST	National Institute for Standards and Technology
NSF	National Science Foundation
NTIS	National Technical Information Services
NTM	Network Transaction Manager
NTMA	National Tooling and Machine Association
OASD(P&L)	Office of the Assistant Secretary of Defense (Production and Logistics)
ODA	Open Document Architecture
ODETTE	Organization for Data Exchange by Tele Transmission in Europe
ODIF	Open Document Interchange Format
ODL	Open Document Language
ODP	Open Distributed Processing
OEM	Original Equipment Manufacturer
OIF	Operational Integration Framework
OLE	Object Linking and Embedding
OMG	Object Management Group
OO	Object Oriented
OO-CORE	Object-Oriented, Change-Oriented Reference Environment
OO-SQL	Object-Oriented SQL
OODB	Object-Oriented Data Base
OSA	Open System Architecture
OSAT	Office for the Study of Automotive Transportation
OSD	Office of the Secretary of Defense
OSE	Open System Environment
OSF	Open Software Foundation
OSHA	Occupational Safety and Health Administration
OSI	Open System Interconnection
P&L	Profit and Loss
P&W	Pratt and Whitney

PC	Personal Computer
PCB	Printed Circuit Board
PCIS	Portable Common Interface Set
PCTE	Portable Common Tool Environment
PDCM	Product Data Conceptual Model
PDCS	Product Drawing Control System
PDE	Product Data Exchange
PDES	Product Data Exchange Specification
PDM	Product Data Management
PDR	Preliminary Design Review
PDS	Product Definition System
PDUSD(A)	Principal Deputy Undersecretary of Defense for Acquisition
PHIGS	Programmer's Hierarchical Interactive Graphics System
PM	Program Manager
POMS	Process-Oriented Management System
POSIX	Portable Operating System Interface for Computer Environments
PRISM	Partnership for Research in Information Systems Management project
PWA	Printed Wire Assembly
QA	Quality Control
QC	Quality Control
QFD	Quality Function Deployment
R&D	Research and Development
RAM	Random Access Memory
RAMP	Rapid Acquisition of Manufactured Parts
RDA	Remote Data Access
REF	Repository Enablement Facility
RFP	Request for Proposal
RISC	Reduced Instruction Set Computer
RM	Repository Manager
ROI	Return on Investment
RPC	Remote Procedure Call
S&CG	Space and Communications Group (Hughes)
S&T	Science and Technology
SA/SD	Structured Analysis/Structured Design
SAA	Systems Application Architecture

SADT	Structured Analysis and Design Technique
SAI	Services Access Interface
SBIR	Small Business Innovative Research
SCC	Strategic Cell Controller
SCCS	Source Code Control System
SCLM	Software Configuration and Library Manager
SE	Software Engineering
SEAS	Standard Electronic Assembly System
SGML	Standard Generalized Markup Language
SIG	Strategic Interest Group
SIGMA	Software Industrialized Generator and Maintenace Aids
SISP	Strategic Information System Planning
SLCSE	Software life Cycle Support Environment
SME	Society of Manufacturing Engineers
SNA	Systems Network Architecture
SOM	System Object Management
SPC	Statistical Process Control
SPO	Subsystem Project Office
SSD	Structured Systems Development
ST	Standards and Technologies
STARS	Software Technology for Adaptable, Reliable Systems
STEP	Standard for the Transfer and Exchange of Product data
STOP	Standards, Technologies, Organizations, Programs
SUMM	Semantic Unification Meta-Model
SVR4	System V Release 4
TCP	Transmission Control Protocol
TES	Tool Encapsulation Specification
TFA	Transparent File Access
TI	Texas Instrument
TIE	Team Integration Environment (IBM)
TIES	Tooling and Information Engineering System
TOP	Technical and Office Protocol
TP	Transaction Processing
TQM	Total Quality Management
TRP	Technology Reinvestment Program

TTM	Time-to-Market
U.S.	United States
UAW	United Auto Workers
UG	Unigraphics
UI	User Interface
UIMS	User Interface Management System
VECTORS	V2500 Engineering Change Tracking and Online Reporting System
VHDL	Very High Speed Integrated Circuit (VHSIC) Hardware Description Language
VI	Virtual Terminal
VLSI	Very Large Scale Integrated circuit
UI	User Interface
WISE	Westinghouse Integrated Systems Environment
XVT	Extensible Virtual Tool kit