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INTEGRATED INFORMATION SUPPORT SYSTEM (IISS)
Volume IV - IISS System
Part 6 - Enterprise Integration Framework (EIF) for Aerospace

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FOREWORD

This technical report covers work performed under Air Force Contract F33600-87-C-0464, DAPro Project. This contract is sponsored by the Manufacturing Technology Directorate, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. It was administered under the technical direction of Mr. Bruce A. Rasmussen, Branch Chief, Integration Technology Division, Manufacturing Technology Directorate, through Mr. David L. Judson, Project Manager. The Prime Contractor was Integration Technology Services, Software Programs Division, of the Control Data Corporation, Dayton, Ohio, under the direction of Mr. W. A. Osborne. The DAPro Project Manager for Control Data Corporation was Mr. Jimmy P. Maxwell.

The DAPro project was created to continue the development, test, and demonstration of the Integrated Information Support System (IISS). The IISS technology work comprises enhancements to IISS software and the establishment and operation of IISS test bed hardware and communications for developers and users.

The following list names the Control Data Corporation subcontractors and their contributing activities:

SUBCONTRACTOR	ROLE
Control Data Corporation	Responsible for the overall Common Data Model design development and implementation, IISS integration and test, and technology transfer of IISS.
D. Appleton Company	Responsible for providing software information services for the Common Data Model and IDEF1X integration methodology.
CNTEK	Responsible for defining and testing a representative integrated system base in Artificial Intelligence techniques to establish fitness for use.
Simpact Corporation	Responsible for Communication development.
Structural Dynamics Research Corporation	Responsible for User Interfaces, Virtual Terminal Interface,and Network Transaction Manager design, development, implementation, and support.
Arizona State University	Responsible for test bed operations and support.

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SECTION 1

INTRODUCTION

1.1 Background

In September 1989, Control Data awarded subcontracts to IBM Corporation and Northrop Corporation for the Enterprise Integration Framework task. This document presents, as an unedited appendix, the final report of the Northrop effort. DAPro document EIF 620350002 provides the IBM Workshop Briefing.

1.2 Disclaimer

The conclusions presented by this document are those of the Northrop EIF Team and do not necessarily reflect those of either Control Data or WRDC/MTI. The release of this document does not imply endorsement by the USAF.

SECTION 2

EIF OBJECTIVES

2.1 WRDC/MTI Statement of Work

In June 1990, WRDC/MTI released a SOW defining the Enterprise Integration Framework task. A simplified version of that SOW is presented in this section.

2.1.1 Background

The Integration Technology Division of WRDC/MTI and their cosponsors will be leading an effort to define, develop, and validate through implementations a national framework for inter and intra enterprise integration based on open systems and national and international standards. This effort will be cosponsored by the Defense Manufacturing Office of the Defense Advanced Research Projects Agency (DARPA DMO), the Computer Aided Acquisition and Logistics Support (CALS) office in the Office of the Secretary of Defense (OSD CALS), and the National Institute for Standards and Technology (NIST). This effort will begin with a preliminary strawman framework development task to serve as the catalyst for national debate and involvement in follow-on longer term programs for the development and implementation of open systems for enterprise integration. It is anticipated that a national consensus will emerge, resulting in a United States model for the development of international standard(s) for integrating many types of applications and industries. Opportunities will be sought for cooperation and coordination with other related international efforts.

This task for development of a preliminary or strawman enterprise integration framework will build off of prior and ongoing work including the European Strategic Program for Research on Information Technology (ESPRIT) consortium developing a Computer Integrated Manufacturing Open Systems Architecture (CIM OSA). For a number of reasons, the United States has been slow to respond in a unified, coordinated manner to this activity. To facilitate the design of a comprehensive enterprise integration framework, the approach of this task is not to start from scratch, but to evaluate the relevance of leveraging the ESPRIT CIM OSA effort as well as other potentially relevant existing initiatives. The resulting framework will provide a stable, low-risk strategy for coordinated investment by government and industry in automated infrastructures. The framework will also provide a common reference model for establishing research priorities, modernization of DoD activities, and standards efforts. A number of closely coordinated activities of the sponsors will support the development of the national framework initiated by the strawman framework from this effort.

2.1.2 Scope of Effort

This enterprise integration strawman framework effort shall span an eight month time period. There will be two tasks executed serially: task one shall last two months, task two shall last six months. The objective of the effort is to employ contractor expertise to work closely with a NIST-led Framework Advisory Board (FAB) to quickly assess the state of the art, develop a strawman framework, and perform a domain impact study for the framework. While the focus of the effort is primarily domain independent, the contractor shall focus primarily (but not exclusively) on aerospace enterprise issues to include an aerospace organization's interfaces to the government and to subtier suppliers. Task 1 should not exceed 25% of the total effort; task 2 shall compose the remainder of the effort.

2.1.3 EIF Tasks

Task 1: Preliminary Scoping Document and Development Plan

1.1 The contractor shall submit a monthly status project status letter to the AFPMO to identify significant events, accomplishments, contractor/government liason activities/meetings, potential problem areas or issues, and related progress throughout this effort. The contractor shall use the IDEF methodologies and other formal structured techniques as required for reporting results when appropriate. The contractor shall develop and document a management plan for performing the activities of task 1 and task2.

1.2 The contractor shall develop an unclassified, annotated bibliography and assessment of existing material which is relevant to the framework development. Using this source material, the contractor shall extract a list of requirements, issues, measurement criteria, and sources. The contractor shall provide input to the NIST-led FAB in order to develop a single clear mission statement and criteria for evaluating the success of the framework strawman.

1.3 The contractor shall develop a list of enterprise processes, building a matrix showing how each process contributes to mitigating the issues in achieving enterprise integration. The contractor shall build a list of information classes for each process. The contractor shall develop a glossary of enterprise integration terminology to submit to the FAB and assist in the development of a single, consistent glossary to be finalized by the FAB.

1.4 The contractor shall participate as authorized by the AFPMO in government led and sponsored discussions with national and international organizations such as ESPRIT.

1.5 The contractor shall evaluate the ESPRIT CIM OSA work and any other relevant initiatives identified in subtask 1.2, and make recommendations on (a) using CIM OSA terms and definitions in the framework and in the enter-prise integration glossary, (b) extensions to CIM OSA reference architecture needed to address the issues identified in subtask 1.2, and (c) using the extended CIM OSA reference architecture to populate the framework processes in task 2.

1.6 Using the results of the previous subtask, the contractor shall develop an EIF development plan for defining a strawman framework interms of requirements, issues, enterprise processes, and information types in task 2.

1.7 The contractor shall present the results of task 1 and the EIF development plan at a government sponsored workshop. Formal approval of the plan shall be provided by the AFPMO prior to the execution of task 2.

Task 2: Development of a Strawman EIF

2.1 The contractor shall develop a strawman framework for enterprise integration based upon open systems concepts and national and international standards. The contractor shall update the glossary and submit it to the AFPMO to be finalized by the FAB.

2.2 The contractor shall provide a report analyzing the potential impact of an approved framework on current programs. Recommendations on the methods of using the framework in these programs and anticipated benefits as well as negative impacts shall be described. The example matrix of subtask 1.3 shall be employed, showing how detailed process elements in these candidate programs map to the strawman. The following programs shall be considered:

Product Data Exchange using STEP (PDES)

DARPA Initiative in Concurrent Engineering (DICE)

Microelectronics Manufacturing Science and Technology (MMST)

Integrated Composite Center (ICC)

Integrated Design Support (IDS)

Advanced Cost Management Systems (ACMS)

Automated Airframe Assembly Program (AAAP)

any other suggested program(s)

2.3 The contractor shall produce and deliver a final Strawman EIF which shall be prepared in contractor formats. The contractor shall present the strawman framework at an end of task briefing to the AFPMO and their cosponsors and selected audiences specified by the FAB and conveyed in writing by the AFPMO. The contractor shall clearly identify all open issues and alternatives. The contractor shall present and deliver the results of this effort to the AFPMO via the Prime Contractor for continued evaluation and use.

APPENDIX A

NORTHROP EIF TEAM FINAL REPORT

ENTERPRISE INTEGRATION

FRAMEWORK

STUDY

FINAL REPORT

DAPRO Contract # F 33600-87-C0464

Task 2.11

Northrop Corporation
Aircraft Division
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31 August 1990

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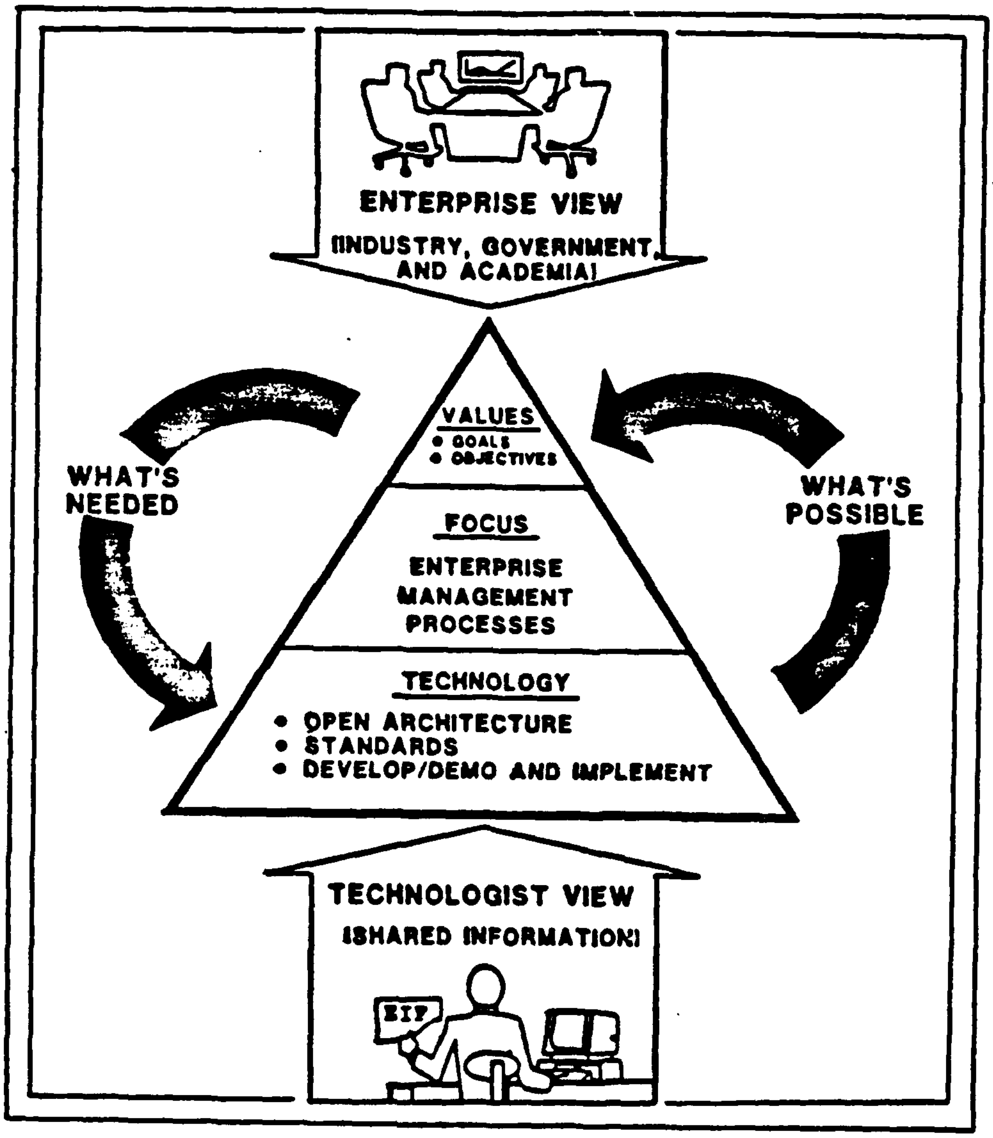
ENTERPRISE INTEGRATION FRAMEWORK

FRAMEWORK DEVELOPMENT



FINAL REPORT

NORTHROP

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ENTERPRISE INTEGRATION FRAMEWORK PROGRAM
EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

The current Aerospace and Defense environment is characterized by increasing global competition, funding and market uncertainty, rapidly advancing technology, and increasingly demanding customers. Today's enterprises have to manage greater business and technology risk, respond more quickly to changes in internal and external conditions, develop closer relationships with the customer, leverage corporate resources more carefully, and provide higher quality products and services at a reasonable cost and with a reduced span time. The DoD and USAF, after much analysis, have determined that a critical success factor in achieving these objectives is enterprise integration. The DoD and USAF, on the basis of this observation, initiated the EIF program and took a major step in the development of a comprehensive, international Enterprise Integration Framework.

The integration of an enterprise is a multi-dimensional exercise in which people, procedures, information, equipment, and other enterprise elements are configured so that they have parts in common. Enterprise integration is manifested in many ways and can include such things as:

- The physical integration of equipment in a Flexible Machining System.
- The integration of the legal infrastructure in a trading partnership.
- The procedural integration of several requirements analysis approaches.
- The logical integration of information systems.
- Human integration on a high performance work team.
- Cultural integration in a strategic partnership (e.g. GM and EDS).

The opportunities for enterprise integration are numerous and have to be understood in the right context to be prioritized and acted upon. The most meaningful integration context is that of the enterprise processes. Processes normally cross the functional boundaries of today's organizations, integrating the flow of information and material into multi-functional continuous flow processes. The enterprise processes are the backbone of the enterprise. These are where the elements of an enterprise come together in the creation of products and value added services. Enterprises are integrated through the integration of their processes. Process elements, such as people, information, machines, procedures, methods, or objectives, must be shared in order to bring about integration. The Enterprise Integration Framework has to support process (which includes technology) integration at various levels of detail across individual organizations, multi-organizational enterprises, industries, and nations.

Numerous attempts at enterprise integration are currently underway and offer insight into the nature of integration. The Northrop/D. Appleton/OCOMAR and IBM EIF teams undertook a joint study of a number of these efforts to better understand their relationship to the objectives of the EIF program. The study led to a better understanding of the individual programs, critical success factors for integration, and the many types of frameworks currently being developed. The effort also established a program comparison format for the positioning of the various initiatives. By advancing the understanding of major integration programs, the first step is taken toward the in-

tegration of such major initiatives as DoD CALS, CIM-OSA, SEMATECH, PDES, and C-4. The coordination and integration of these programs alone would be a major political, economic, and technical step toward the accomplishment of enterprise integration.

The body of knowledge uncovered during our program analysis comprises many important lessons. Top on the list is the fact that the enterprise processes must be understood and improved prior to their automation or integration. This is consistent with the current TQM, Concurrent Engineering, and Continuous Process Improvement initiatives and is the reason for process-based approach proposed for the EIF. The process orientation is supported by the use of models, which are a common element in all successful integration efforts. The Northrop/D. Appleton/OCOMAR EIF has been developed in the context of a set of interrelated enterprise models. The OCOMAR aerospace model is an example of one way in which these enterprise models may be configured. The aerospace model also addresses another important element of enterprise integration, the integration of enterprise requirements. Enterprise requirements are a vital link between the enterprise management, products, services, workers, and systems. Enterprise requirements and objectives must be well understood, analyzed, flowed down, and tracked. The integration of this process is central to the improvement of the enterprise.

Successful enterprise integration efforts also share the idea of a control architecture as the basis of business and technical integration. A control architecture is especially powerful when combined with the use of business performance metrics. The performance metrics are the basis for understanding the statistical nature of the business, and are the cornerstone of Business Configuration Management (BCM). BCM is the key to the management of a dynamic enterprise in a changing environment. BCM allows the enterprise to be understood through models and performance metrics and continuously improved through incremental changes in the business process configuration. The EIF supports the use of BCM by providing an architecture for the integration of the business processes.

One of the final lessons learned from other integration efforts is that the role of management is critical to success. This fact is widely known, but often ignored. The Northrop/D. Appleton/OCOMAR EIF work has focused on the role of management in enterprise integration. Areas such as risk management, simulation, requirements, and BCM are all important to management. A management oriented simulation, in particular, would be of value in breaking down cultural barriers and fostering human integration within the enterprise. The value of the framework is seen in the integration of these areas within and between organizations.

The EIF program identifies a number of important lessons learned and provides a basis for understanding the dimensions of enterprise integration. As the importance of enterprise integration increases, so will the need for the further development of the EIF.

BACKGROUND

This section is a background summarization of the results of Phase I and II of the Enterprise Information Framework (EIF) study. The mission of the Enterprise Integration Framework (EIF) study effort is to define and develop, for national consensus, a disciplined top-down approach or framework that will significantly improve U.S. industrial competitiveness through the structural improvement of enterprise and trading partner processes, to support further integration. The purpose of Phase I was to define the scope and strategy for the framework development to be undertaken in Phase II. The Problem statement of this final report describes the current American industrial environment, the impact of CIM on manufacturing enterprises, and what changes are needed in the future to increase American manufacturing enterprise productivity and competitiveness. The Objectives statement summarizes the EIF effort in terms of what is planned to be accomplished and how these plans are to be implemented. The Scope section describes the expected results of the EIF; and finally, the approach section of this document defines the strategy used to study the framework concepts and develop a strawman aerospace model.

We decided to focus our EIF efforts in a single industry direction. This permited the developers to describe the salient features of manufacturing operations within a more limited, yet fairly generalized environment that can thereafter be extended to other manufacturing industry types. The aerospace and defense industry was chosen for this focus to permit the developers to draw upon their extensive knowledge and experience. The industry oriented EIF reference model was used to critique the CIM-OSA concepts.

The EIF Strawman Aerospace Model is a set of interrelated reference models which describe the infrastructure and behavior of an enterprise. The EIF model provides a conceptual structure to assist management in determining and understanding the most important factors that are influential to the overall performance of the enterprise. This EIF model is different from more traditional models of the enterprise in that it deals with the total enterprise; management strategies, people, facilities, equipment, computer systems, processes, and information; within the context of a dynamic high-technology business environment.

PROBLEM STATEMENT

State of the American Industry

The initial part of our study dealing with the developing of an Enterprise Integration Framework (EIF) was a review of current literature concerning productivity of U.S. industry. The sources are listed in our Bibliography, but the *1989 MIT Study on U.S. Productivity most saliently helps* us to define the first issue. The findings of this study reveal that American industry has not maintained an adequate level of productivity to remain competitive with the Japanese and European industries.

Because of past efforts America has become the leader in research and development; however, the advantages of this position will fade unless significant focus is placed on manufacturing productivity in terms of continually improving product design and production processes. In addition, American industries must strive to develop adequate rewards for efforts involved in making these improvements. The report further states that in order to attain effective productivity, American companies must place stronger emphasis on improved quality, lowering cost, and innovation as measures of performance in relation to the strongest competitor.

The Report's single most useful recommendation is that American companies should measure their performance - in raising quality, lowering cost, and innovating - against the best companies wherever they are. "We have consistently tended to underestimate the competition", says Sloan School Dean Lester Thurow.

The most sweeping conclusion, and perhaps the most striking one, takes the commission far from its early focus on productivity to urge more cooperation in all aspects of business - within companies, between companies and their suppliers and customers, and among companies in the same industry. Furthermore, the study identified patterns common to firms that are adapting successfully to the continual global change in business. These include many of the concepts that make up TQM initiatives launched by the Defense Department and aerospace/defense contractors, such as:

- Developing closer ties to customers and meeting their needs.
- A focus on continuous improvement of processes to reduce cost and improve quality of products or services.
- Fostering closer quality-based relationships with a select group of suppliers.
- Breaking down organizational hierarchies to improve communication between traditional functional areas. Levels of management are reduced and fewer separate units are the end result.
- Applying technology to advantage through a strategic, long-term approach.
- Developing human resource policies and rewards that promote employee participation, teamwork, flexibility and continuous learning.

A key point is made by one of the primary authors of the report, Michael L. Dertoouzos. He states that these concepts must be implemented as a unified strategy, not a pick-list of individual items for implementation.

Computer Integrated Manufacturing (CIM)

The second issue is most effectively covered in the Computer Integrated Manufacturing (CIM) Report for the House Armed Services Committee by the Office of the Secretary of Defense, 1989. This report addresses the technical feasibility, cost and benefits of world class manufacturing, and analysis and planning techniques of CIM implementation.

This discussion addresses CIM feasibility as a whole, not just as it relates to defense production. Most of the challenges encountered by commercial industry are also encountered by defense industries. The implementation of CIM does not necessarily require that existing equipment, systems, and procedures be replaced. Integration is basically an organizational issue, with technical changes following organizational changes. However, a proper foundation must be established for CIM to succeed. First, cultural and organizational changes must be made to obtain a simplified organization and to promote clear lines of communication. There must be changes in management's outlook on long term investments and the return on these investments. After an integrated manufacturing environment is established and the manufacturing processes are understood, it is appropriate to turn to an analysis of computer applications to aid in manufacturing. The underlying requirements for implementing CIM are management commitment and active participation, a top down implementation strategy, and education of managers and users. The basic message is that technical tools are available to implement CIM and, software tools for managing and integrating an enterprise are also available, as well as systems to handle large amounts of data, including relational data bases; however, before these can be effectively deployed, the management infrastructure (of policies, motivation, organization, etc.) must be significantly improved.

The report found that investments in CIM are generally recouped within five years, if properly instituted. These findings were based on several case studies which concluded that 80% of the savings resulted from cultural and organizational changes. These changes required very little capital investments. Moreover, the expense of CIM implementation can vary dramatically depending on the amount of currently existing technology and on the particular manufacturing processes being supported.

The Secretary of Defense's office defined World Class Manufacturers as those companies that area able to compete based on high quality and low cost in the world market; and, Richard Schonberger adds to this definition those companies that have implemented CIM. Therefore, the external influence of competitive pressures have made CIM implementation more pressing. From the position of the world class market, CIM means managing a manufacturing company through the use of technology. The management of the company therefore necessitates organizational restructuring around team work, concurrent engineering and new or better accounting methods.

The final area of the study addressed is analysis and planning techniques for use in implementing CIM. The planning for CIM involves the definition of processes, products, and information required to support the business. Requirements for change are then based on integrating processes and information flows to improve the operations. One of the methodologies developed in support of this process is IDEF (ICAM Definition) which defines the relationships between functions and information to produce products. In addition, the study concludes that additional tools/methodologies are required to support the analysis of costs (direct and indirect) and material; also the analysis of hardware and software in order to optimize the CIM implementation.

Future Management Responsibilities

The third and last part of our issue definition is identified in an article "IT (Information Technology) in the 1990s: Managing Organizational Interdependence," Sloan Management Review, Winter, 1989. This article concurs with the other two in that, American companies must make considerable changes in order to compete with Japanese and European industry. Some of the changes in culture and organizational structure will require substantial reorientation in management as well. Management's role will become increasingly more complex because of organization changes which impact the internal processes and procedures of how work is currently accomplished. In addition, management's participation will be more challenging because of teaming efforts which result in unclear lines of authority and decision making. With regard to the teaming efforts, managers will need improved skills in task-definition and dealing with "subordinates" as peers. Also, with the onset of changes in American industry, management will need to develop new methods for measuring performance/success of individuals who participate in these teams as well as the team itself.

The future role of management must include new planning approaches fostered by more effective use of information and simulation tools which emphasize relevant and critical issues. Finally, the development of an information technology infrastructure based on networked data will facilitate a foundation for productive integration. The article further states that the challenge here is for management to understand the future effect of current investments in organization and technology to aid the people-intensive, integration mechanisms resulting from competitive pressures.

Summary

To become world class, U.S. industrial companies must rethink some basic management premises, including:

(1) Performance must be measured against the <u>best</u> of the competition.

(2) The basic processes used in our businesses must be restructured for better flow of information and product, and then must be continuously measured in terms of performance and continuously improved, ala TQM principles.

(3) Automation is available and can increase productivity, but primary attention should be focused on improving the management infrastructure, including policies, processes, and organization.

What Is Needed Now?

American industries should embark upon a multifaceted effort aimed at improving both the management and technical processes of product development. This may require a wide-spread industry education program. In the case of the aerospace industry, the Department of Defense should take the leadership role in viewing the industrial processes top-down, and overcome the organizational barriers that prevent aerospace managers from seizing this initiative primarily by adjusting its acquisition policies to better reflect the team management premises of the previous paragraph. The aerospace industry must develop improved processes to manage the enterprise in ways that are most beneficial to producing the final deliverable, which is what the Department of Defense is most interested in as the eventual customer. Industry has generally been unwilling or unable to take this action in any unified fashion, for a variety of reasons. However, once this initiative is properly developed and understood, the Department of Defense can promote it through its acquisition policies.

To do this, the Department of Defense needs an unbiased, top-down management vision of the industrial environment. This means that the industrial processes must be portrayed according to a set of established rules that do not reflect any one company's view of functional or departmental constraints. The Enterprise Integration Framework is such a vision. It depicts the enterprise in terms of (1) the integrated processes that really are taking place (but currently in highly inefficient means) and which must be more effectively structured and managed; (2) the information requirements of processes (rather than of organizations); and, (3) the tools and technologies needed to make the enterprise function best.

By using the EIF the Department of Defense can promote the development of industry accepted process "templates" around which commercial vendors can rally to develop process tools (in much the same way as PDES and EDI are developing standards for information technology integration). Vendors and industry leaders will also use the framework to guide development of management processes that when taken together will yield vastly improved industrial operations and ultimately world-wide competitiveness.

The framework must address three distinct, but not unrelated, business environments and these are illustrated in Figure 2-1. At the root of this context is the single business enterprise, composed of distinct functional organizations that work to achieve enterprise results.

The other two areas of interest, trading partners and industry, involve interorganizational cooperation of independent enterprises. The first of the interorganizational or multi-enterprise efforts involves integration of the efforts among non-competing business enterprises in the so-called trading partners environment. The multiple enterprises join together to cooperatively produce a final product. Alternatively, there are multi-enterprise efforts involving non-cooperative, highly competitive business enterprises. These enterprises operate within the bounds of what we customarily call an industry. Foreign interests have achieved significant industry improvement through cooperative efforts of independent enterprises. The development of industry-wide standards that permit national productivity gains in combating foreign competition is viewed as a principal means of addressing this competitive issue.

Regardless of the breadth and depth of the solutions developed, the framework must address all three areas of integration concerns in order to be of ultimate value in improving the enterprise, product development, and industry-wide optimization and effectiveness in the national and international marketplace.

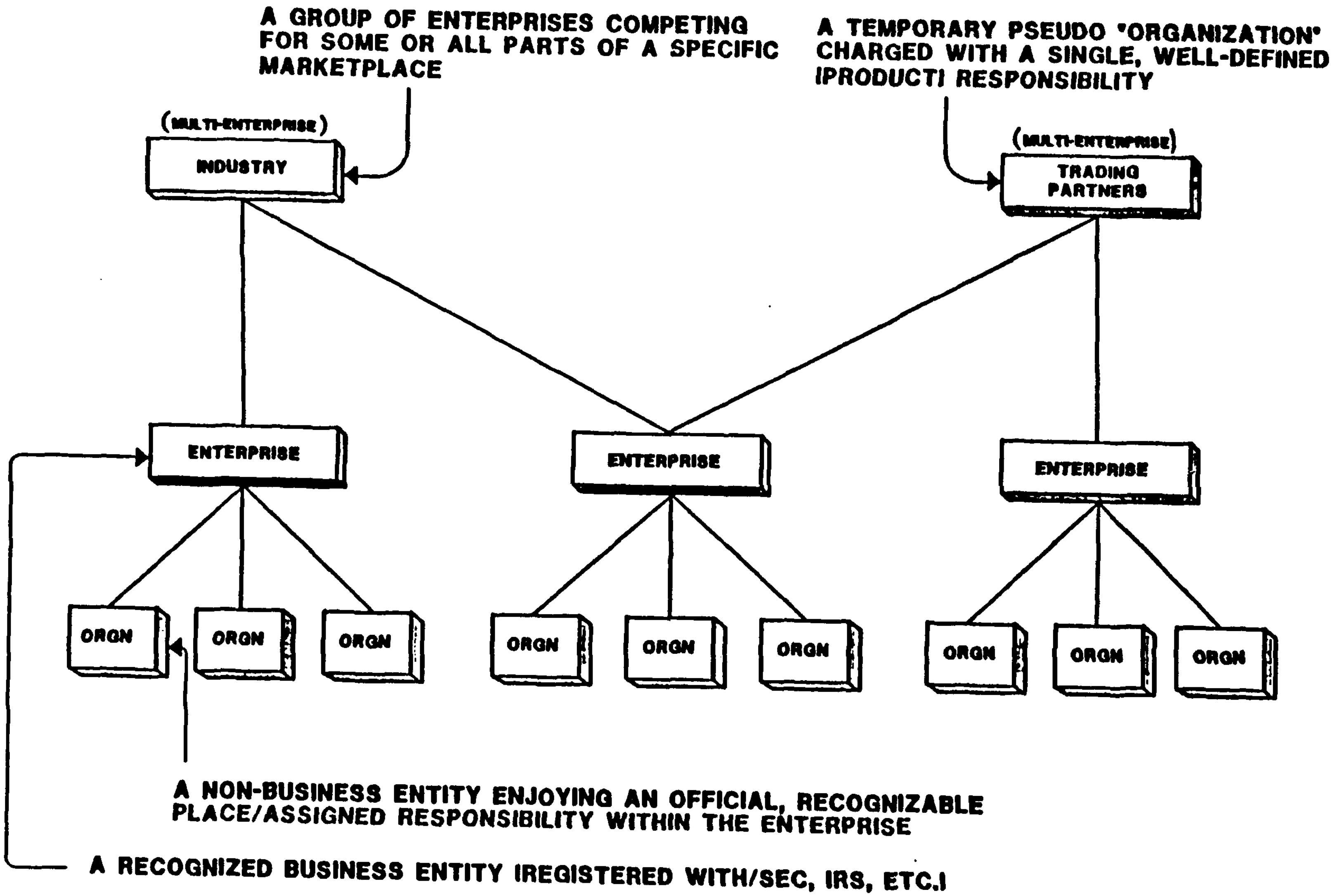

FIGURE 2-1 - MULTI-FACETTED ENTERPRISE INTEGRATION

OBJECTIVE

The objective of the Enterprise Integration Framework (EIF) task has been to define and develop, for national consensus, a disciplined top-down "context", or strawman framework that will significantly improve U.S. industrial competitiveness through enterprise and trading partner integration.

SCOPE

The scope of the EIF program has been to develop a decision tool which middle and executive levels of customer agencies, contractors, and information technology developers may use as:

- A refined focus for current and emerging government and industry improvement initiatives.
- A comprehensive structure for establishing trading partner working relationships - resulting in the identification of requirements for management standards to facilitate inter-company processes and information sharing.
- A guide for planning and implementation of improved management strategies and processes within individual manufacturing enterprises.
- A structured and systematic overview of enterprise integration concepts and requirements for system builders and integrators.
- An overall requirements context for development and demonstration of enabling technologies through both cooperative and private development projects.
- A unifying concept for common industry standards for enabling technologies - resulting in improved technology vendor support for manufacturing enterprises.

APPROACH

The work in Phase I of the EIF project was oriented at establishing foundation concepts and an overall approach from which a comprehensive EIF strawman could be developed. Based on this preliminary work, Phase II solidified the Phase I findings and demonstrated the validity and appropriateness of the framework concepts. Therefore, in order to ensure that the EIF would be developed with the appropriate perspective, varied sources of information were sought. Available information that related to architectural frameworks, CIM, and the American industrial environment was evaluated. Throughout this effort a cross section of publications and reference documents were used to establish the formulation of the EIF concepts. As part of the research a bibliography was created which documents the source of references which were utilized for this project. The material contained in the bibliography (see Section Five) relates to various topics, some of which are available to the general public and others which are specific to particular enterprises. Nevertheless, they all contributed to an understanding and the development of EIF concepts.

One of the more valuable of these references was the work of the European consortium of companies working on a similar concept for an Open System Architecture for Computer Integrated Manufacturing (CIM-OSA) in Europe. Initial evaluations of their CIM-OSA Reference Architecture Specification and Tutorial has revealed some potentially valuable concepts that are being developed to support business process definition and the integration of enabling technology. However, additional definition is required before the concepts can be proven or validated.

As the reference material was identified and analyzed, the team conceptualized and continually refined an aerospace strawman concept for a generalized framework that can be used by much of the United States aerospace manufacturing industry to guide operational and management changes that result in manufacturing productivity and product quality improvements. The experience of the team, when combined with the material extracted from the references, was used to define an appropriate bound for the framework, as well as the contents of each of the views or elements contained therein.

The views or elements of the aerospace strawman model were studied and defined in greater levels of detail, although not all were analyzed to the same degree within the bounds of this contract. Due to contract resource limitations, the efforts here concentrated on those elements that are expected to bear the greatest relevance to integration of enterprise and multi-enterprise operations. These include:

- o the management and operational issues that drive the need for change,
- o structured improvements to the processes that are performed in enterprises,
- o the shared information classes that comprise the information flow needed to sustain the processes, and
- o the evaluation metrics that are used to measure the process effectiveness and changes introduced into them.

The aerospace model consists of the necessary general rules that properly interrelate the elements of that model. In other words, the team developed the relationships between the issues, processes, etc., such that exercising of the results provides a reasonably accurate representation of an aerospace enterprise's operations. For the aerospace model, these interrelationships are called element extensions, and the sum of all the extensions is the aerospace model. Combined with a methodology for employing the model, the EIF aerospace model is conceptualized. This result is presented in Section Four, EIF Aerospace Simulation Model.

Aerospace industry consensus needs to be sought for the extensions that define the industry model. Again, the reference material and EIFWG (Enterprise Integration Framework Working Group) participation should be the prime validation mechanisms. On the other hand, "prototype" testing and validation of the strawman framework was accomplished by using the framework to compare a select number of government sponsored projects and initiatives. Such initiatives as CALS II (Computer-Aided Acquisition and Logistics Support), PDES (Product Definition Exchange Standard), and AAAP (Automated Airframe Assembly Program) are included in Section Three of this study.

TASK GROUPINGS

A series of tasks were designed to develop at a conceptual level what a functional model represents and to study the viability of utilizing the CIM-OSA Framework as a candidate for the Enterprise Integration Framework. In addition, for educational purposes, several special studies were requested from the EIF Working Group.

Phase I of the EIF Program was devoted to conceptualizing a functional (aerospace) model and studying framework requirements.

Phase II continued on with the development of the functional (aerospace) model, evaluation of the CIM-OSA Framework, and several educational tasks for the EIFWG.

The task assignments by this grouping is as follows:

A. Framework Studies

Tasks

- 2.1 Lessons Learned
- 2.2 IDEF-0 & IDEF-1X Analysis with CIM-OSA
- 2.4 Evaluation of Enterprise Integration Framework
- 2.6 EIF National Initiative Program Positioning
- 2.8 ESPIRIT CIM-OSA Assessment
- 2.9 Mapping of the EIF Aerospace Strawman Model Onto the CIM-OSA Framework

B. Functional (Aerospace) Model

- 2.5 Development of EIF Aerospace Strawman Model
- 2.10 Conceptual Definition of EIF Aerospace Simulation Model

C. EIFWG Educational Studies

- 2.3 Jigsaw Puzzle Mapping
- 2.7 AFX Cost Reduction Scenario

The following section summarizes each of these tasks.

TASK

2.1 Lessons Learned - Activity Modeling

This study was requested in order to document Northrop Aircraft Division's experience in using IDEF-0 activity modeling. NAD has been using this methodology since our initial involvement in early ICAM work. The summary and conclusions contained in this report were as follows:

Northrop now has a number of years experience in using the IDEF-0 methodology to develop activity models. This experience has taught us some valuable lessons concerning the IDEF-0 methodology, how that methodology can be strengthened, how the use of such models can be extended, and, in particular, some extensions to the methodology which would be useful for process modeling.

The Europeans (CIM-OSA) are currently developing new standards for process modeling. It is important that the United States moves to protect the very large and valuable legacy we have in IDEF models by developing extensions and improvements for the current IDEF-0 constructs, so that the mass of existing IDEF models may be converted and used in the future. We should try to do this cooperatively with CIM-OSA, if at all possible, as both the Europeans and the United States will benefit from this cooperation.

These extensions should tie activity models, and the information about how a company does business, directly to the information architectures, control architectures, and system architectures which that company uses to manage and direct technology development and implementation.

These extensions should also lead to the ability to computer simulate IDEF-0 models. Computer simulatable process models should become as important as a tool to the management of U.S. industry as structural models are to the aerospace structural engineer. An integrated CASE tool should be developed to support the development, validation, and use of these models. If we succeed at this, we will have converted the IDEF methodology from a suspect, labor-intensive "toy" of too little recognizable benefit to management, to a fundamental management tool used to continuously develop and refine processes to meet increasingly competitive business standards.

2.2 IDEF-0 & IDEF-1X ANALYSIS WITH CIM-OSA

This study was requested in order to define the relationships between the IDEF modeling techniques and those under development by CIM-OSA. The results of this study are summarized as follows:

CIM-OSA modeling efforts apparently have concentrated on developing highly refined process modeling techniques. These techniques provide for certain formalities in definition of processes that are not inherent in the IDEF-0 activity modeling methodology. The techniques described rely heavily on a "forms" type of documentation. It does not appear that there is a well defined graphic syntax for specifying the interactions among processes and activities. It also seems that there are some differences between the CIM-OSA and IDEF-0 philosophies for the application of process and activity modeling to the enterprise.

Information modeling techniques developed for CIM-OSA are less advanced and refined than their process modeling techniques. CIM-OSA has identified the need to use a three-schema approach. There is a Meta-Model relating the three schemata. The Meta-Model incorporates considerable detail about the external information views as objects and relationships among objects. On the other hand, there is minimal detail about the Conceptual Schema and Internal Schema.

There is no indication that there are manuals or training materials for the modeling methods similar to those for IDEF-0 and IDEF-1X.

Task 2.3 "Jigsaw Puzzle" Mapping

This study was requested by the EIF Working Group. It consisted of a comparison of Enterprise Integration Framework Characteristics versus those of other known integration programs. The results of this study were incorporated into the EIF National Initiative Program Positioning Report, Section Three.

Task 2.4 Evaluation of Enterprise Integration Frameworks

and

Task 2.8 ESPIRIT CIM-OSA Assessment

These studies were requested to define areas a framework must encompass. The results of these studies are summarized as follows:

EIF Concepts

EIF Program Comparison

Enterprise integration has been the subject of a wide variety of development activities. A study of these activities was undertaken by the Northrop/D. Appleton Co./OCOMAR and IBM EIF teams. The result was a better understanding of the individual programs, critical success factors for integration, and the many types of frameworks currently under development. A baseline comparison format was also created for the positioning of the various initiatives.

A complete list and profile of all programs studied is contained in the EIF National Initiative Program Positioning document (Section Three). The programs were analyzed and compared from a variety of perspectives including problem definition, scope of integration, integration solution strategies, modeling techniques, and type of deliverables. This work is, potentially, a first step in the integration of such major programs as DoD CALS, PDES, SEMATECH, CIM-OSA, and C-4. Full scale coordination, cooperation, and integration of these programs alone would represent a major political, technical and economic step toward the objective of enterprise integration.

Types of Frameworks

During the course of the EIF program, it was concluded that there are a number of different types of frameworks that support different levels and types of enterprise integration. Each level of framework forms a rough umbrella over the next lower level. Higher level frameworks exhibit a greater scope, while lower levels contain a greater amount of detail.

The principal frameworks that were identified (in ascending order) are the following:

Technology-oriented Frameworks view the enterprise as a customer for information technology products. A technology framework defines components and standard interfaces for various pieces of information technology. Major vendors, such as IBM and DEC, have their own frameworks which define how their products work together. As the demand for open systems has increased, greater emphasis is being placed on standards, defined as a cooperative effort between vendors and users to permit the interoperability of multiple vendors products and to allow for smooth transitions to new technology. Many of today's standards, such as SQL, focus on interfaces to information technology products, totally independent of the business integration strategy.

Firm-oriented Frameworks see the enterprise as a single, vertically integrated business unit and view the integration objective as improving throughput of products and increasing productivity. In the past, many firm-oriented frameworks were actually only slight variations of one or two vendors' technology frameworks. An MRP software package, for example, was identified as a component of integration through the process of inventory management remained undefined. However, the insight that process simplification must precede automation has led many firms to focus on the business process architectures, which stand apart from a specific architecture for hardware and software, but can map to it. Many manufacturing companies have formalized their own internal architectures for integration and in some cases have placed individuals in charge of maintaining the architecture. A top-down factory analysis study conducted as part of a Phase I IMIP contract is an example of this type of framework.

Conglomerate-oriented Frameworks view the enterprise as a collection of semi-independent business units that operate under the same corporate umbrella. Many conglomerates have from 10 to 100 strategic business units (SBUs) and strategic support unts (SSUs). These SBUs and SSUs operate autonomously and interdependently, according to the roles assigned to them by a higher level corporate authority. In this environment, the framework describes general operational, financial, and technaical standards for controlling these diverse elements of the corporate resource portfolio. These standards usually relate to "common business processes" and "common information technology". Although each SBU may have its own firm-oriented integration framework, the conglomerate framework must define how SSUs interact with SBUs. The NADSARP architecture is an example of a conglomerate framework.

Trading Partner-oriented Frameworks view the enterprise as a team of firms that work together to produce products and services for a specific group of customers. Various elements of each firm become a value chain. The framework improves interorganizational efficiency by integrating the business processes and information technologies of team members. In the past, the default strategy has been to adopt the conglomerate framework of the prime contractor as the framework of the team. As team relationships have grown more dynamic, this approach has become unacceptable. The problem is especially significant at the subcontractor level where a single subcontractor may have to support a number of conflicting prime contractor standards. Trading partner-oriented frameworks must therefore rely heavily upon standards which all team members can support. The GM C4 Program is an example of an integration effort which is primarily a trading partner framework.

Industry-oriented Frameworks view the enterprise across a group of firms with a common product and customer focus. These frameworks establish common standards for business processes and deployment of information technology which will aid the formation of trading partner teams. Industry frameworks are becoming more and more important to resolve conflicting standards of conglomerate and trading partner team frameworks. They also have an interesting side effect in that they establish market requirements for information technology products. The CALS Program is a good example of an industry framework where the DoD is a common customer served by many different trading partner teams.

Global-oriented Frameworks view the enterprise as existing across international boundaries. Such frameworks seek to create international standards that foster multi-national industries. As with the preceding frameworks, the global combines the traits of various frameworks to achieve a more extensive form of enterprise. Thus global frameworks incorporate the characteristics needed to address industry, trading partner, conglomerate, and firm issues. The current effort to unify the U.S. and European aspects of SEMATECH is an example of an international effort. In addition, there is interest in extending CALS to an international base, and also in elevating its concepts to address multiple industry issues.

These six types of frameworks, in fact, represent six types and views of enterprises. Each one serves a purpose and addresses a different dimension of integration. The frameworks reflect the evolution of integration approaches and the different views of integration found at the various levels of an enterprise. Integration frameworks initially arose out of a need to integrate information systems. In time the growing awareness of non-technical integration issues resulted in increasingly process-oriented frameworks with an expanding scope of application. Each level of framework seeks to guide the application of lower level frameworks so that information systems, firms, conglomerates, trading partners, industries and nations can be better integrated. It is possible for several of the frameworks to exist at the same time and even within the same enterprise. Technology frameworks, for example, are a component of many higher level enterprise frameworks. The specific relationships among a set of frameworks is dependent upon the specific objectives of the enterprise. In one case the objective may be information systems integration and in another, the objective may be physical integration of machine tools, or the integration of a strategic planning team. These different objectives influence the types of frameworks required and the relationships among them.

Three Architectures

Every program reviewed, regardless of the framework type involved, identified the integration and sharing of information across all businesses processes throughout the product life cycle as a principal strategy for integration. A common reference point for these strategies was a concept developed by the American National Standards Institute in 1971 called the "three-schema architecture". This idea is supported by ISO work and is fundamental to CIM-OSA as well as many of the Air Force ICAM projects. The IBM repository, central to IBM's integration strategy, also utilizes it. Basically, the three-schema architecture separates data management into three related but distinct views:

- <u>External Schemas,</u> which define information as it supports the requirements of enterprise activities.

- <u>Internal Schemas,</u> which define the structures that store information in an automated environment.

- <u>A single Conceptual Schema,</u> which establishes one set of consistent data definitions and integrity rules used to logically integrate and consistently interpret the enterprise data.

Although the three-schema approach was developed specifically to improve data management, early ICAM projects extended it to delineate three types of architectures for addressing overall integration problems. This three architecture concept is central to the creation of enterprise integration frameworks. The three architectures exhibit a set of characteristics similar to those of the three schemas. Each architecture is a view of the enterprise and although integration is performed primarily in the Management Control Architecture, the other architectures must be equally well understood. Taken as a whole, the three architectures define an enterprise, its user views, technologies, and control mechanisms. A thorough understanding of the architectures is the basis for the intelligent management of enterprise resources, deployment of technology, and management of user requirements. A poor understanding of any one architecture, on the other hand, could spell disaster for the enterprise.

Business Architecture

The Business Architecture is a generalization of the External Schema in a Three Schema Architecture. As such, the Business Architecture is a user view of the enterprise. The user of a business may be a trading partner, a company executive, a program manager, or a government agency. In the case of a program manager, the user view of the business is the behavior needed to support the development of a product or service. The behavior may be the rapid development of a quality product (e.g. a fuselage, computer, airplane, or missile) that is easily produced and supported. A financially oriented user, on the other hand, may be looking for a different behavior expressed in terms of assets, earnings and profits. These external views of the enterprise are mapped into the internal systems and technology. The specific internal technologies are of little interest to the user who's only concern is the ability of the enterprise to satisfy his particular requirements.

Influences on the Business Architecture invlude:

- <u>Trading Partner Relationships,</u> in which an organization is responsible for some value-added contribution to the team.

- <u>Total Quality Management,</u> which is frequently driven by customers who desire a high quality product or service that improves over time.

- <u>Regulatory Agency Activities,</u> including increasingly strict restrictions on environmental protection and worker safety and health.

- Global Competition, resulting in the need for the rapid deployment of new technology in high quality products that are reasonably priced and fast to market.

Technology Architecture

The Technology Architecture describes the nuts and bolts of the organization, its networks, people, product and process technology, computer hardware and software, and other systems. The Technology Architecture defines and interrelates these items and in doing so, defines the mechanisms used in the execution of the business processes. A technology architect has many technologies to choose from. In responding to a requirement to develop high quality products, a technology architect may choose a hierarchical organization using workstations, local area networks, and relational database technology. The same requirement, on the other hand, may be mapped into a cross functional team using Design for Manufacture (DFM) technology and no computer systems. Various technologies can produce a variety of results. Over time the technology architecture evolves so that it can better support current user requirements (as defined in the Business Architecture). The technology architect, like any decision maker, has to consider the available alternatives and make a decision on the basis of performance, life expectancy, purchase, installation, and support costs of each.

Influences on the Technology Architecture include:

- Organizational Technology, ranging from steep hierarchies to flat hierarchies, task focusing teams, quality circles, and holarchies.

- Design Technology, resulting in designs exhibiting low cost, and high producibility, operability, and supportability.

- Manufacturing Process Technology, which ideally has a low cost and a low variability.

- Distributed Processing, which lets independent computers share databases and software transparently.

- Distributed Database Management, which manages data distributed over an array of geographic locales.

- Layered System Services, which offer common user interfaces, application control, data management, and communications services across all applications and computing platforms.

- Object-Oriented Development, which handles graphic interfaces more adeptly, leads to better programs in less time, and helps aging legacy systems migrate upward.

- Integrated Digital Communications, which allow simultaneous transmission of voice, image, and digital data.

Management Control Architecture

The Management Control Architecture enables the other two Architectures to develop independently. It controls the translation of Business Architecture requirements into technology solutions and provides support structures such as standards, modeling techniques, measurement techniques, and change control procedures. The Management Control Architecture effectively handles adaptation to change and exploits the potential of information and other technologies.

The control architecture is especially powerful when combined with the use of business performance metrics. Performance metrics are the basis for the statistical management of the business and are the cornerstone of Benchmarking and Business Configuration Management (BCM). Through Benchmarking and BCM the enterprise is modeled, its performance capabilities are understood, and its configuration improved in a structured and orderly manner. The EIF supports the use of BCM by providing a framework for the integration and characterization of business processes.

Influences on the Management Control Architecture include:

- Layered Standards, which separate the definition and use of standards according to their role in controlling functions, data, or technology.
- Business Modeling, which uses a business descriptive language to define the elements and dynamics of the enterprise in a way that allows simulation of management decision making and the automatic generation of information system definitions.
- Business Rules, which define consistent meanings for shared data across all business processes.
- Quality Function Deployment, which maps customer requirements into product and process technologies, organizations, information systems, and other elements of the technology architecture.
- Three Schema Data Management, which separates the user view of the data from the computer view of it, and allows each to evolve apart from the other.
- Asset-Oriented Methodologies, which guide integration planning and systems implementation to create reusable enterprise assets.
- Business Performance Metrics, which quantify the capabilities of the business processes.

The need for enterprise integration is driving programs such as the EIF toward an improved understanding of integration, its various dimensions, benefits, cost, and role in enterprise improvement. This understanding was the basis of the program positioning activities and the departure point for the development of the Aerospace Model.

2.5 Development of EIF Aerospace Strawman Model

The development of the Aerospace Strawman Model was the other major study area of the EIF Program. It's purpose was to develop an industry oriented EIF in order to describe the salient features of manufacturing operations within a fairly generalized environment that can thereafter be extended to other manufacturing industry types. The aerospace and defense industry was chosen for this focus to permit the developers to draw upon their extensive knowledge and experience.

A summary of this study and its conclusions follows:

Presentation of Final EIF Aerospace Strawman (EIFAS) Development Tasks

INTRODUCTION

Three interrelated development tasks were performed during the EIF contract, the first two of which were preplanned, and the last of which was added after the initial results from the first two were jointly reviewed by the contractor, the customer, and the EIF Working Group (EIFWG). The first task consisted of developing a strawman concept of an enterprise integration framework that would support the customer's and industry's efforts to improve the performance and competitiveness of the U.S. manufacturing industry, in general, and of the aerospace industry, in particular, for this first phase of the development. The principal inputs for such development were expected to come from three primary sources, these being from published industry and government initiatives' work in enterprise and multi-enterprise architectural developments, from the contractor team's own aerospace industry experiences, and from other industry experts who would contribute through their participation on the EIFWG.

The second task involved studying the recommended Computer Integrated Manufacturing Open Systems Architecture (CIM-OSA) approach being developed by Amice, a European consortium, and determining its compatibility with the findings and recommendations of the EIFAS concept. The principal objective of this study was to determine the appropriateness of adopting the CIM-OSA framework as the EIF approach, while also determining the differences in the EIFAS that should be considered as an enhancement to CIM-OSA if it were adopted for EIF.

After reviewing the CIM-OSA work, the Northrop team reached the conclusion that, while not at cross purposes, the CIM-OSA and EIFAS approaches to the manufacturing improvement problems were sufficiently different to warrant the initiation of a third task to aid in the final recommendations, this being the development of a prototype simulation model that attempts to merge the two directions being taken by EIFAS and CIM-OSA.

The EIFAS approach, which is described in the next section, is to provide enterprise management with a tool that supports better understanding of their complex product development operations, and, therefore, that supports more informed decision making in developing and managing their enterprise's resources through a process-focused approach; i.e., through modification and management of those processes. Initially this was being provided in the form of a manager's handbook. Although the CIM-OSA approach can be applied to management education and decision support, it is much more directed at manufacturing performance improvement through technology development and management, and is, therefore, being developed more for use by technologists than by management. Because the CIM-OSA architecture has this as the primary focus, a more detailed and precise enterprise modeling is required, and hence CIM-OSA is also working towards the objective of developing an industry accepted enterprise operations simulation specification that could be used to implement its results.

Both perspectives are important, and if kept in proper balance, will both play an important part in improved manufacturing performance and competitiveness. Accordingly, the EIFAS has already undergone a migration from a hard copy form to a computer-based simulation, and the recommended modeling approach has been expanded to support both high-level management modeling for learning and decision support, and detailed operations modeling for process and technology development and management.

EIF AEROSPACE STRAWMAN (EIFAS)

Development Approach

The EIFAS had as its basic underlying objectives to develop a management aid that was both process-based and all encompassing; i.e., that would capture the salient features and performance drivers in the enterprise, and permit management to address any of the high-level issues that an aerospace executive is likely to encounter in the highly complex and competitive, multi-enterprise operating environment typical of modern weapon systems acquisition and development. Such issues are expected to include business-type decisions involving contract negotiation with the Department of Defense, multi-enterprise trading partner relationships with subcontractors and suppliers, and operations-type decisions involving infrastructure and cultural change. This approach is viewed as being quite different and more advanced than the traditional approaches to performance improvement taken during the 1970s and 1980s, wherein the principal attention was directed at only operations-type improvement, and with these concentrating primarily only on technology change. This approach has produced only marginal results and has permitted foreign competition to leapfrog past the United States in performance in a number of key and ever growing areas of manufacturing.

To understand the reasons for this, we must understand what is meant by the process-driven or process-oriented approach. Processes are the way activities are performed in companies to produce desired and definable results. Processes are made up of the activities they encompass, the resources that perform these activities, including the information and product that flows between and is created by the activities, and the controls that constrain the way the activities are performed and the resources are allocated. Processes exist at all levels of the enterprise, ranging from the highest levels, such as product definition, to single person procedures, such as performing a welding operation in the shop. The existence of processes is independent of organization structure, or of how companies choose to represent or build their operational architectures.

However, the management, facilitation, and continuous improvement of processes is highly dependent on their recognition and understanding, and therefore, on how well they are represented to company management. This is the principal role of the process-oriented architecture; i.e., to enhance management understanding and control over the company's processes, thereby paving the way to greater levels of enterprise integration and performance optimization through process management and control, rather than the traditional functional (i.e., organizational) view of the enterprise. The latter always results in function rather than process optimization, and is characterized by enterprise facilitation by function or organization, thereby creating the "islands of automation" that typically result from the functional approach to performance improvement. This is the big difference between the traditional, functional architecture approach and the EIFAS process-oriented approach.

At the higher levels of enterprise operations, processes are poorly defined and are, therefore, less recognizable and understood. Product definition, for example, is an existent process in every aerospace manufacturing company, because design, analysis, evaluation, planning, and tooling development are all carried out. Sometimes their key interrelationships are treated with enormous importance to the enterprise, and so product definition is not only recognized as an important process, but it is separately managed and facilitated. In this regard, there is a separate manager appointed to manage the product definition phase of a program, either as a program officer through a matrixed organization approach or as a separately established line organization with a traditional organization manager. Improvements to the process, including changes and additions to the technologies employed, are done with respect to their effects on the overall process rather than to a portion of it, such as design or manufacturing planning.

In most cases when a process such as product definition is recognized and managed as such, company procedures have also been modified to change the design, evaluation, and planning subprocesses in it from a primarily sequential processing to a parallel or simultaneously performed, highly interactive and closely integrated operation; hence the name simultaneous or concurrent engineering. The architecture that is developed to represent such an operational approach and guide its facilitation and process improvement, explicitly defines such high-level processes as product definition, product delivery, and product support. Activities are grouped according to their interrelationships and importance to the process rather than according to who "owns" and executes them.

In more traditional manufacturing enterprises, high level processes such as product definition are barely recognizable and are modeled as a series of loosely coupled subprocesses in the enterprise architecture. Design, analysis, developmental and proof-of-design testing, producibility evaluation, tooling development, and manufacturing process planning show up in different (functional) legs of the architecture because this type of architecture reflects the way the company, and hence its processes, is organized, managed, and facilitated. Process, or more precisely, subprocess optimization is then performed based on recognition and understanding of the subprocesses only, namely by organization or function, to satisfy organizational requirements and improve functional performance. This is done without real regard for that of the enterprise, and, of course, invariably results in process and performance suboptimization and the proliferation of what has become to be known as "islands of automation" in the enterprise.

For the Enterprise Integration Framework Project to be successful, it is important for the adopted framework structure to make this important distinction. It is the best way, and perhaps the only effective way, to ensure that the framework will focus on process and enterprise optimization rather than on functional optimization in specifying, developing, and implementing integration technologies into the enterprise. This will maximize the return on investment in the EIF Program and its implementation in the using enterprises, and will help the U.S. manufacturing industry make the transition from traditional improvement approaches, which have produced only marginal results over the past several decades, to the types of results needed to achieve world-class manufacturing performance and competitiveness. The process-oriented integration focused framework must define the processes and encompass and satisfy all process element requirements including the definition, management, control (i.e., scheduling, budgeting, measurement, and continuous improvement), personnel and their training, information, and technologies. The traditional approach has classically concentrated only on subprocess improvement principally through focus on information and technology, and has neglected the management, control, and cultural or people issues involved with integration and improvement.

EIFAS Content and Structure

The EIFAS structure was determined from a combination of (1) deciding what content or enterprise operational features would be required to support both the management orientation and process basis sought for the framework, and (2) applying the definitions of these features to determine their relationship to one another. Three distinct enterprise operational features were determined as essential parts of the framework, these being

- o the individual enterprise characteristics or elements that are needed to describe a manufacturing enterprise,
- o the models that relate the behavior of the enterprise in terms of these constituent elements, and
- o the application scenarios that drive the models to demonstrate an enterprise's response to one-or-more stimuli.

Five enterprise elements were selected for the strawman (from a more general set developed for the generic manufacturing enterprise model), all relating specifically to the execution, control, or facilitation of the enterprises processes. These elements are

(1) the processes themselves,

(2) management's objectives stated in terms of process performance expectations (i.e., performance metrics),

(3) management's requirements stated in terms of the problems and concerns that the processes must address (i.e., issues),

(4) the information classes that describe the content of the information and product flow created or used by the processes, and

(5) the enabling technologies that describe the resource characteristics needed to facilitate the processes.

Viewed from an $IDEF_0$ perspective, the processes would be equivalent to the activity descriptions, the metrics and issues would be management's control over the processes, the information classes would be the process inputs and outputs, and the enabling technologies would be the mechanisms used to execute the processes.

Five types of models were initially recognized as contributors to describing enterprise behavior in terms of the five selected enterprise elements. These include

(1) simple element-to-element relations that describe the fundamental, one-on-one interdependencies between the enterprise elements; matrices are used to display the results of this (element relationship) model class,

(2) static, activity-type models that display the composite of the large number of enterprise element interrelationships that occur in enterprise operations; functional block diagrams and $IDEF_0$ models are two of the methods used to display the results of this (process) model class,

(3) dynamic, flow-type models that display the composite of the large number of timing rules followed by the process activities; critical path flow diagrams and simulation models are two of the methods used to display the results of this (flow) model class,

(4) cost models that describe the combination of enterprise element characteristics needed to predict process execution cost; algebraic equations or statistical processes are two of the methods used to compute the results of this model class, and

(5) information models that uniquely describe the information entities and their attributes that occur many times over in the various information flows used in and created by the enterprise processes; $IDEF_1$ and $IDEF_{1X}$ models are used to display the results of this model class.

There are an endless number of application scenarios that could make use of the EIF in addressing management's various business and operational concerns about their respective enterprises. Only a specific handful were initially considered in establishing the form and utility of the EIFAS, and all were based on exercising only the element relationship models developed specifically for the EIFAS in this strawman study. These scenarios included establishing the effective bounds for and evaluating the direction taken by either enterprise projects or DoD sponsored initiatives dealing with manufacturing infrastructure development and performance improvement, and for predicting the cost of executing both enterprise and multi-enterprise business processes. This latter application was then used as the basis for the continued study of the EIFAS in the third development task added to the initial study after evaluating the results of the initial EIFAS concept and the comparison to CIM-OSA. This is described in more detail in Section IV of this paper.

The three enterprise features included in the EIFAS were formed into an overall framework metamodel by considering some generally accepted definitions of framework descriptive terms, these being:

- An element is a fundamental building block that represents the inherent properties that are needed to fully characterize a subject (i.e., the aerospace manufacturing enterprise). Hence, the term enterprise element was adopted for the set of enterprise characteristics that encompassed processes, metrics, issues, information classes, and enabling technologies.

- A model represents the relationship between two or more of the basic properties of a subject (i.e., an enterprise). Hence, the term model was adopted for the set of enterprise relationships describing operational behavior that encompassed element relationship, process, flow, cost, and information model types.

- A reference model is a schematic representation of all or part of a subject (i.e., an enterprise). The combination of the models and the descriptions of their constituent elements would therefore comprise the reference models of the subject we call enterprise operations.

- A scenario is a documented set of actions performed to accomplish a given objective or to produce a given result (i.e., a business application). This describes the set of application scenarios describing the use of the framework reference models to address management concerns.

- An architecture is a representation of one aspect of a complex subject (i.e., an enterprise). The combination of a given scenario, addressing a specific aspect of business operations, combined with the relevant reference models for that application, would therefore comprise the architectures of the enterprise framework.

- A framework is a set of related architectures, each of which expresses a view or aspect of a single complex subject (i.e., an enterprise). The EIF is, therefore, the total set of architectures of reference model-application scenarios needed to address all of management's business and operational concerns as described by the set of enterprise issues included in the enterprise element set.

This set of six interrelated definitions was used to build the structure of the EIFAS metamodel, and the three sets of enterprise operational features (i.e., elements, models, and application scenarios) were used to populate it. The primary thrust in populating the initial strawman was in issues, with several hundred issues being defined from a handful of recognized expert sources on enterprise development and performance improvement, and in the high-level, generic processes that comprise aerospace manufacturing operations. Initially, five (5) such high-level processes were identified, each of which was decomposed into a set of subprocesses to help show the composition of the high-level process, these being enterprise management, product definition, product delivery, product support, and enterprise facilitation. The full set into which these were decomposed consisted of twenty-four (24) second-level enterprise processes, and these too were further decomposed one additional level to better explain the intended content of the second-level processes. As will be seen in the next section of this paper, this decomposition would have to be continued until the enterprise's most basic (and industry generic) manufacturing activities were exposed to satisfy the CIM-OSA generic construct approach, if this is adopted as the basis for the EIF.

A schematic representation of the EIFAS metamodel is shown in Figure 2-2. Neither the proposed structure nor its content have been subjected to the detailed industry critique needed for a consensus acceptance of it. However, because it is largely based on and is not in conflict with the findings and recommendations of the prior industry studies referenced in its development[1], significant modification or redirection of the recommended aerospace framework direction is not expected.

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[1]The EIF bibliography is included as Section Five in this report

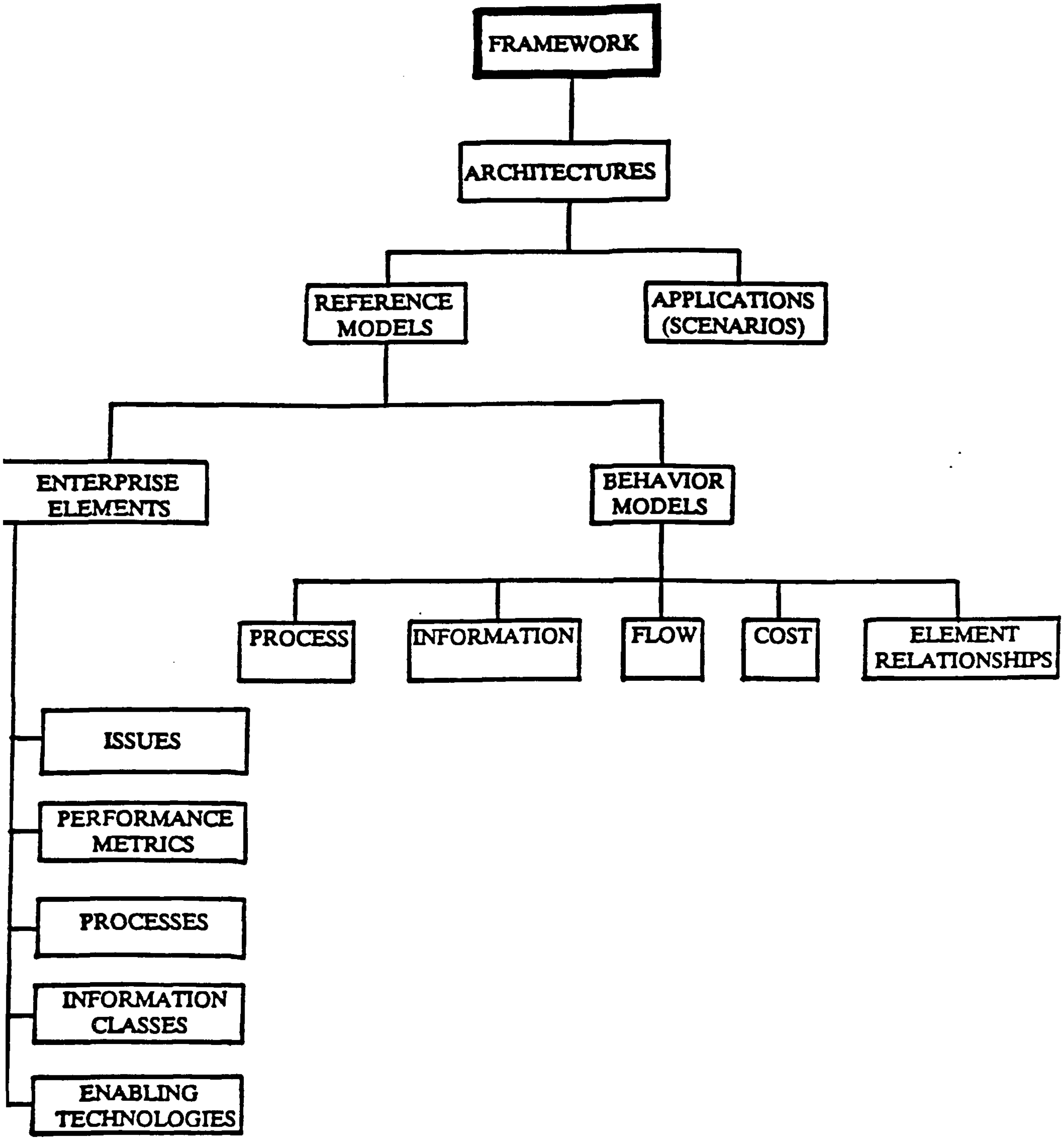

FIGURE 2-2 - EIF AEROSPACE STRAWMAN (EIFAS) METAMODEL

COMPATIBILITY BETWEEN THE EIFAS AND THE CIM-OSA ARCHITECTURE

The CIM-OSA Architecture

The CIM-OSA architecture is described in terms of its scope of application, its (specification) content, and the constructs that implement this specification. CIM-OSA's scope is described in terms of three dimensions of architecture or model development, these being the level, type, and view of the model, respectively.

Three model levels are treated, these being the enterprise or requirements level, the intermediate or detailed design level, and finally the implementation level. Although it has been under way for a number of years already, CIM-OSA, like the EIF, is considered to be in the requirements phase of its development.

Three levels of models or architecture are used, ranging from the most generic (i.e., activities that would apply to any industry or enterprise), to partial (i.e., reference models that combine the generic activities into models that apply only to specific industry segments), to particular (i.e., partial models that have been tailored to represent the operations of only a specific enterprise within the industry segment covered by the partial model). Finally, four enterprise element views are considered in the CIM-OSA scope, these being function, information, resource, and organization. These appear to be closely aligned with the basic $IDEF_0$ modeling construct, with function aligning with activity, information aligning with information, resource aligning with mechanism, and organization aligning with the activity constraints.

From the information made available to the Northrop EIF Team, it appears as though each of CIM-OSA's construct specifications will be built on a uniform format, in that each will contain a functional part, a structural part, and a behavioral part. The functional part appears to be reserved for describing the inherent aspects or characteristics of the enterprise element to which it refers, while the behavioral part is used to describe the use of the functional part, and the structural part describes the decomposition level or level of detail of the functional part. Because of both the conceptual development and proprietary nature of the CIM-OSA effort, only parts of the construct specification are known to the Northrop Team. These relate to function, resource, and resource occurrence. Nothing is known about information or organization at this time. In addition to these specifications, an implementation construct for the function view specification has been developed, and, as discussed in the next topic, was used to determine how well the $IDEF_0$ based EIFAS process models mapped into the CIM-OSA framework.

The Comparison of the EIFAS and CIM-OSA

The comparison of the EIFAS to CIM-OSA took on two perspectives, one being a detailed mapping of the EIFAS processes into the CIM-OSA function view, and the other being a general comparison of other, not so well developed aspects of the EIFAS into the not so well known or understood CIM-OSA architecture. This latter comparison involved all EIFAS elements except issues, all models except cost, and all CIM-OSA model views except organization.

In the detailed mapping, the first two process levels of the EIFAS were successfully mapped into the CIM-OSA function view constructs. In the first level, the entire enterprise was treated as the model domain, with five (5) business processes (enterprise management, product definition, product delivery, product support, and enterprise facilitation) being identified in the domain.

The domain interfaces included company owners, customers, trade partners, governmental regulating agencies, competition, the community, and technology suppliers. Each of the business processes was decomposed into their respective enterprise activities, which numbered twenty-four (24) in total.

Only a sample mapping was done at the second level of decomposition to demonstrate the approach that could be taken. To do this, each of the five first level business processes in the enterprise domain was treated as its own domain, and the steps followed in decomposing the first level were then repeated at the second level. This technique is a different way of applying the structural part of the function view standard, but gives the same results as would be obtained through successive decomposition of the business processes into lower level or ever increasingly finer subprocesses, as is intended by CIM-OSA in ultimately driving out the generic enterprise activities sought for the generic architecture level of the framework.

Findings

The findings from the comparison is done in three categories. The first are the findings about CIM-OSA itself. These are that

(1) CIM-OSA information is currently limited because it is a proprietary architecture, making understanding and evaluation of it difficult at best. For the evaluation performed on this contract, only portions of the function and resource views (construct standards) were known.

(2) CIM-OSA includes a behavioral part in its function view, which provides a needed standard to support process simulation.

(3) The CIM-OSA information view appears to have the same objective as the $IDEF_{1X}$ modeling methodology; i.e., that of supporting the development of the conceptual layer of a three schema information architecture.

The second set of comparison results relate to the general approaches taken by CIM-OSA and the EIFAS. In this case, the CIM-OSA approach appears to be being developed primarily as an enterprise infrastructure development tool. This conclusion is supported by the following observations about the great amount of detail included in and produced by the CIM-OSA approach, and includes;

- the development of a specification for a manufacturing enterprise simulation language from which a commercial product could be spawned (or an existing one modified)
- the development of a "tool kit" of basic manufacturing enterprise elements, including activities, information, resources, and management charters and responsibilities (generic level)
- the development of a set of basic process models based on these elements (partial level), and that can be tailored to (and added to from the tool kit, if necessary) to represent the specific operations of the using enterprise (particular level)

The EIFAS approach is quite different from this, and has as its objective an enterprise infrastructure management tool. Accordingly, its approach involves:

- the development of industry generalized and accepted (by national consensus) process models that can generally represent, at a high level, any aerospace enterprise's operations, and that "automatically" tailors the results to a specific enterprise based on how it is used by the manager

- the inclusion of a management oriented, issue driven front end that produces enterprise response from application scenarios built by the manager through focused expression of his specific problems and concerns (i.e., issues)

- the use of a commercially available, general purpose simulation program to make the EIF implementation as realizable and generally portable as possible to the many potential, dispersed, and differently equipped users in the industry.

The third set of comparison results relate to the specific content of the two architectures. In regard to enterprise elements, the two architectures appear to be in substantial agreement, with only enterprise issues being omitted from CIM-OSA. In regard to models, the two architectures again are in good agreement, but with some small and potentially important differences. CIM-OSA appears to omit all reference to issues and cost in their modeling, while the EIFAS has no simulation language standard included to support flow-type modeling. In regard to framework applications, the two architectures are in substantial agreement in stated objectives, but are, in fact, different in what they really support. CIM-OSA concentrates on supporting enterprise infrastructure development and improvement, and appears to ignore program and business management scenarios. The EIFAS supports most management-level and some infrastructure development and improvement scenarios (related to information systems), but tends to ignore all other implementation scenarios.

These comparisons are based on the definition and understanding of the two proposed framework approaches as such existed at the time of this study. CIM-OSA is an evolving and only partially understood concept with limited exposure to those outside its development consortium. As more detail is developed and understood, and as the EIF strawman concept further evolves, and is critiqued and modified to achieve an industry consensus, the apparent differences between the two may lessen or go away altogether. This can be facilitated through the cooperative development of a single framework that satisfies the combined objectives of Amice and the EIF.

EIFAS IMPLEMENTATION: A MANAGEMENT-LEVEL (FEASIBILITY) SIMULATION MODEL

Purpose

The EIFAS development task showed the breadth of aerospace operations information that must be organized and represented to provide management with the data base from which to make more informed decisions about how and where to change company infrastructures in improving manufacturing results and company competitiveness. The mapping and comparison task to CIM-OSA showed the EIFAS concept to be quite compatible with the CIM-OSA framework, as well as the potential usefulness of a simulation tool providing management with the best means of accessing the EIF data. These conclusions led to a third development task being added to the initial EIF study; that of investigating the feasibility of the simulation model in best presenting the framework data to management. With this in mind, the simulation task was initiated with the following objectives:

- to demonstrate the feasibility of developing a common language tool that facilitates multi-enterprise and multi-disciplined communications for program optimization and product cost, schedule, and quality improvement
- to determine the benefits of management-level simulation in organizing and communicating enterprise operational data to management to support their decision making processes
- to show the usefulness and applicability of the EIF aerospace strawman model in addressing management-level concerns
- to provide a basis for a more detailed modeling effort that can expand the content, accuracy, and usefulness of the prototype for more general manufacturing enterprise and multi-enterprise applications (the strategy for pursuing this is described later in this Section)

Approach

The simulation model developed in this task was done as a feasibility prototype to demonstrate the EIFAS model and its usefulness to aerospace managers. Two modes of use are expected. These are (1) as an education and communications tool that supports management awareness and understanding of cross-functional processes, and (2) as a management gaming and decision support tool that permits them to determine how they can improve company performance and competitiveness.

Management education and communications is accomplished by exposing different enterprise and functional managers to what can be accomplished through state-of-the-art infrastructure development and management based on a process-oriented approach, and then by what effects different functional activities have on changing and optimizing the performance of a program and the enterprise. The simulation provides the basis for doing this through inclusion of an industry consensus process-oriented approach to product development that allows managers to compare their company's performance to what the rest of industry can accomplish, and by permitting them to view both their respective organization's results and those of the enterprise. This functional manager viewpoint is invaluable in the gaming mode, where individual (functional) performance can be altered and examined for its effects on where it counts the most; i.e., on that of the entire enterprise. Such changes also afford management with a comparative view of how the company is expected to perform in relation to the rest of their industry, which, of course, includes potential competitors.

To demonstrate these capabilities, the approach taken for the prototype included development of a finite set of management-oriented scenarios that address specific management concerns in controlling the business and development programs of the enterprise. These scenarios include:

- How are program costs effected by the prime contractor's implementing concurrent engineering to develop a contracted for product?

- How are program costs effected by one or more subcontractors also implementing concurrent engineering to develop their portion(s) of subcontracted for portions of the product?

- How are program costs effected by changes in yearly production rates, both in terms of total levels and earlier or later peaks?

- How are program costs effected by delays or interruptions at various points in the program's production phase?

- How are program costs effected by changes in customer requirements at various stages of product develop (i.e., definition or delivery)?

The Prototype Simulation Model

The simulation model used to demonstrate the EIFAS and its management usefulness was based on a Sun microcomputer, and used the G2 general purpose simulation language package. The model contained the subset of the EIFAS processes relevant to addressing the chosen management scenarios, which includes the customer, program management, system engineering, structure and subsystem design, design evaluation, auxiliary product definition design (tooling, packaging, support and special test equipment, etc.), subcontractor product definition, configuration management, manufacturing resource planning (MRP), production purchasing, subcontractor and supplier product delivery, receiving and receiving inspection, stores and kitting, auxiliary design fabrication and assembly, production batch manufacturing, production line flow manufacturing, test, and shipping. The model uses a pair of information or product flow pipelines to interconnect and represent the closed-loop relationships that exist between pairs of interacting processes/subprocesses. A number of "busses" are used to replace multiple pipelines, thereby simplifying the model where either multiple, summed inputs from different generating processes must be transmitted to another, single using process, or where divided outputs need to be distributed to different using processes from an input from a single other process that generates that output. Finally, the model incorporates algorithms that have been generated to simulate the cost results of

(1) changes in program and major process duration in production rate and in production learning rate, and

(2) the effects of contractor and subcontractors independently choosing to implement concurrent engineering practices to perform the product definition process and of disruptions in the production phase of the program.

Findings

The lessons learned from this task include those determined from designing, building, refining (i.e., evolving), and exercising it. The more salient of these include the following:

- High-level, management-type simulation modeling of complex manufacturing enterprises can effectively be performed in a top-down manner, wherein high-level (i.e., undecomposed) processes can be simply described and cause and effect relationships can be easily modeled using simplified algorithms that express the results of changes rather than how the changed processes work or how the changes are implemented.

- More complex and accurate models can be evolved from these high-level models through decomposition of the high level processes and continued research into and more precise understanding of the cause and effect relationships between process stimuli and enterprise and process performance.

- A number of existing commercially available language packages appear to have all the necessary capabilities to perform complex manufacturing enterprise simulations; however, all contain their own language peculiarities and would require a different implementation of the same EIF developed industry "standard" process and technology descriptions.

- The relatively simple, high-level management-type simulations can be performed on microcomputers; however, as such models are expanded to accommodate more detailed simulations to satisfy new process design development users, it is unlikely that such would continued to be the case. This could require transition to the use of larger machines on which to perform very lengthy, time consuming computations, or would require partitioning and integration of smaller models used to simulate partitioned processes.

- The easiest part of enterprise and process simulation is the construction of the model on the simulation tool. By far the more challenging, time consuming, and costly part of the task involves

    - studying and understanding of the complex cause and effect relationships that actually exist in such enterprise operations

    - designing the simulation model to accurately and as simply as possible, algorithmically represent these relationships

    - compiling accurate, discrete statistics (i.e., metrics) from enterprise historical and current operations records with which to populate the designed model.

Strategy for Continued Modeling

ENTERPRISE INTEGRATION FRAMEWORK - SIMULATION MODEL
EIF - SIM

EIF-SIM I is an industry consensus enterprise model which Northrop proposes be developed to simulate the underlying generic, high-level processes (the user will be able to simulate both As-Is and To-Be versions of each process) of a typical manufacturing enterprise. The To-Be version of the processes in the model will be optimized and integrated to reduce the cost and schedule, and to improve the quality of manufactured products. This model is employed as a problem-framing tool in the development of an enterprise strategy.

EIF-SIM II is a simulation model of the existing (As-Is) operating environment of a specific company. It would be developed by an individual company based on EIF-SIM I. Like EIF SIM I, EIF-SIM II is envisioned as a multi-person simulation (business gaming) model used to enhance communication between different organizational groups and to promote mutual understanding of the problems and objectives of these groups.

EIF-SIM I

An important application of simulation is as a learning tool for complex decision making which involves different functional managers. The EIF-SIM I is a multi-person simulation tool which allows a company to expose individuals to different management roles and perspectives as members of a multi-functional team, in order to have them experience the viewpoint from which other managers observe multi-functional problems. Hence, multi-manager simulation is a powerful tool to create a common (language) basis for discussion of the problems of improving enterprise process management.

This common language also serves to reduce barriers between organizations (based on an improved understanding of other managers' problems) and to develop an enterprise-level team. The traditional teams are functionally oriented (Manufacturing, Engineering, etc.) and this proposed concept is designed to develop enterprise-wide, multi-functional management teams. The EIF SIM-I simulation will provide discrete probabilistic simulations of the primary processes in a typical aerospace manufacturing company. It will allow management teams to simulate both "As-Is" and "To-Be" modes of execution of these processes through utilization of parameters to modify the processes to reflect current or proposed operational policies.

The EIF SIM-I model will allow executive management to simulate proposed "structural" changes -- such as greater multi-discipline teaming and parallelism, or the conversion of "batch" processes to continuous flow processes -- to generic industry processes, like those used today in their companies.

EIF-SIM II

EIF SIM-II is a customized version of EIF-SIM I, developed by company technologists to simulate one or more of the company's "as-is" high level management (business) processes. This effort, done with frequent executive management interaction, will develop "buy-in" by both executives and a core team of technologists, laying the groundwork for real cultural change. In utilizing EIF-SIM II, a company management group can simulate major cross-functional problems in their company today, based on todays processes and procedures, and evaluate differences between existing processes (EIF SIM-II) and the optimized processes (EIF-SIM I), along with their potential impact on the productivity of the enterprise. Next, potential changes in the process structure can be discussed and choices can be made with regard to what changes to implement. Once having developed their own SIM-II simulation, and having validated it with appropriate other company management, the team would proceed to modify their model to reflect proposed changes to their current processes (again, using the EIF SIM-I model as a guideline) and use the simulation to test the effects of each change. This whole experience will also help to form the group into an integrated enterprise team. (Reference Figure 2-3)

SUMMARY

American manufacturing management has a narrowing window of opportunity in an increasingly competitive world business environment to remove significant cost and flowtime from our current process and to improve our product quality. The EIF SIM-I simulation could be an important tool to assist executive management in this complex, risky, and politically-charged competitive effort. There are two types of complexity that make enterprise problems hard to solve: the *technological* complexity and the *organizational* or *cultural* complexity. Both types of

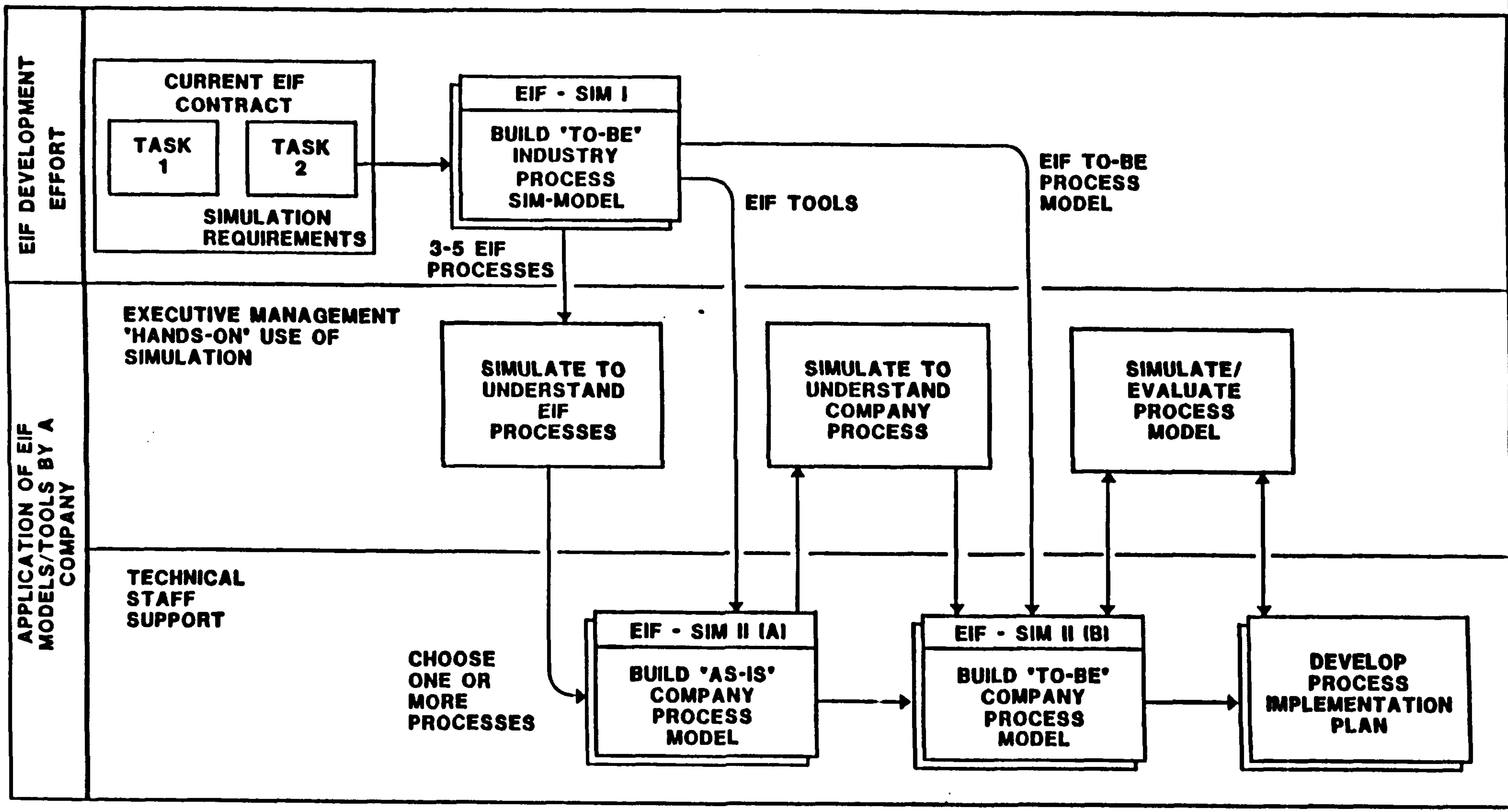

FIGURE 2-3 - SIMULATION MODEL FLOW CHART complexity need to be addressed before any real enterprise policy-making can take place. The EIF-SIM I explains enterprise process theory, while providing a common "language" in which enterprise issues can be simulated and discussed. EIF-SIM I is specifically oriented towards the *organizational* problem of h....g different 'cultures' within the organization that all view and affect functional problems differently. In EIF-SIM II, a base is established for a particular company so that the technical and organizational process of policy making can start, potentially resulting in improved enterprise management.

2.6 EIF National Initiative Program Positioning

This study was requested by the EIF Working Group in order to better understand the relationships of a number of government and commercial programs (which address the issues of enterprise integration) related to the objectives of the EIF. This is a joint study by the Northrop and IBM teams and the report is Section Three of this Final Report.

2.7 AFX Cost Reduction Scenario for the EIFWG

This scenario was designed to explain in a short story form one of the several uses of the Enterprise Integration Framework (EIF) in a specific business situation. The approach to developing this scenario was as follows:

- o Summary definition of the Enterprise Integration Framework - General explanation for those readers that are not familiar with the EIF.
  - -- Business Benefits
  - -- EIF Usage
- o Industry Background - Orient the reader to any unique characteristics of the specific industry selected, i.e. Military Aircraft.
- o Enterprise Context for Concurrent Engineering
- o Scenario Premises
- o Scenario
- o Summary

While this scenario was based on a hypothetical situation, the approach was based on extensive industry experience in similar situations. This experience was not limited to dealing with product cost reduction situations but also included extensive experience in studying the underlying processes of an Aerospace Manufacturing Enterprise. This report was presented to the EIFWG in May, 1990.

2.9 Mapping of the EIF Aerospace Strawman Model Onto the CIM-OSA Framework

The purpose of this analysis was to determine the applicability of the CIM-OSA framework in representing the content of the Aerospace Strawman Model. The conclusion of the study was the CIM-OSA framework was found to provide a good structure into which the Aerospace Strawman Model could be mapped.

2.10 Conceptual Definition of EIF Aerospace Simulation Model

This study was based on the work completed in Task I, and Tasks 2.5, 2.7, and 2.9C of Task II. The study is located in Section Four of this Final Report.

EIF PROGRAM SUMMARY

This program has been a fascinating learning experience for all team members. It was felt appropriate to share the more significant observations for the benefit of those interested in this subject matter.

We determined after our initial review with the EIFWG that senior executives consider the EIF subject matter extremely complex and abstract. Part of the reason for this reaction was much of our presentations were technically rather than management oriented. We concluded that there are two separate audiences, management and technologists.

Each of these groups has their own language and a common language does not exist. Consequently, when reviewing this subject matter, use one or the other language, mixing the two may result in confusion.

The Working Group emphasized the critical nature of identifying cultural issues that mitigate against change. We incorporated this advice into our Simulation Model Recommendation (Page 2).

We found the CIM-OSA Framework to be very comprehensive in breadth, but equally shallow in depth. A significant amount of work remains to be done to populate the cells in the CIM-OSA Framework. Our recommendation for continued development of partial models recognizes this situation.

The joint project with IBM on Program positioning demonstrated the credibility of the EIF Program. This project utilized the EIF process management concept and clearly showed its effectiveness.

In summary, EIF is credible. The work that has been accomplished by both the Northrop and IBM teams has made a contribution toward the understanding of the complexities and magnitude of an Enterprise Integration Framework. There is no doubt in our minds that such a framework is required.

RECOMMENDATIONS

1. Simulation. A management oriented enterprise simulation should be developed. This simulation should be aerospace industry based with the consensus of the major industry players. The simulation should be game-oriented and utilize a "user"-based language that, unlike typical simulation languages, would be meaningful to executive level management. The simulation would enhance the understanding of the various functional components of enterprise performance, first in a business-as-usual environment and then in an integrated, optimized environment. Such a simulation would be a powerful learning tool and reduce the cultural barriers to integration. Properly configured, the simulation would also be a solid basis for risk analysis, enterprise performance analysis, and business configuration management. The simulation should include reference models for processes such as concurrent engineering and integrated logistics support and should be offered to CIM-OSA for inclusion in their framework as validated partial (aerospace) models. (Reference Report - EIF Aerospace Strawman Prototype Simulation Study - EIF Task 2.10 and Section Four - EIF Aerospace Strawman Model).

2. Coordination of Integration Programs. There is a dramatically increasing number of integration programs currently underway. Many of the programs are working on the same problems with little understanding of their contemporaries. There should be established a coordinating body for these integration programs. National initiatives such as CALS, PDES, and SEMATECH should be included along with other comparative key industry and academic efforts. In support of the national coordination body, Some entity should extend the EIF program positioning approach to deal with detailed program issues, integration methodologies, and technical specifics. The detailed program positioning approach should be offered to the coordinating body as a tool for the integration of the various national and international initiatives.

A focused development and coordination activity is recommended in the area of product data integration. This area is vital to any manufacturing enterprise, where the data used to define, produce, and support a product has to be made available to trading partners, suppliers, government agencies, and a host of other organizations. Product data integration is a unique opportunity for the EIF because a significant amount of work has been done in the detailed development of product data integration technology. The PDES activities in particular provide a springboard for the demonstration of true product data integration. Two actions are required. Current PDES activities in the development of a product description language should be focused and supported, and a research environment established with the goal of achieving a PDES Level 4 implementation in 5 years. (Reference Report - EIF National Initiative Program Positioning - Task 2.6 and Section Three - EIF Concepts).

3. Joint Development with CIM-OSA A government agency should become a focal point for the U.S. participation in the development of CIM-OSA. It should represent the position of the numerous U.S. integration initiatives lacking the means to participate individually. It should continue an involvement in CIM-OSA to ensure that the EIF requirements and lessons learned are understood by the CIM-OSA membership. The EIF requirements for an Enterprise Description Language should be defined, developed, and offered to CIM-OSA as a building block in the construction of their business description language. The development of an approach to high level business integration should be undertaken jointly by CIM-OSA and the U.S., one of the goals of this effort should be the development of more of a management-styled front end to CIM-OSA, as opposed to the process and technology development and implementation-oriented interface now planned. Properly orchestrated, these coordination actions could aid the filling of the rooms of the CIM-OSA house possibly with the validated EIF aerospace models and constructs. Two specific tasks are recommended in this regard, these are:

a. A team of system experts, representing a reasonable cross-section of the aerospace manufacturing industry and, therefore, a possible first cut at an industry consensus, should be assembled and charged with the responsibility for accumulating and selecting the best and most representative of the aerospace industry's large existing inventory of $IDEF_0$ manufacturing enterprise models, transforming them into the beginnings of the CIM-OSA constructs, and then completing these with the auxiliary behavior information absent from the IDEF methodology.

b. A team of information analysts similarly formed should likewise study the requirements of the CIM-OSA information view and determine the applicability of the $IDEF_{1X}$ methodology to satisfy them, and then develop whatever modifications to the methodology found necessary and appropriate by them.

The recommended actions in the above areas are a logical extension of the work performed in the EIF contract and will advance key aspects of enterprise integration. The U.S. government is the correct agency to be sponsoring these activities since it alone is capable of pulling off integration on this scale. The first step has been taken but there are many more that must follow.

APPENDIX B

EIF NATIONAL INITIATIVE
PROGRAM POSITIONING REPORT

EIF
NATIONAL INITIATIVE
PROGRAM POSITIONING
REPORT

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ENTERPRISE INTEGRATION FRAMEWORK
DAPRO CONTRACT # F 33600-87-C0464
PHASE TWO
TASK 2.6

EIF
NATIONAL INITIATIVE
PROGRAM POSITIONING
REPORT

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Appendix A Enterprise Viewpoints - Detail Charts A-1

Appendix B General Focus - Detail Charts B-1

Appendix C Technology Approach - Detail Charts C-1

Appendix D Information Group/Process Matrix - Detail Charts D-1

INTRODUCTION

A number of government and commercial programs address the issues of enterprise integration from a variety of standpoints. The IBM and Northrop/D. Appleton Co. Enterprise Integration Framework (EIF) teams studied these programs to better understand how their objectives related to those of the EIF. This report documents the findings of that activity and represents the viewpoint of both teams. This program positioning exercise was a highly successful first step in defining the state of the various integration activities and in developing a reference frame for characterizing and potentially integrating them.

The programs included in the survey are sponsored and supported by a wide range of industry, government, and academic organizations. Collectively these programs represent a national effort addressing enterprise integration. The specific programs included in this evaluation are the following.

- Automated Airframe Assembly Program (AAAP)
- CAM-I Computer Integrated Enterprise (CIE)
- CAM-I Cost Management System (CMS)
- CAD Framework Initiative (CFI)
- Computer Integrated Manufacturing - Open Systems Architecture (CIM-OSA)
- DoD Computer Aided Acquisition and Logistics Support (CALS)
- DARPA Initiative in Concurrent Engineering (DICE)
- Geometric Modeling Applications Interface (GMAP)
- GM - CAD, CAE, CAM, CIM (C4) Program
- Engineering Information System (EIS)
- Product Data Exchange Specification (PDES)
- Purdue CIM Reference Model
- Rensselaer Polytechnic Institute (RPI) CIM Program
- SEMATECH CIM Architecture

There is a huge body of material associated with each of these programs. This comparison is a top level condensation of that material. Its purpose is to position the programs relative to a set of criteria agreed upon by the IBM and Northrop/D. Appleton Co. teams. The criteria were chosen for their ability to characterize the programs and differentiate between them. They are the following:

a. The levels of the organization addressed by the programs.
b. The coverage of multiorganizational enterprises.
c. The variety of modeling tools and methods associated with the

programs.

d. The product life cycle phases addressed by the programs (i.e. requirements, design, production, and support.)
e. The impact of the programs on the enterprise "regeneration process" (as opposed to the product life cycle).
f. The current status (level of definition) of the programs.
g. The approach of the programs to technology.

No single chart can address all of these issues in a comprehensible way, so the issues were divided into a set of charts which, when taken together, provide a picture of the individual programs and the relationships between them. The resultant charts are explained in the following discussion.

CHART DESCRIPTIONS

1. Enterprise Viewpoints Charts (Product Life Cycle vs. People & Orgs.)

A typical manufacturing enterprise is strongly influenced by the programs in which it is participating. For this reason it is important to understand integration issues in the context of the product life cycle. This chart format is used for that purpose. It positions the programs relative to their impact within and between organizations and across the product life cycle. The organizational axis is composed of the following internal and external organizations and relationships.

Internal	External
Executive	Customers
Manager	Trading Partners
Analyst	Suppliers
Planner	
Users (men & machines)	

The simplified product life cycle on the horizontal axis consists of Requirements, Design, Production, and Support. The individual programs were mapped onto the space defined by the two axes. The composite chart indicates the number of programs addressing each area. Areas with a significant amount of program overlap are candidates for cooperation, and areas with little emphasis are potential candidates for future development work.

The Enterprise Viewpoints summary chart (Figure 1) is most easily examined in two steps. The top half represents the coverage of issues within or

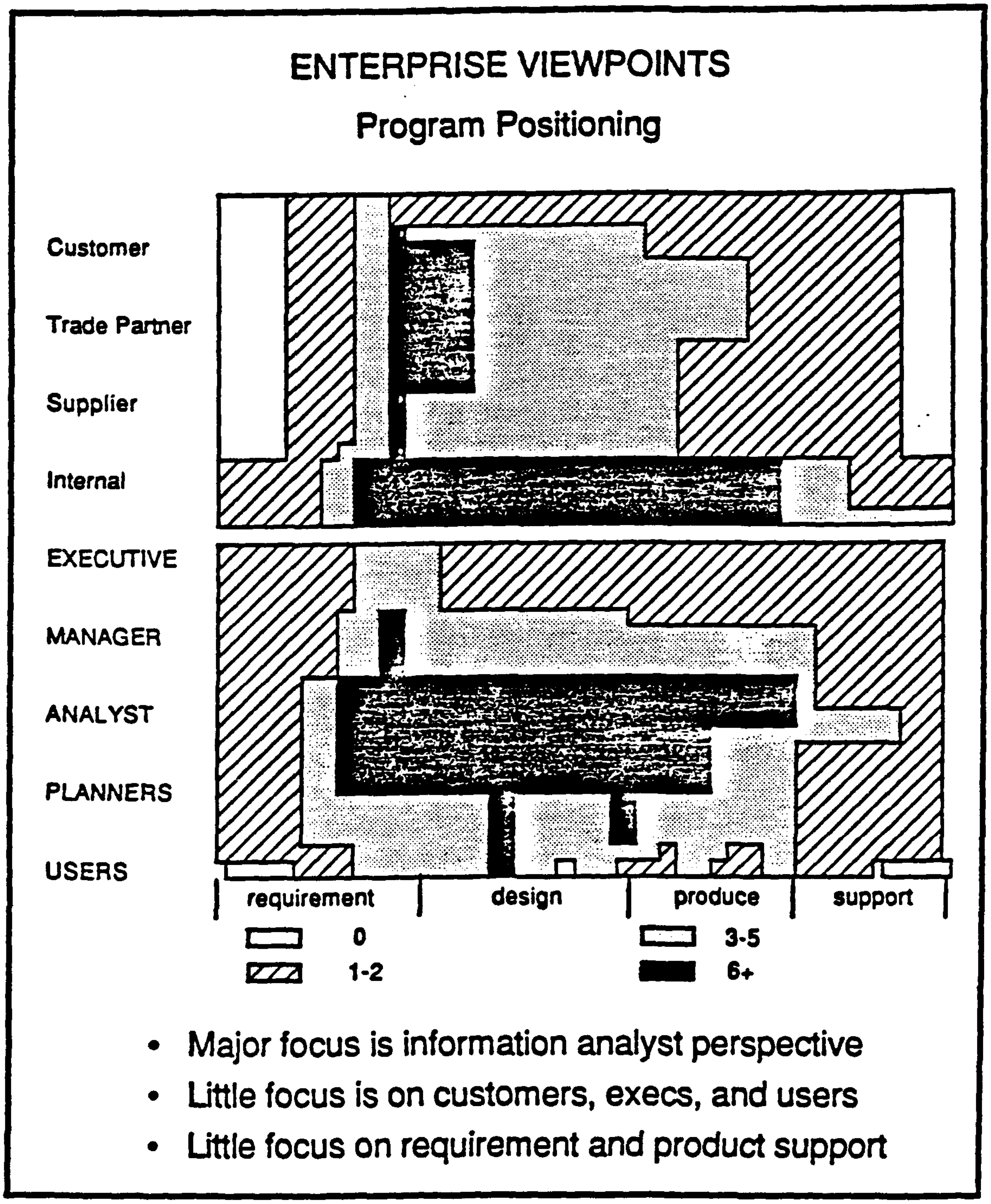


Figure 1 - Enterprise Viewpoints Summary

between organizations. The data indicates that the majority of integration programs have focused primarily on internal issues and much less on customers, trading partners, and suppliers. The lower half of the chart is an explosion of the "internal" category found on the upper half. It indicates that the vast majority of programs are focused on "information analysts" and not on management or other end users. Both the upper and lower halves of the chart indicate a focus on the design and production phases of the product lifecycle, with much less emphasis on requirements and support. One exception to this general trend is CIE (see Appendix A-2). This chart suggests both a wide number of users and a focus that, although it does overlap into design, emphasizes requirements. Other individual program charts summarized in Figure 1 are also found in Appendix A.

2. General Focus Charts

While integration is often a function of the product life cycle, it is also a function of the enterprise "regeneration process" and must be well understood in that context. The process by which an enterprise is regenerated involves an understanding of the internal and external environments and a corresponding set of adjustments to the business configuration (systems, people, etc). Enterprise regeneration is the basis of the continued survival and well-being of the enterprise and is typically independent of any one single program. This chart format is used to position the programs with respect to their impact on this process which is defined in terms of following steps.

a. The development of descriptive models (process, activity, information, etc.)
b. The development of enterprise systems (in this case *open* systems & Open System Architectures or OSAs)
c. The operation of the enterprise (in which the systems are built, installed, maintained, improved and (ultimately) retired).

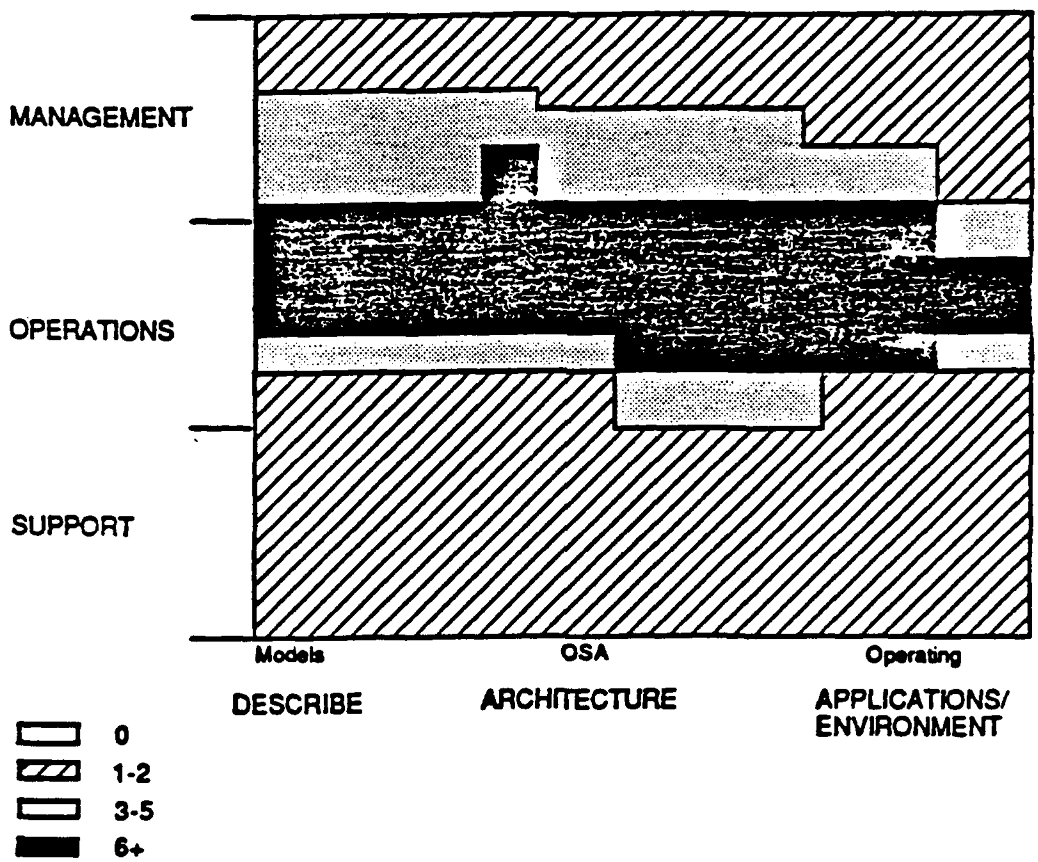
The enterprise systems which are the subject of this discussion are not limited to computer and information systems. Instead, they include all of the systems required to support the full range of enterprise processes. This means that an open system is defined in terms of the practices and procedures, physical interconnects, human interfaces, and information and communications systems required for integration. These systems are used in the support of one or more of the following enterprise "areas."

a. Management (Planning, Organizing, Staffing, and Control)
b. Operations (Execution)
c. Support (Providing & maintaining the necessary environment for Management and Operations)

The charts indicate the areas in which the programs are addressing technology. The individual program charts are found in Appendix B. The summary chart (Figure 2) indicates the overlaps among programs which, again, are candidates for coordination. The greatest overlap is in open systems architectures in the enterprise operations area. Almost every program is adapting or developing some portion of an open systems architecture. AAAP (Appendix B-2), is a clear example of a program forcused wholly in the operations area. The management and support areas, on the other hand, are the focus of little attention. A more detailed treatment of the technology associated with the various programs is contained in the following section.

GENERAL FOCUS

Program Positioning



- Focus is on operations (not on management or support)
- CIM-OSA concepts address total envelope
- Most programs address necessary breadth (across chart)

Figure 2 - General Focus Summary

3. Technology Approach Charts

These charts are the basis of the "Technology Considered" chart described in the previous section. The Technology Approach charts identify the specific technologies addressed by the programs. The individual charts [illegible] each program are found in Appendix C and are summarized in Figure [illegible] The

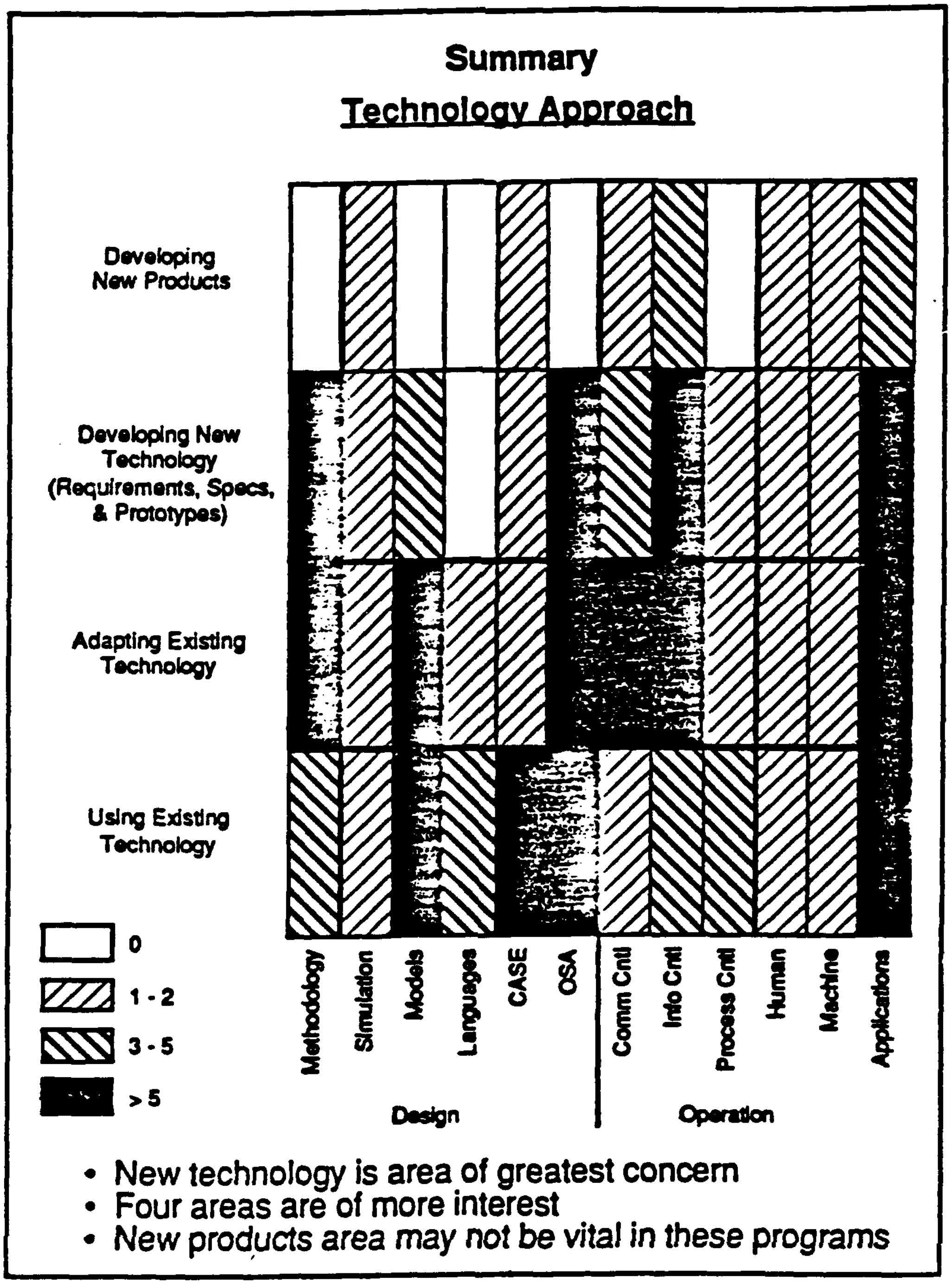


Figure 3 - Technology Approach Summary

technology is defined in terms of whether it is being developed, adapted, or used "off the shelf" by the programs. The chart also identifies those technologies which are being developed into new products by the various programs. The technologies are grouped into the areas of design and operations in the following manner.

Design	Operations
Methodology	Communications Control
Simulation	Information Control
Models	Process Control
Languages	Human (Interfaces)
CASE	Machine (Technology)
OSA	Applications

These charts identify the technologies that are of *interest* to a program that are not actually being developed *by* that program. Programs such as CALS are focused on the adaptation and use of existing technologies instead of the creation of new ones. This distinguishes CALS from a program such as the Automated Airframe Assembly Program (see Appendices C-2 and C-4), in which a significant amount of new technology *is* being developed. The summary chart in this series indicates that the development of technology is greatest in four specific areas. These areas, namely Methodology, Open Systems Architectures, Communication Control, and Applications are strong *candidates for coordination* across programs. Areas of overlapping technology use and product development are also identified on the summary chart, but are of less interest, because of a smaller potential for conflict.

The lack of product development in many of the technical areas is not necessarily a cause of concern. Although many of the surveyed programs are not developing products, it is entirely possible that the technology is being transitioned to other agencies that perform the actual packaging and productization.

4. Information Group/Process Matrix Charts

These charts position the programs from an information and process standpoint. The processes are those used by the people in an enterprise to design, build, and support the product, to manage these "doing" processes, and to support the enterprise processes with the resources that they require. The information groups are those categories into which all data in a typical manufacturing organization can be sub-divided.

Each program is mapped onto an individual chart. The individual charts are found in Appendix D. The individual chart for the CAM-I CMS program (Appendix D-6), for example, indicates a focus on financial management information (horizontal axis) across all but three of the enterprise process areas (vertical axis). Each individual program has a different process and information focus and a different range of enterprise coverage.

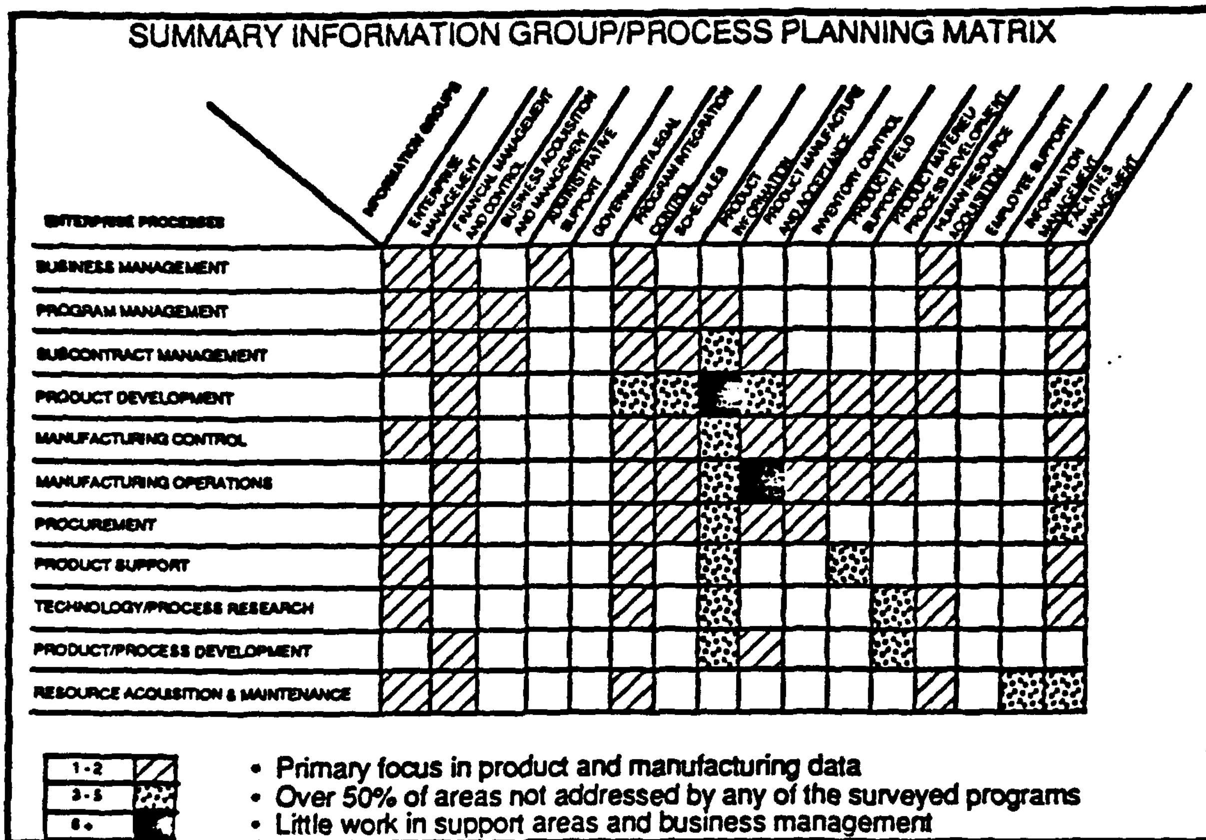


Figure 4 - Information Group/Process Matrix Summary

The summary chart (Figure 4) is a composite of the individual program charts. It indicates the overlap across programs which is, not surprisingly, greatest in the information management and product information areas. The overlaps would be even more significant if programs such as the Electronic Data Interchange Format (EDIF), VHSIC Hardware Description Language (VHDL), and other similar programs were mapped into the matrix. Both VHDL and EDIF, for example, would add another box to the already crowded intersection of product development (vertical axis) and product information (horizontal axis). In contrast to these overlaps, half of the enterprise areas are not addressed at all by any of the integration programs included in this survey. Clearly, the message in this chart is that the majority of the current integration programs are focused on a small subset of the enterprise, while the majority of the enterprise is left unexamined.

5. Program Level of Definition Charts

The program level of definition is an important measure of the forward progress of the programs. When used in concert with the scoping charts (Figures 1 - 4), the result is a unified picture of a program's intent and detail. These charts position the programs in terms of their current status in three areas:

a. Architecture (Defining the program structure and direction)
b. Modeling (Providing the detailed description of the environment)
c. Integrated Infrastructure (The physical systems supporting a. & b.)

The current program status is defined in terms of the following phases.

Concept	Requirements identification, general design concept investigation and modeling resulting in a preferred alternative.
Design	Development of the preferred alternative into detailed specifications, interface specs, and demonstrated models.
Implementation	Operational *pieces* of the design are implemented.
Installation	Fully operational design is implemented.

The level of definition charts (Figures 5 and 6) indicate that many of the more focused programs (e.g. GMAP and AAAP) are closer to implementation than the programs with a broader scope (e.g. CAM-I CIE & CIM-OSA). This indicates a potential opportunity for cooperation and joint development with one or more programs with a similar intent to that of the EIF. A concept phase program such as CIM-OSA is a strong candidate for a joint activity in which the Air Force and aerospace industry perspectives could be used in the definition of the overall approach and execution of the program.

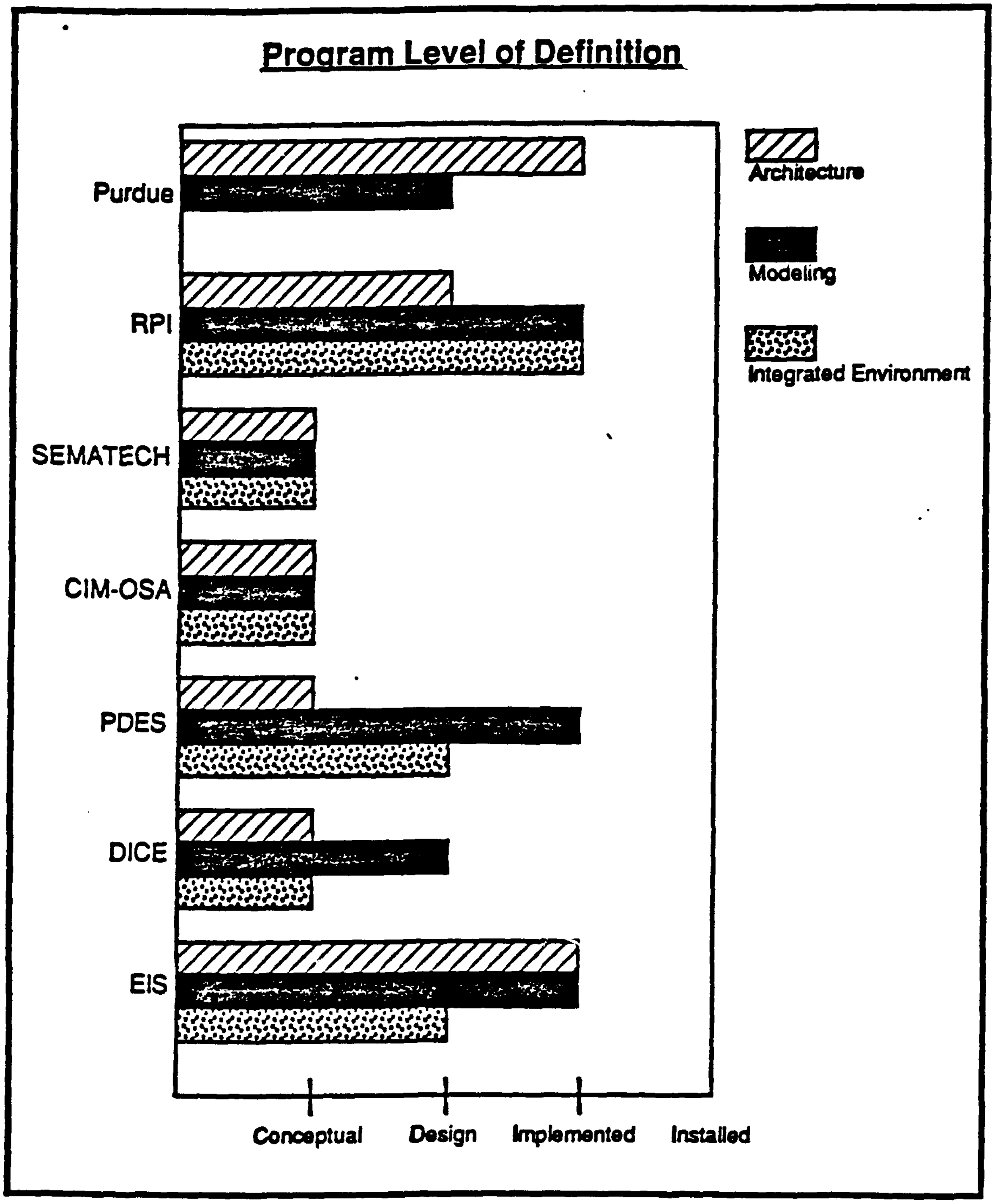


Figure 5 - Program Level of Definition (Part 1)

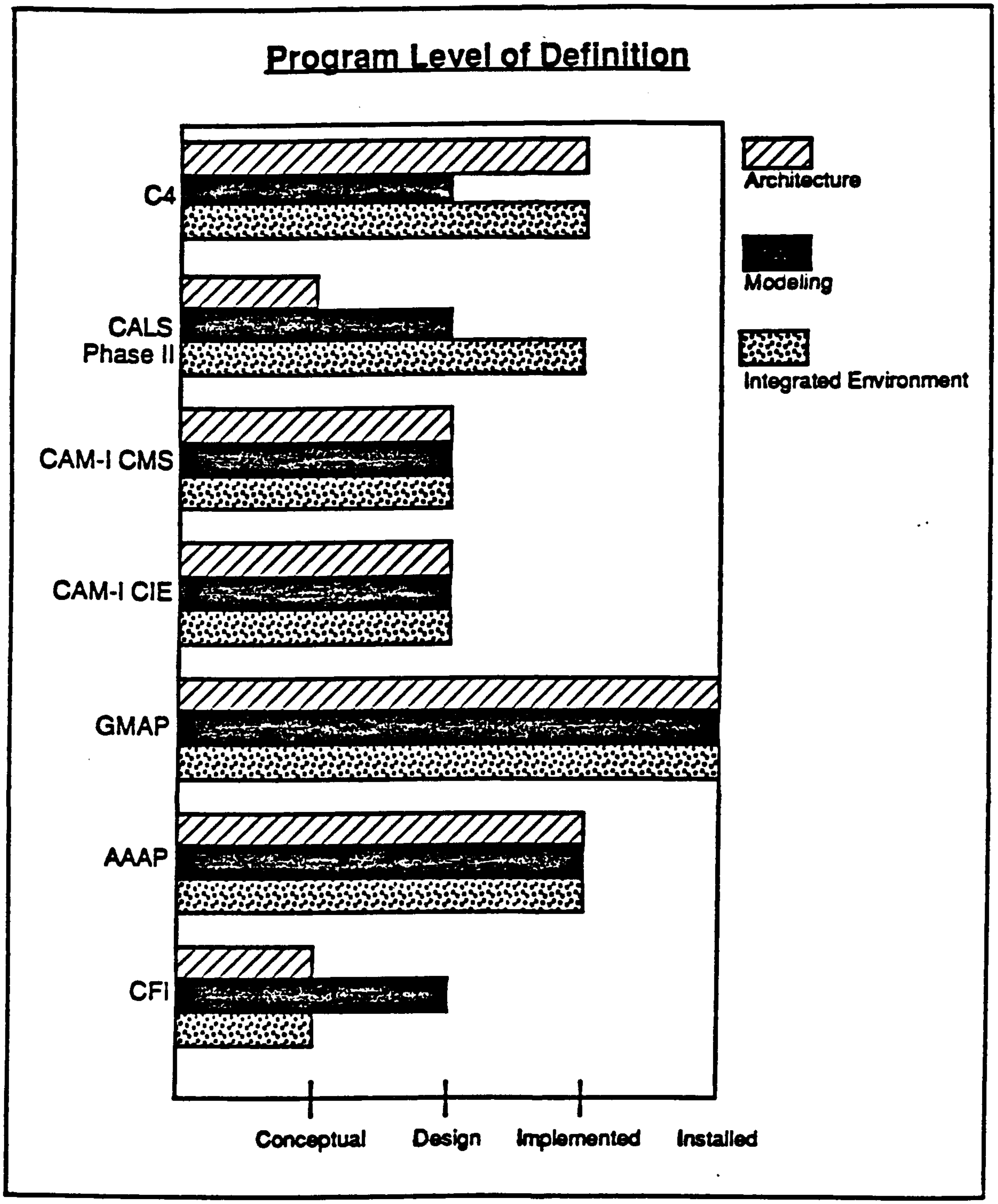


Figure 6 - Program Level of Definition (Part 2)

CONCLUSIONS

A number of conclusions have been suggested in the body of the text and will not be repeated in this section. This section deals, instead, with general observations about the comparison results and the cooperative process used to arrive at them.

The first observation relates to the difficulty in concisely and accurately defining integration programs. "Boxing" an initiative such as CALS or PDES is a subjective exercise in which the current status of the effort, its future intentions, the current and projected funding levels, stated and implied objectives, and a number of other factors must all be considered. Fortunately, the actual positioning of the program is less important than the communication initiated in the process. This communication is a powerful integrating force and clearly needs to be continued in the future.

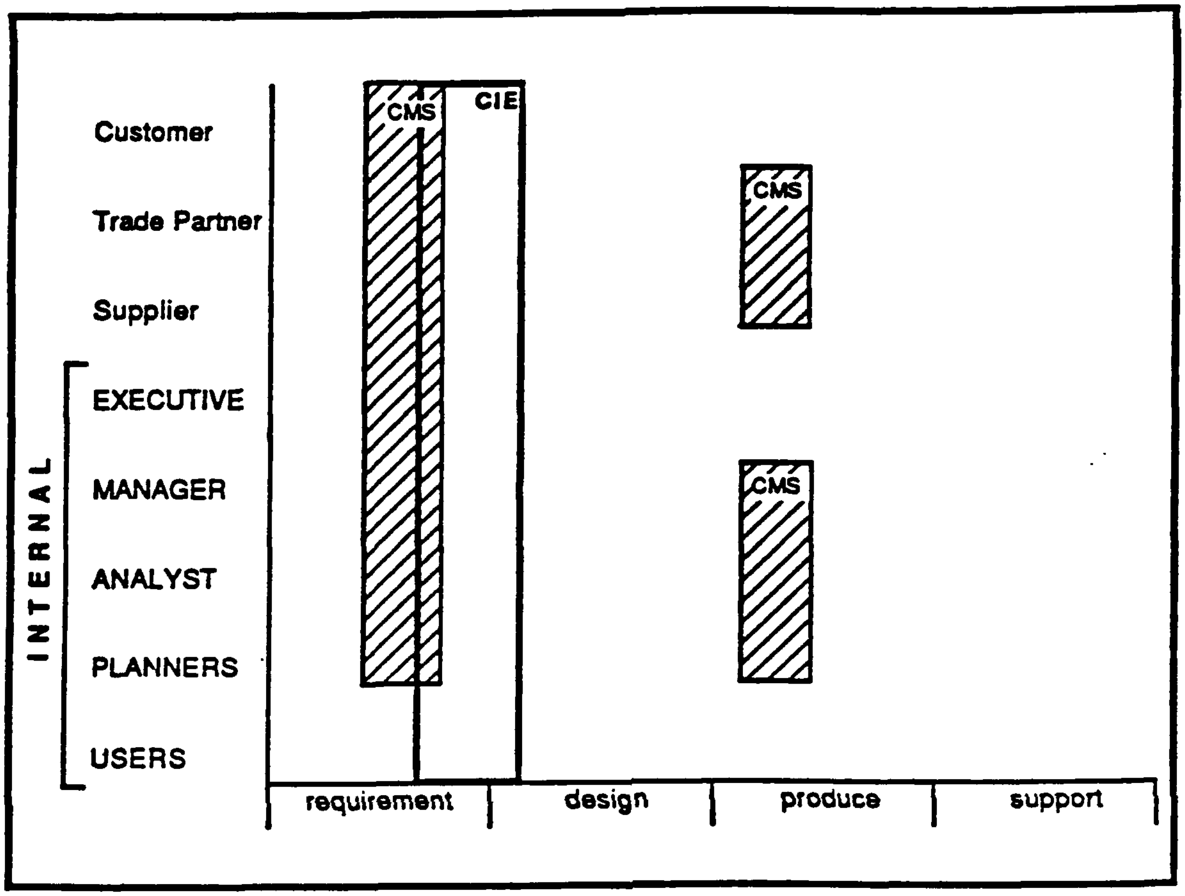
Even more fundamental than characterizing the integration programs is understanding integration itself. More than once, the EIF team was compelled to return to the basics of enterprises, integration, and processes in order to understand the issues. The *process* view of integration, in particular, was effective in identifying and understanding integration issues. The process view of enterprise integration is based on the realization that the enterprise processes are the means by which enterprise products and services are designed, produced, sold, and supported. Continuous improvement of products and services is achieved through the improvement of enterprise processes which, in turn, are frequently improved through (more effective) integration. This view allows the issues of human, legal, procedural, physical, and information integration to be dealt with on a common footing. These basics, better defined as a result of the EIF, are a key to the integration process.

A final observation is that a set of recurring themes is evident throughout the various positioning charts. There is an emphasis on the modeling of the business, the creation and use of functional and data standards, and the development of a "management control architecture" as the basis of enterprise integration. This approach is not a revolutionary one but rather a reinforcement of the values advanced by the DoD and MANTECH organizations in the past decade. As this work is performed it becomes increasingly important that there be cooperation and integration across the various programs in order to maximize their benefits. The EIF program positioning exercise and related work can be the basis of an umbrella under which these integration efforts are understood, related to other initiatives (e.g. Concurrent Engineering and Total Quality Management), and ultimately used to more effectively advance the interests of the Air Force, DoD, and industry.

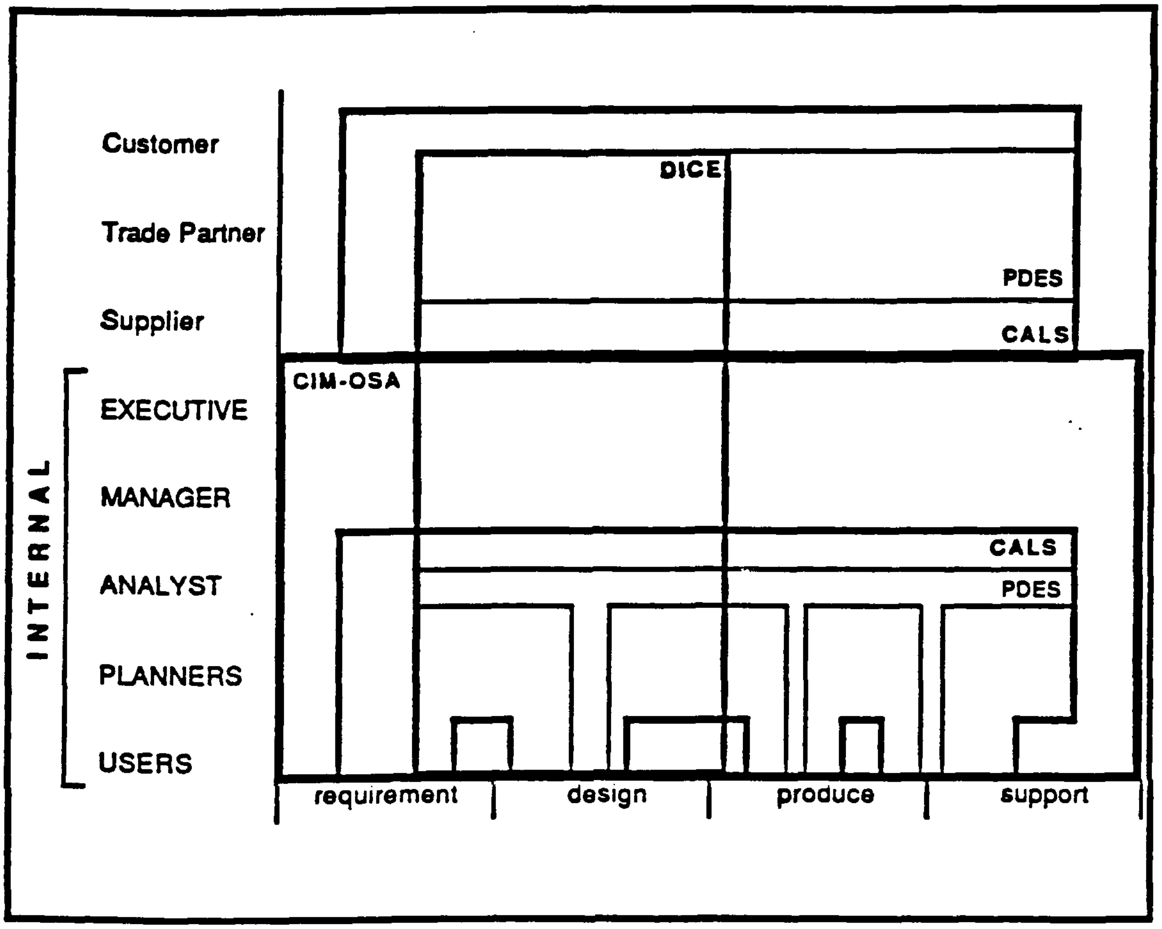
Appendix A

Enterprise Viewpoints - Detail Charts

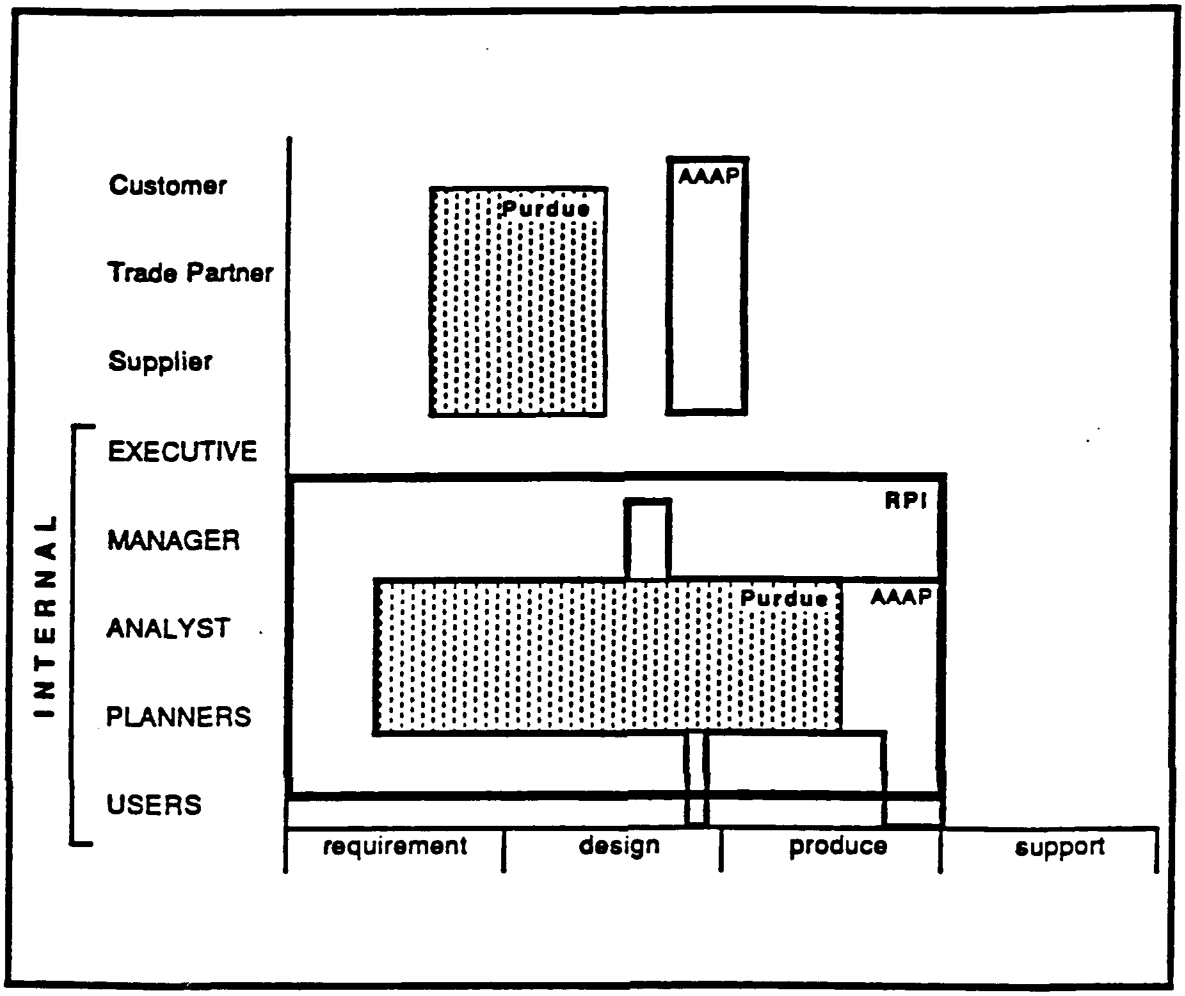
Enterprise Viewpoints



Enterprise Viewpoints



Enterprise Viewpoints



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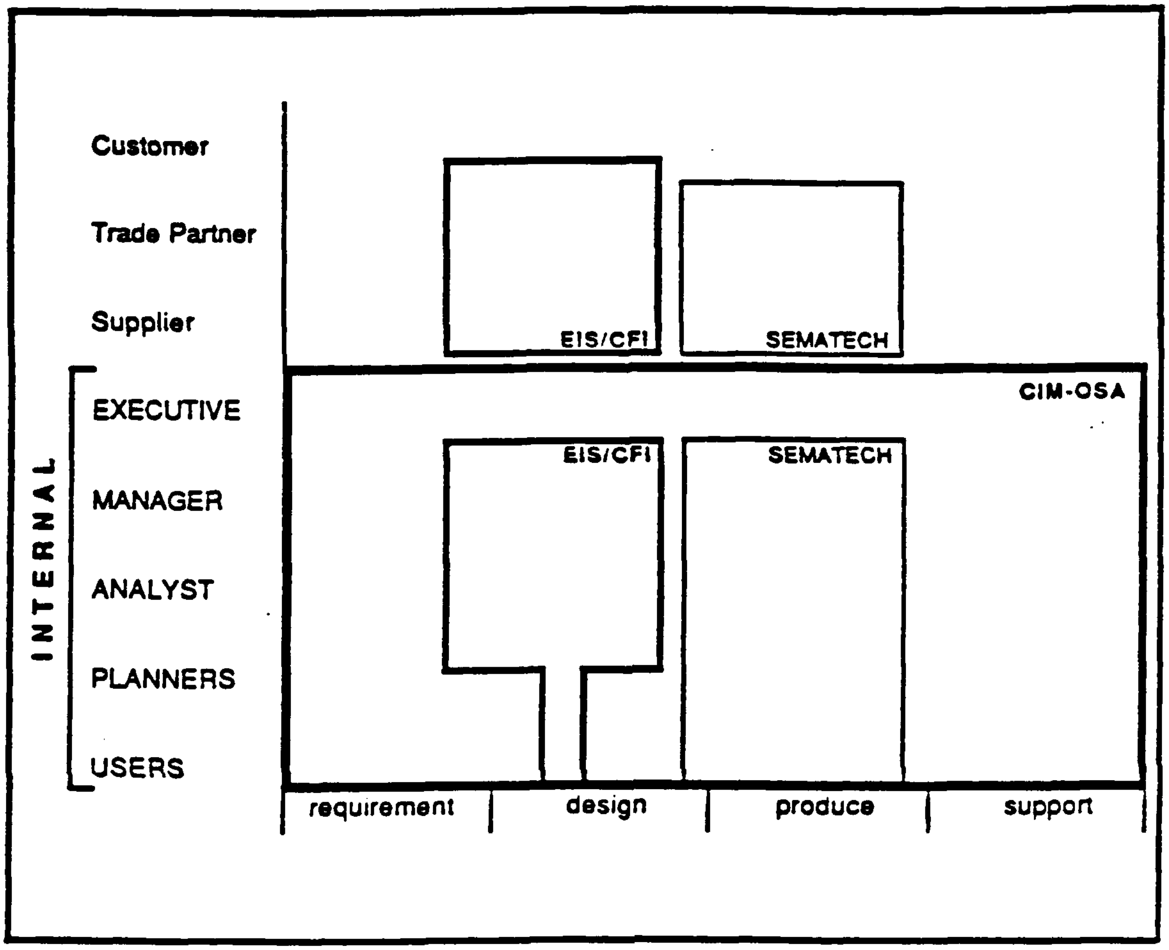
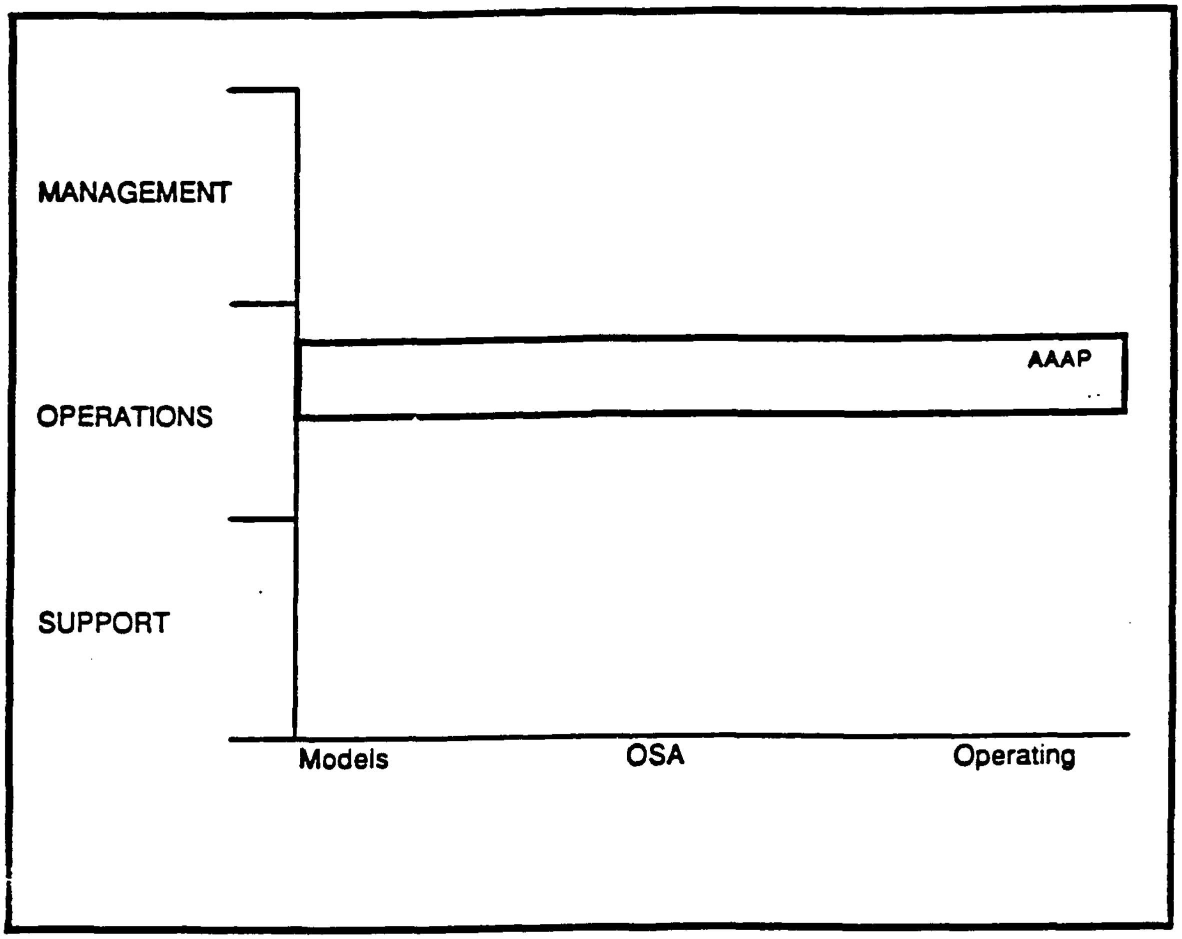
Enterprise Viewpoints



General Focus - Detail Charts

General Focus



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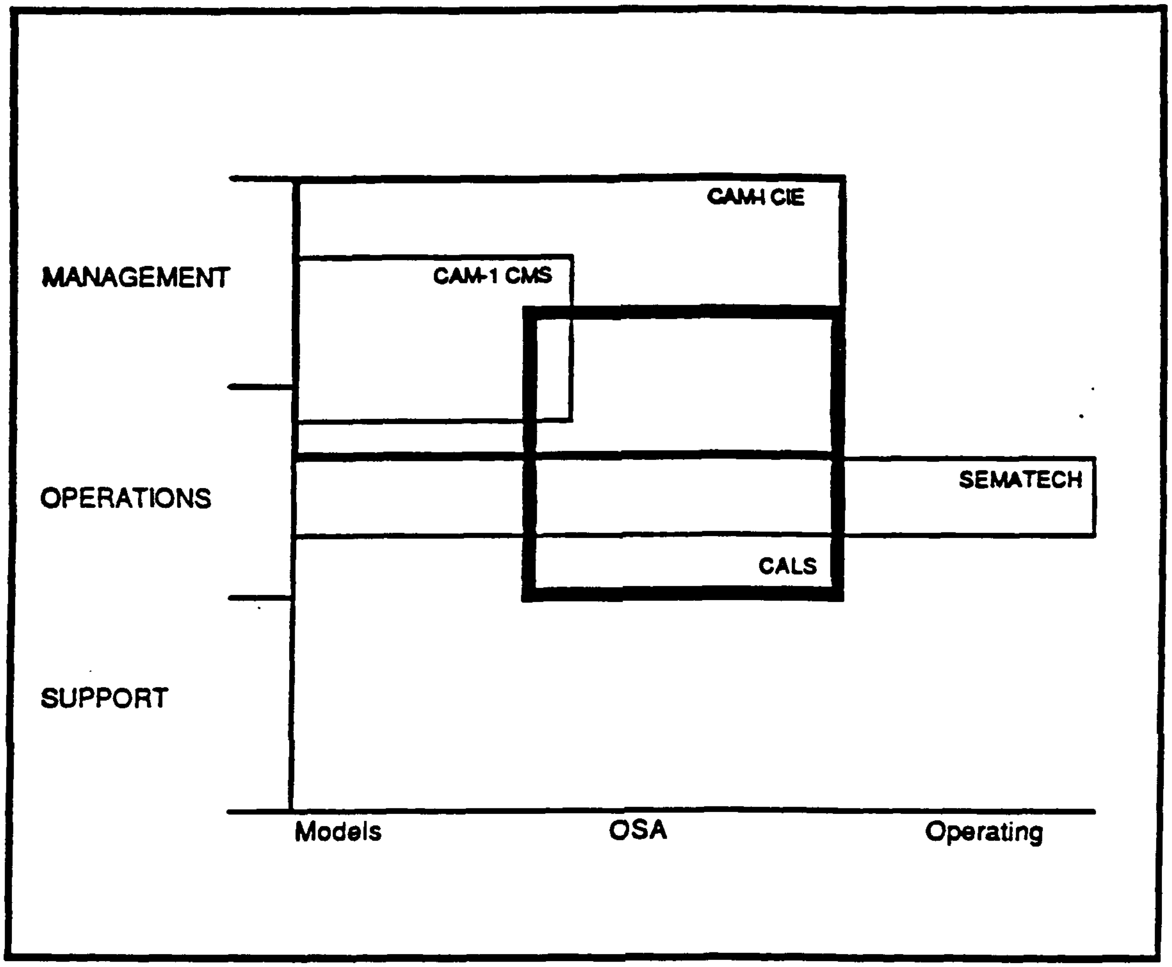

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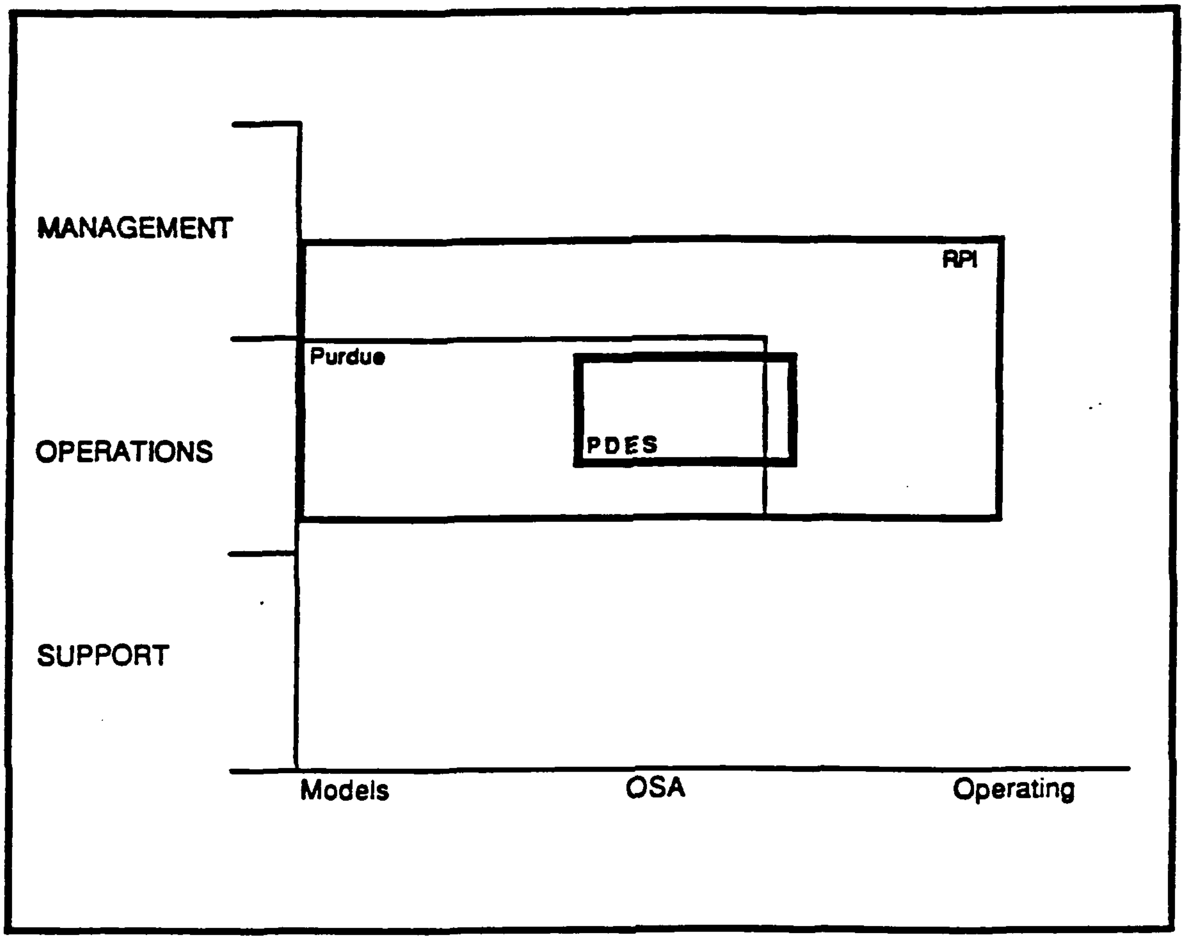

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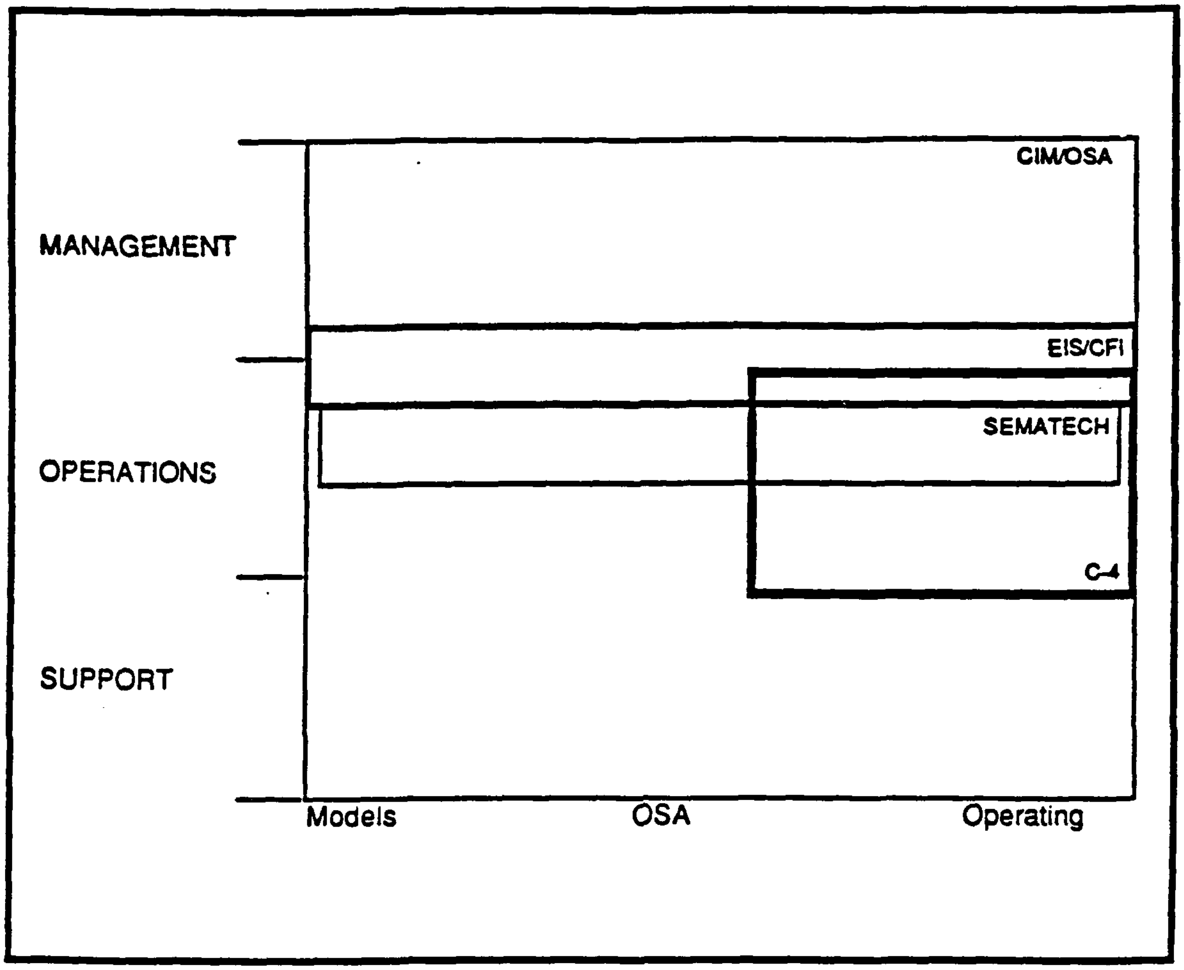
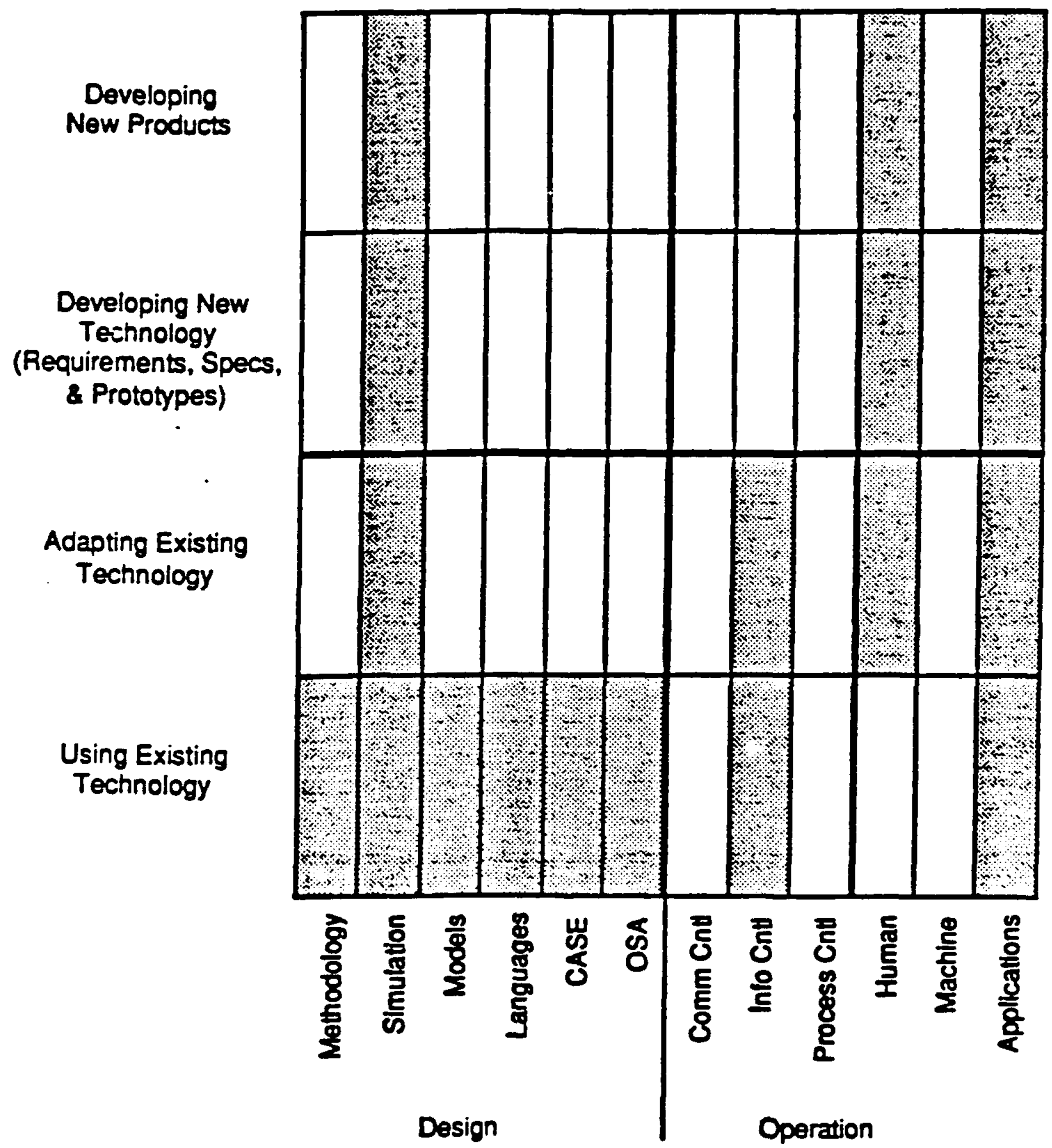
General Focus



Technology Approach - Detail Charts

AAAP

Technology Approach



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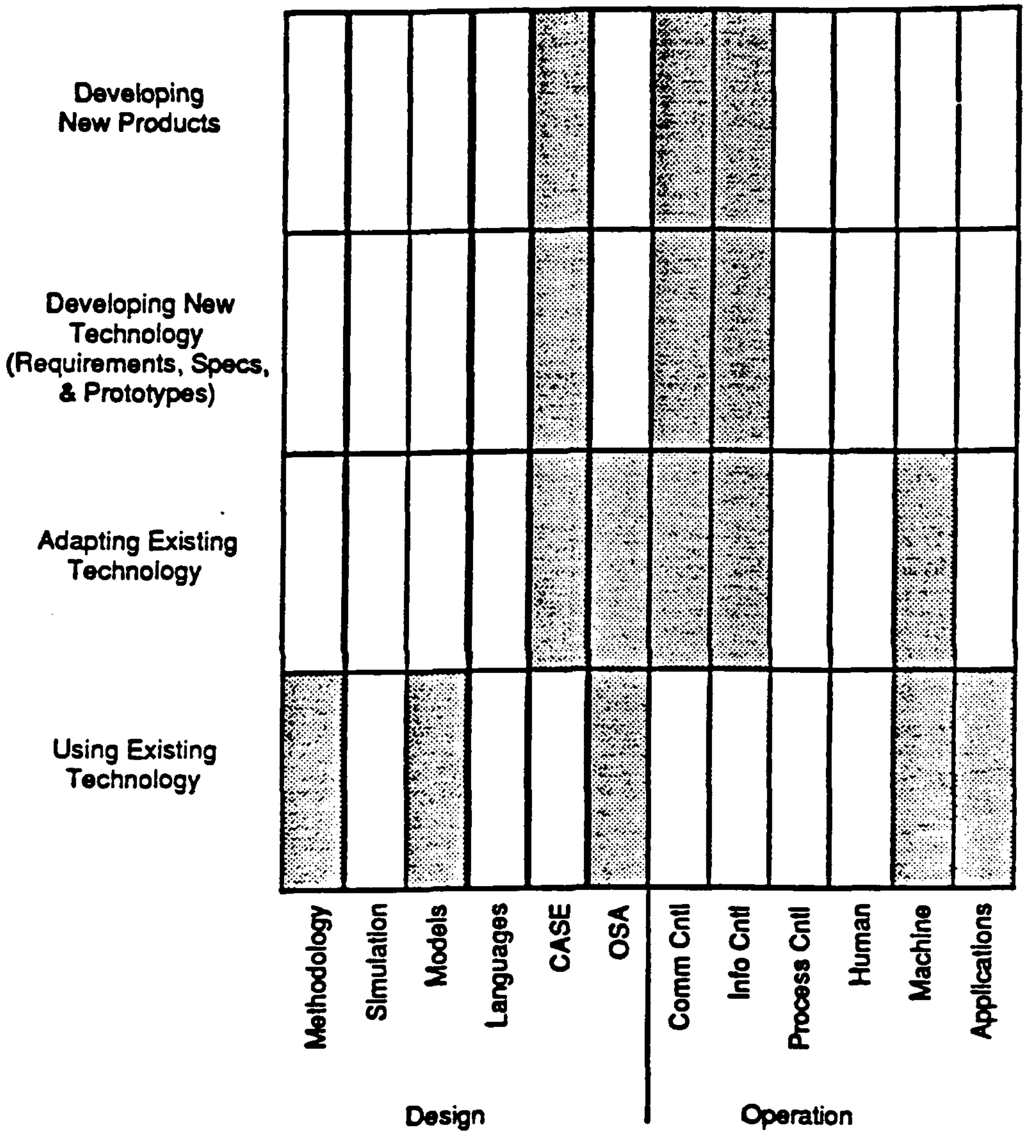
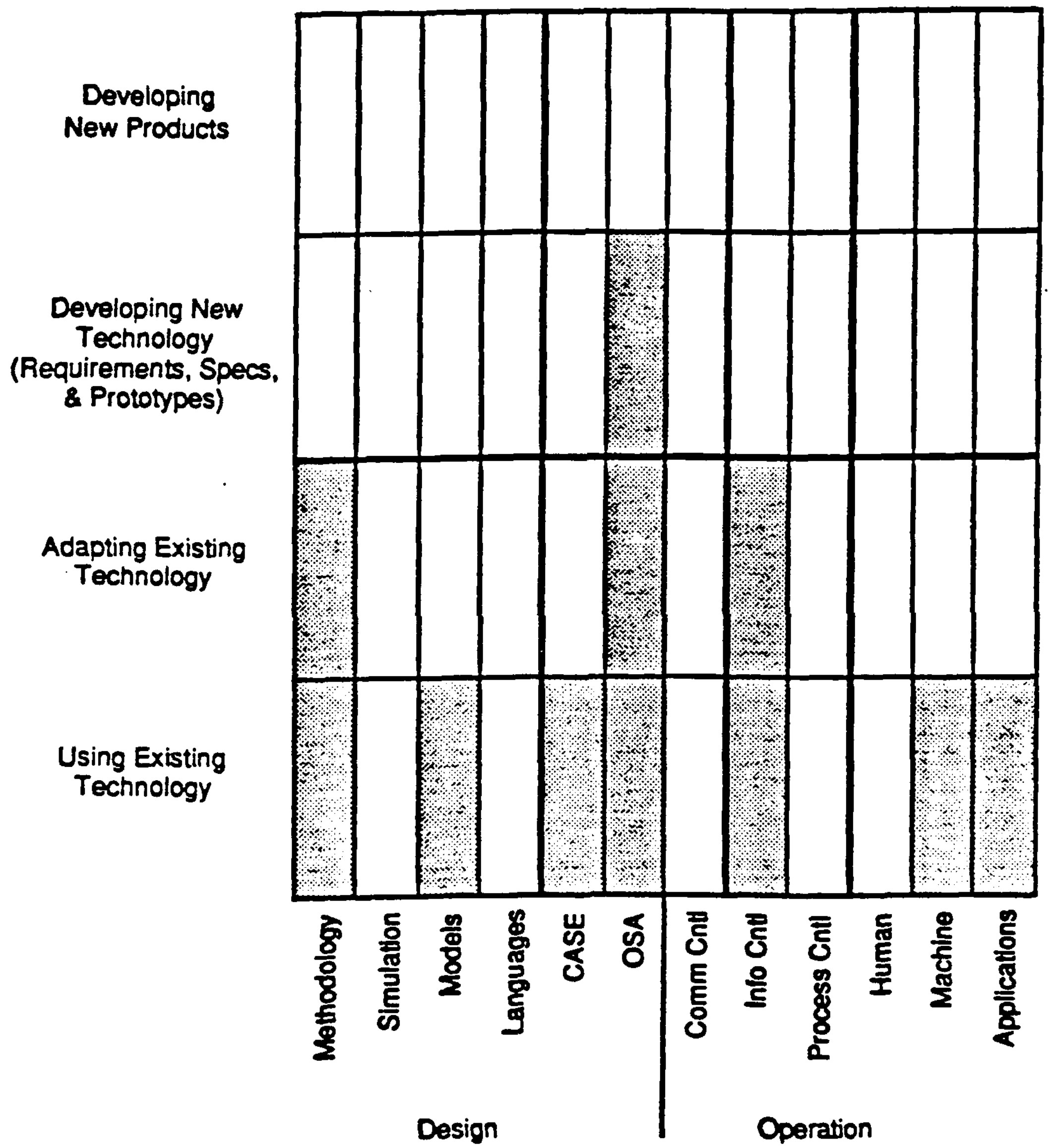
C-4

Technology Approach



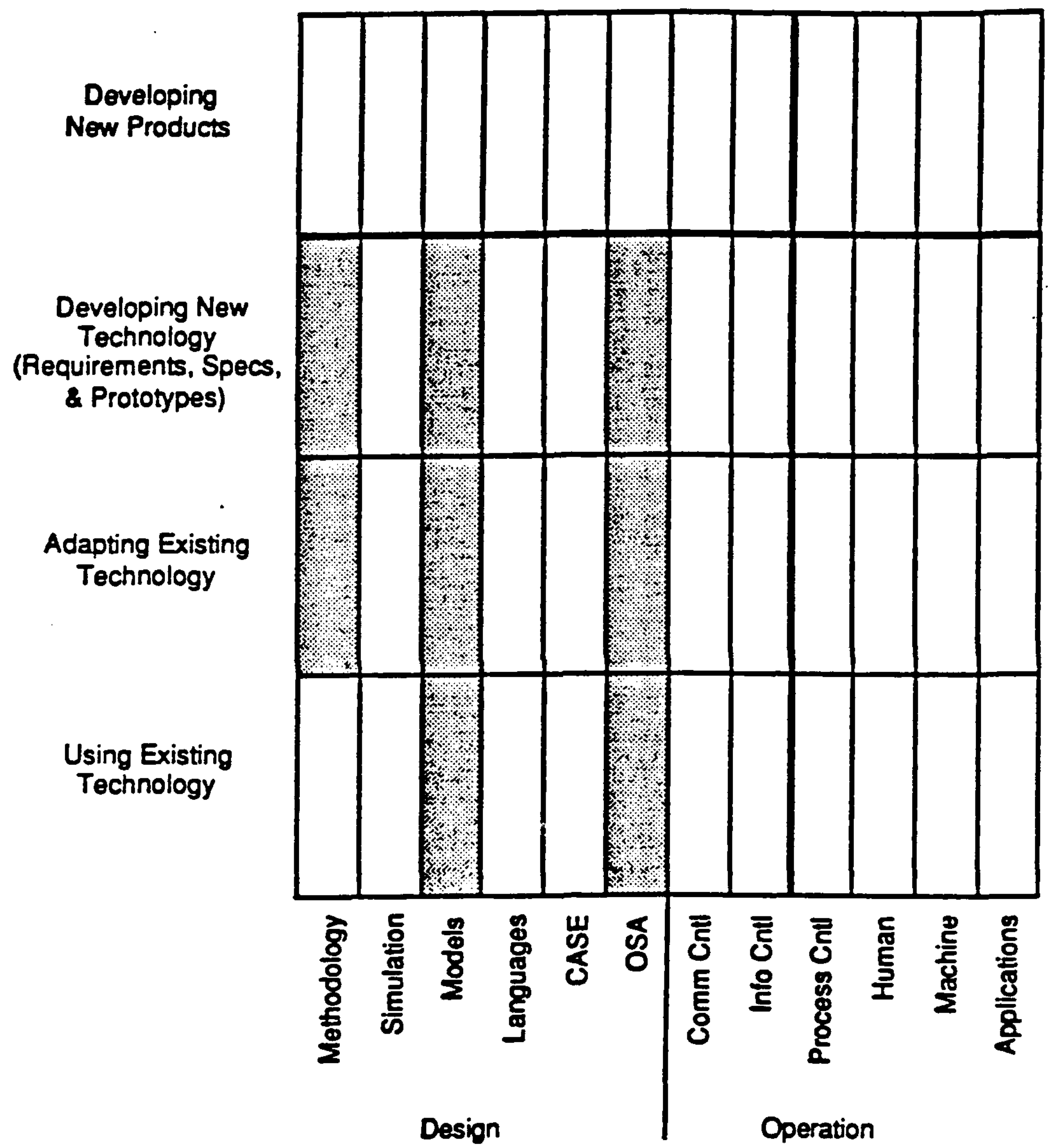
CALS

Technology Approach



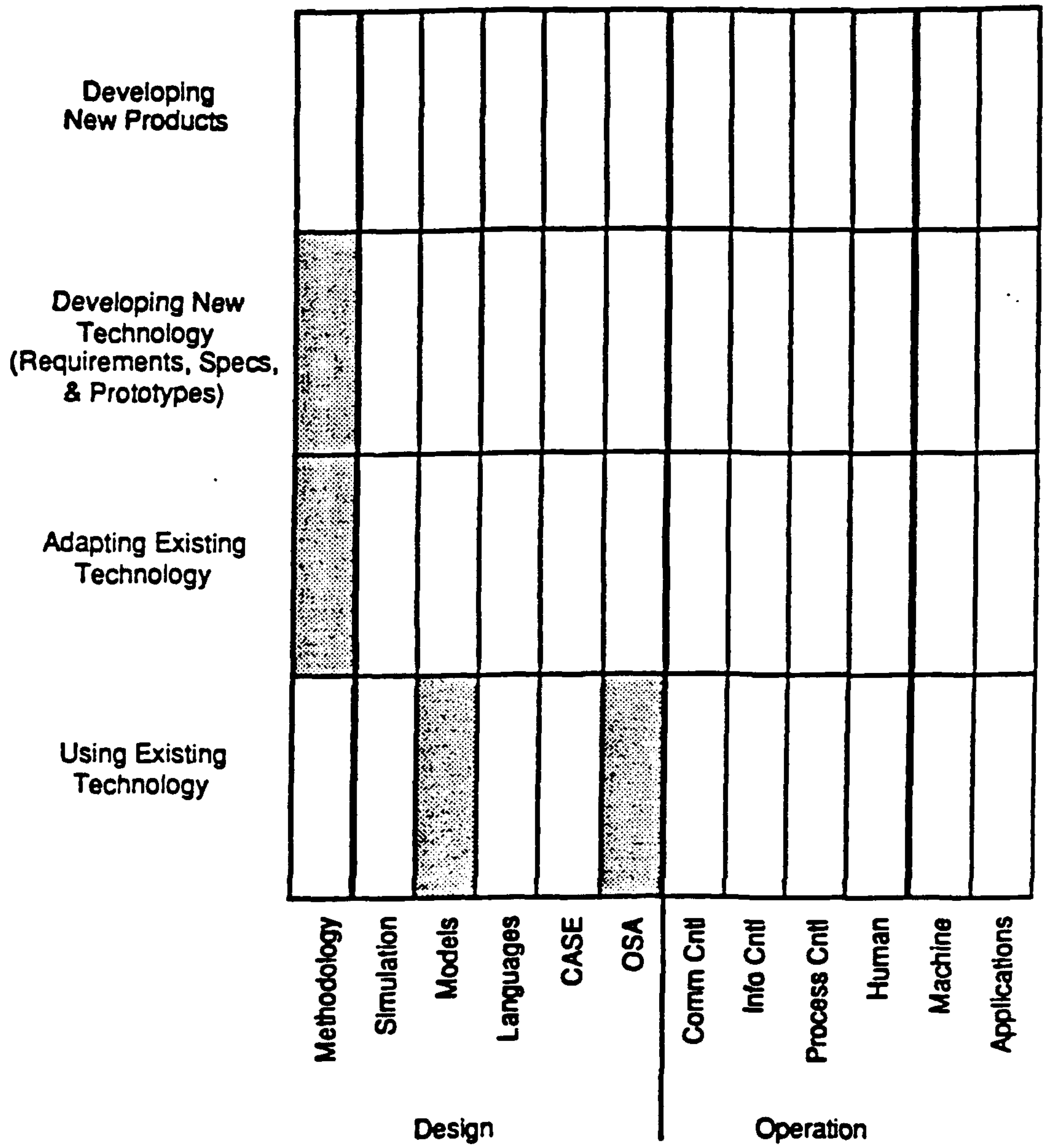
CAM-I CIE

Technology Approach



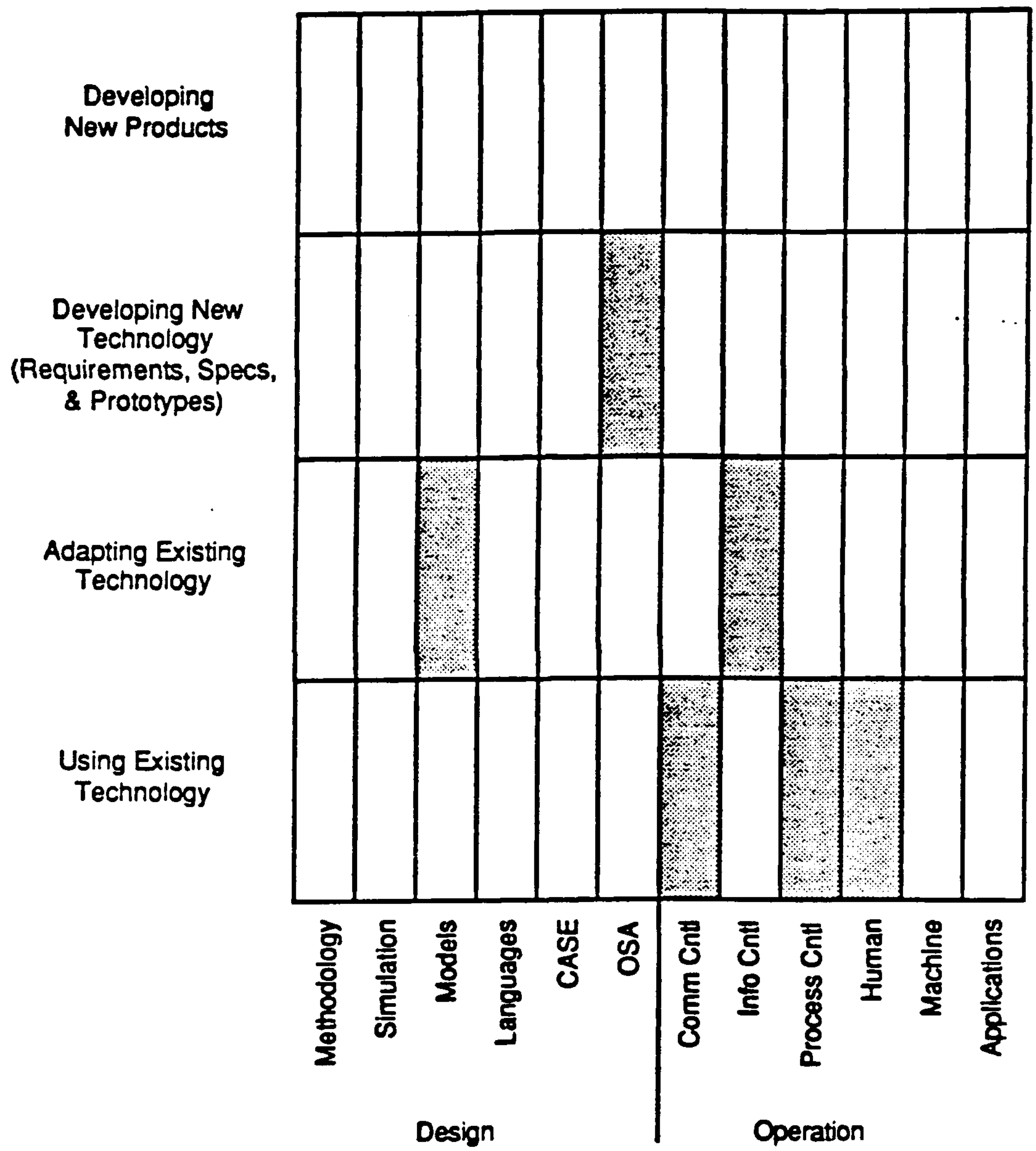
CAM-I CMS

Technology Approach



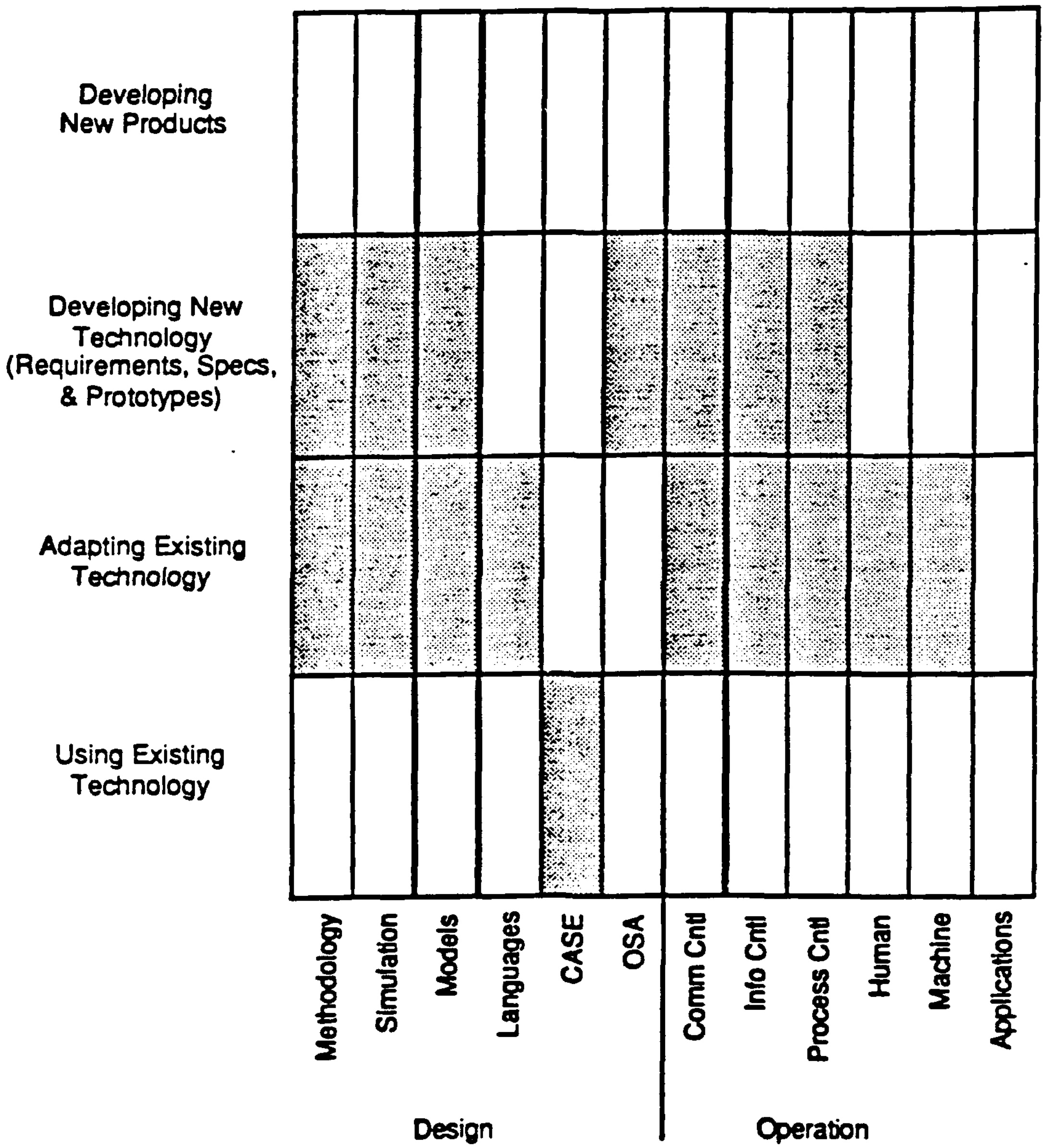
CFI

Technology Approach



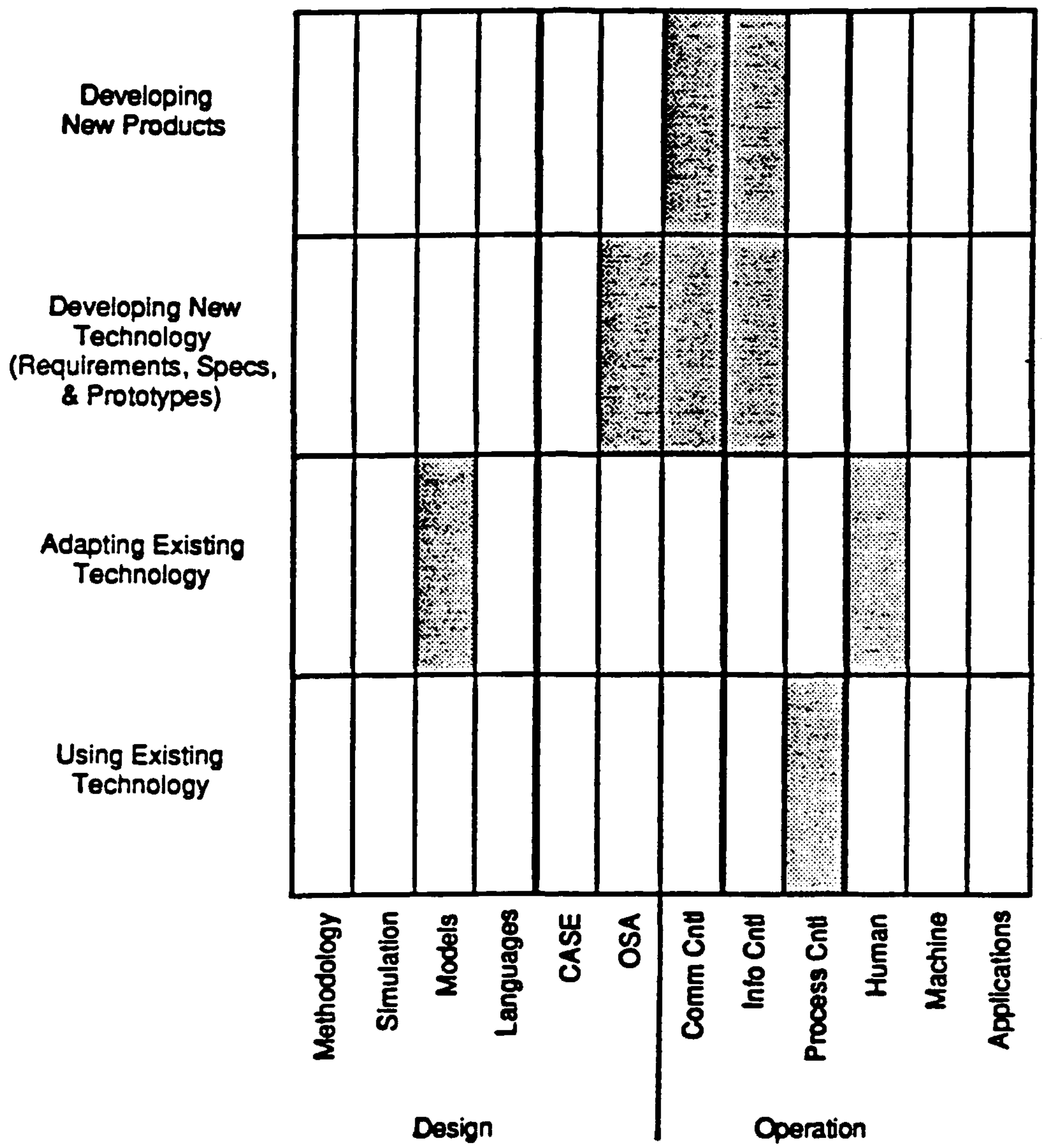
CIM-OSA

Technology Approach



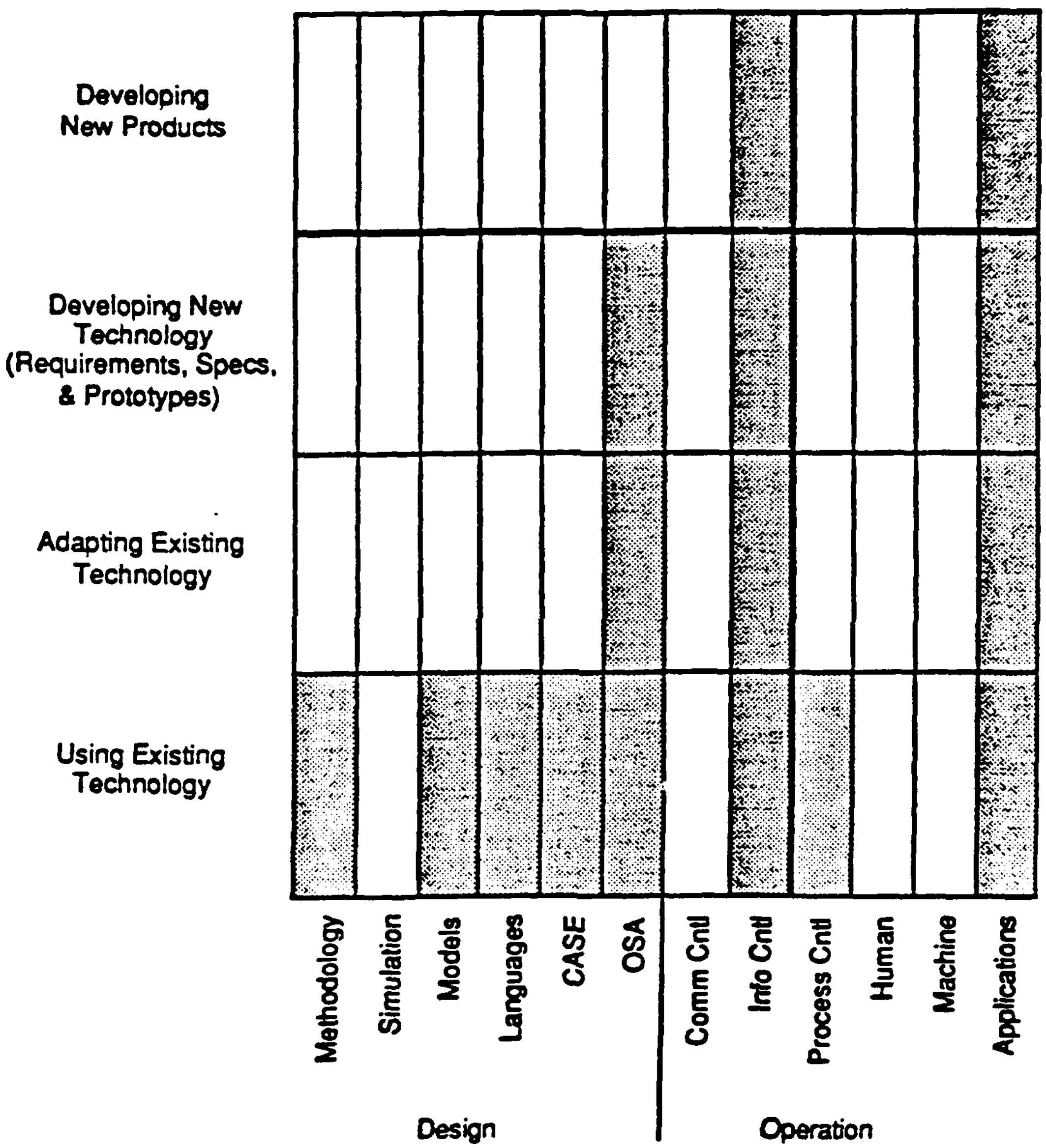
EIS

Technology Approach



GMAP

Technology Approach



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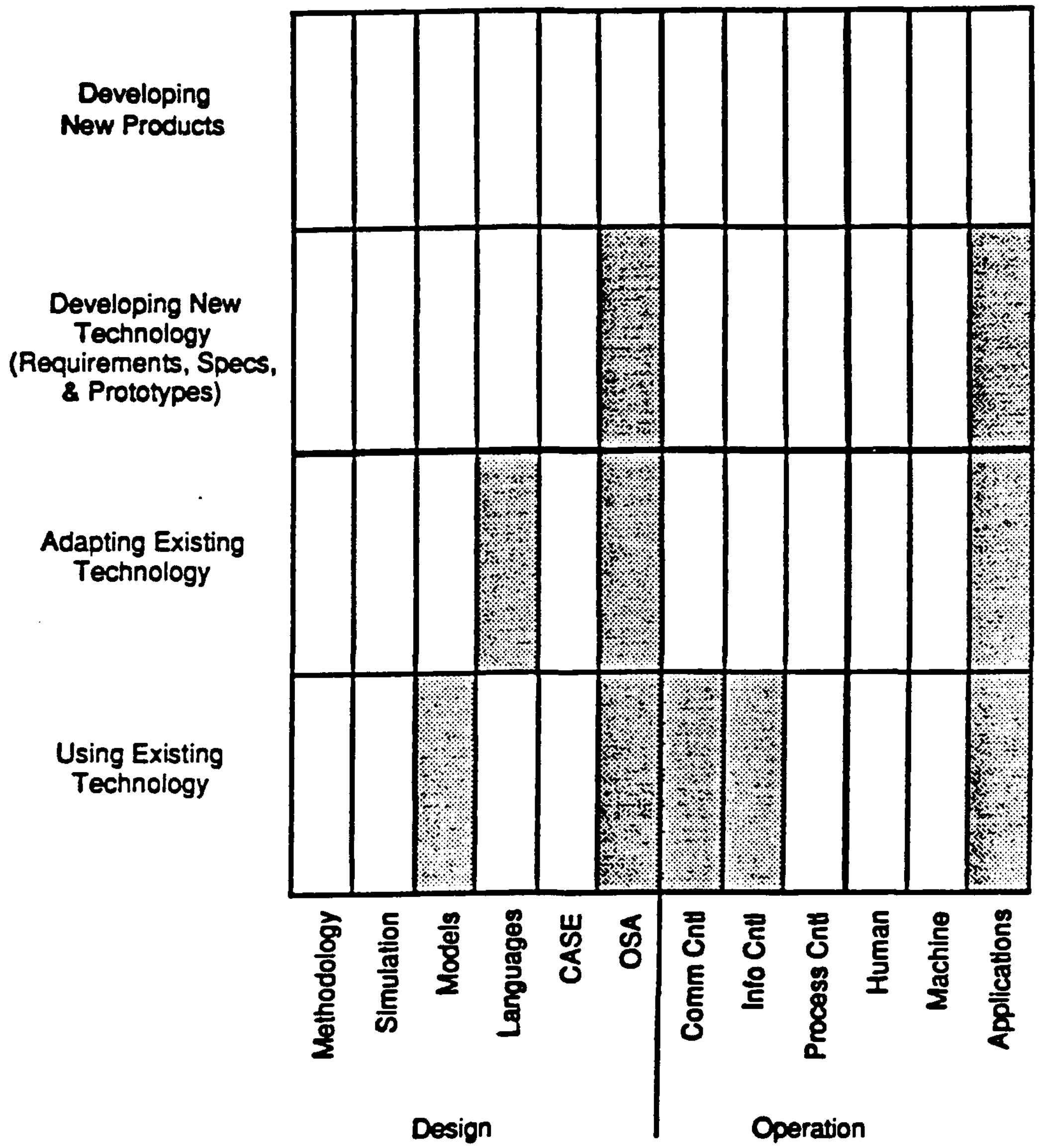
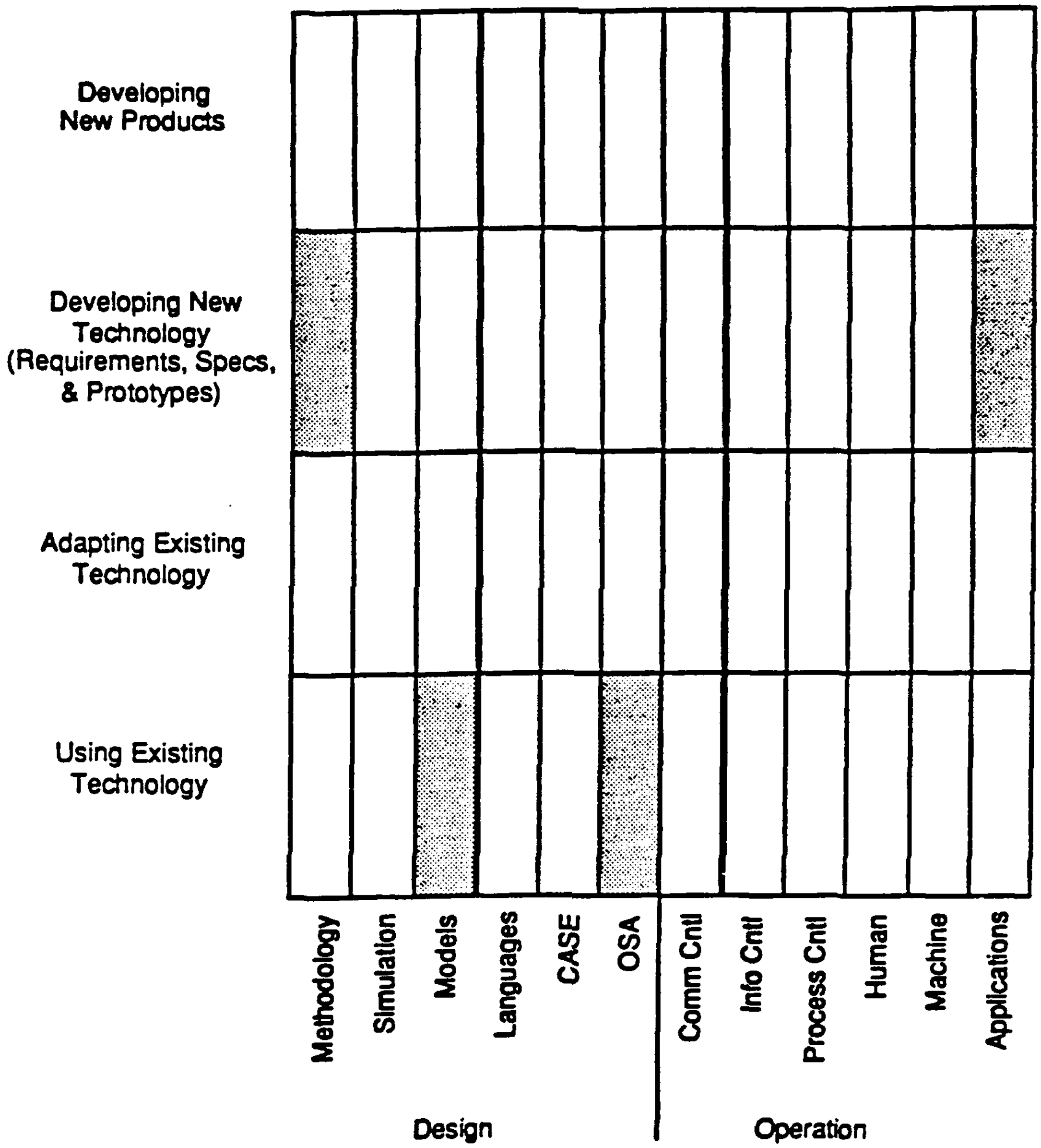
PDES

Technology Approach



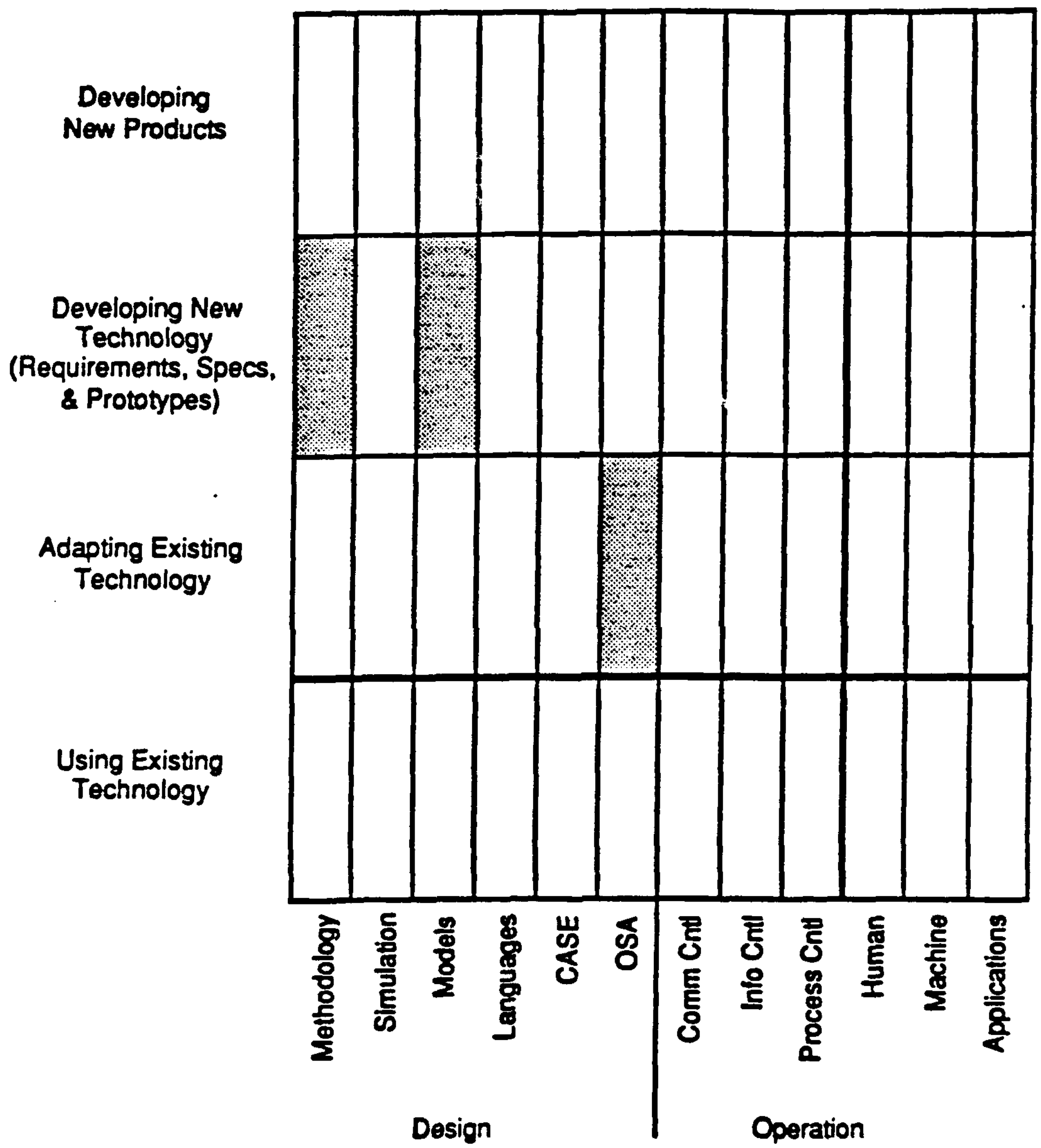
Purdue

Technology Approach



RPI

Technology Approach



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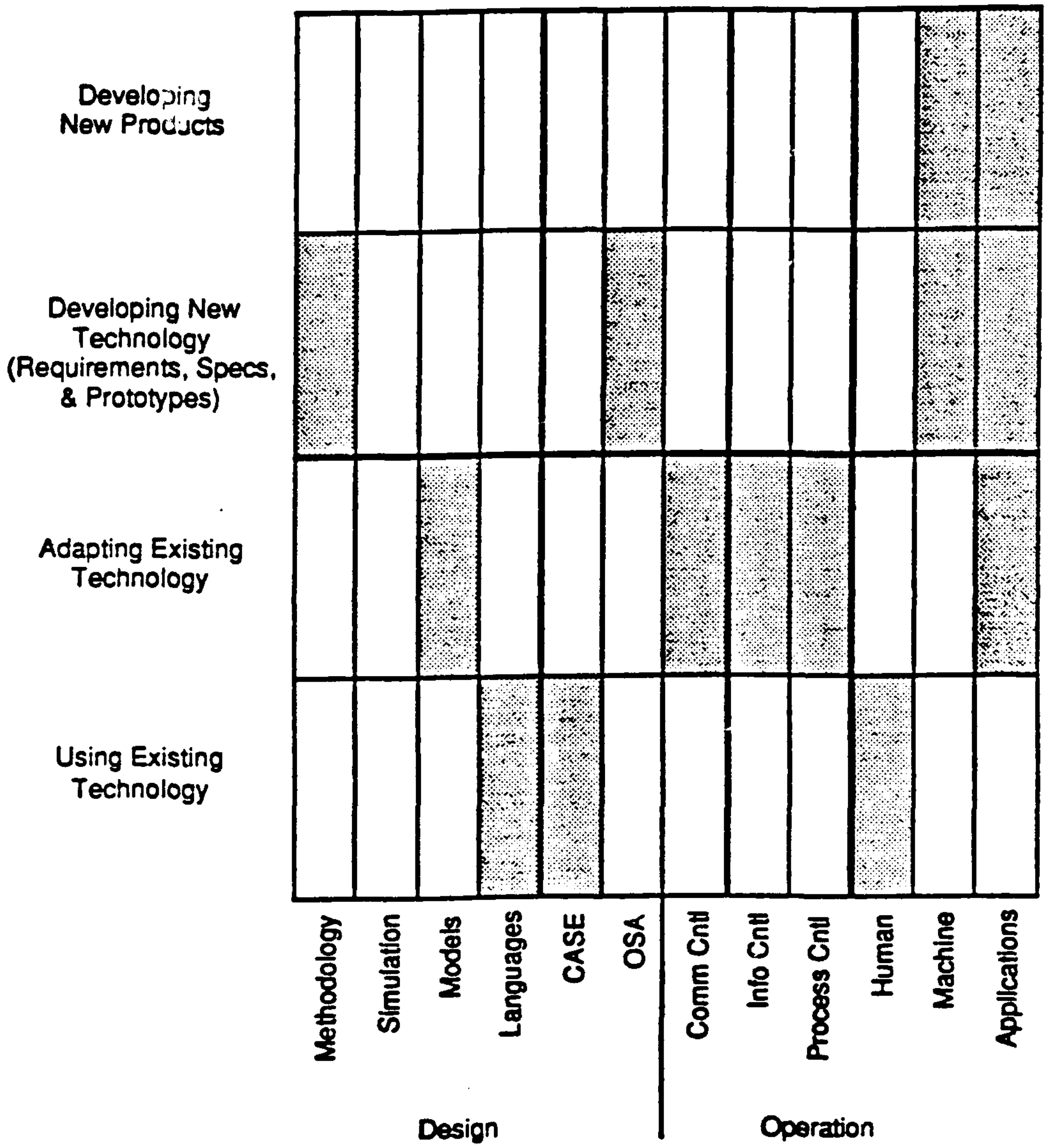
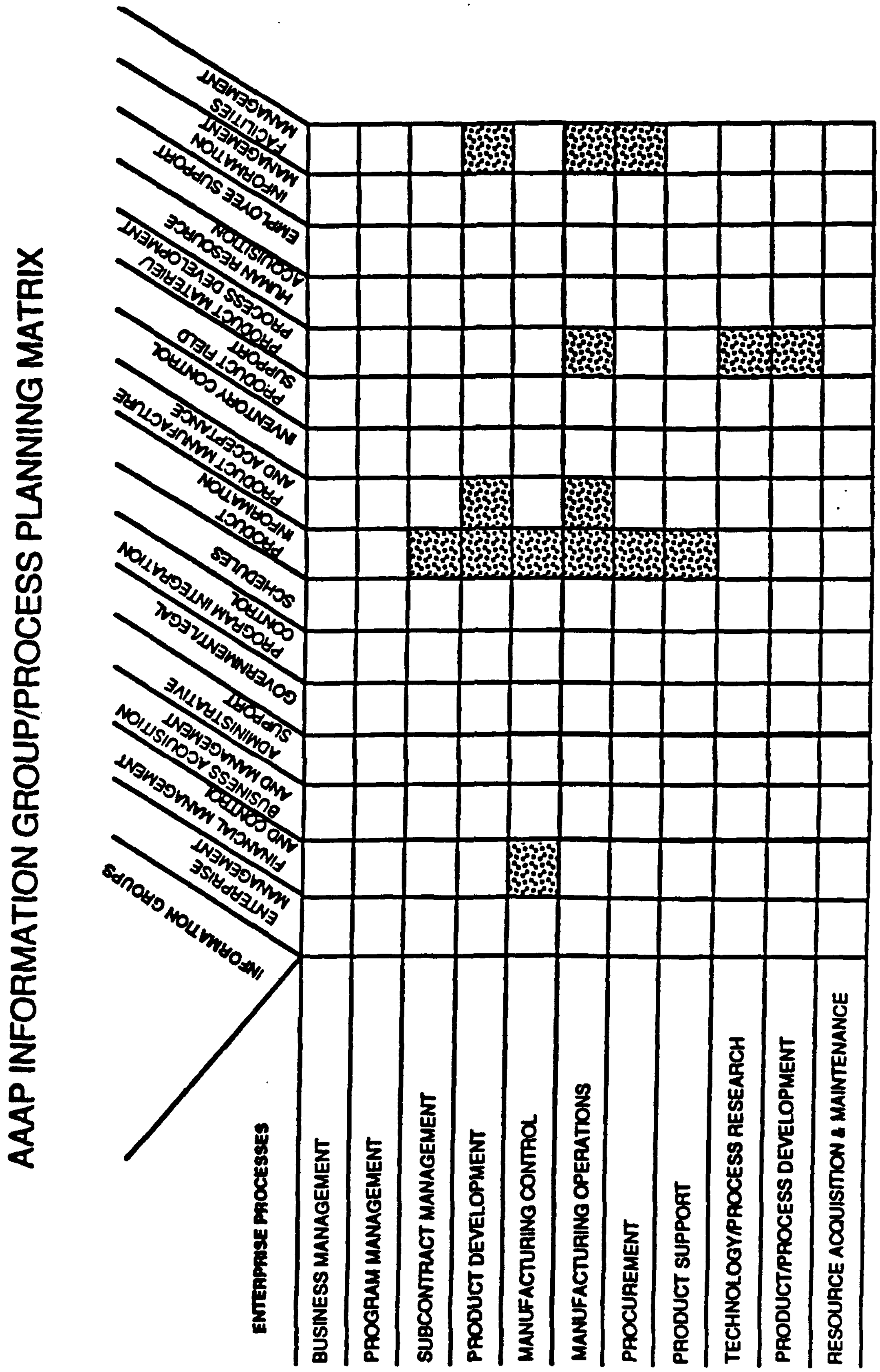
SEMATECH

Technology Approach



Information Group/Process Matrix - Detail Charts



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C4 INFORMATION GROUP/PROCESS PLANNING MATRIX

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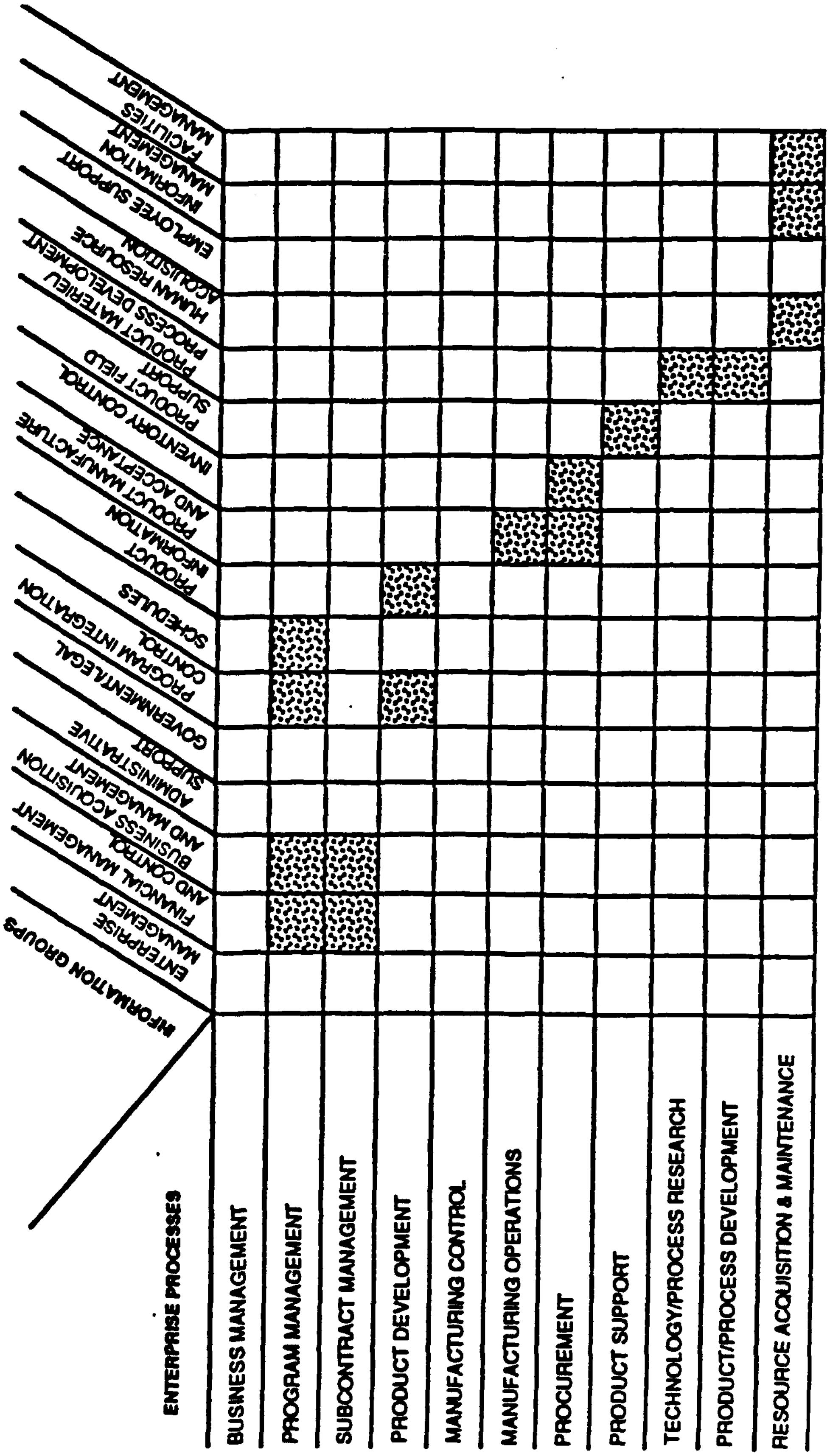
BUSINESS MANAGEMENT																
PROGRAM MANAGEMENT																
SUBCONTRACT MANAGEMENT								■								
PRODUCT DEVELOPMENT								■	■		■	■				■
MANUFACTURING CONTROL																
MANUFACTURING OPERATIONS								■	■							■
PROCUREMENT								■	■							■
PRODUCT SUPPORT								■								
TECHNOLOGY/PROCESS RESEARCH																
PRODUCT/PROCESS DEVELOPMENT																
RESOURCE ACQUISITION & MAINTENANCE																

CALS INFORMATION GROUP/PROCESS PLANNING MATRIX



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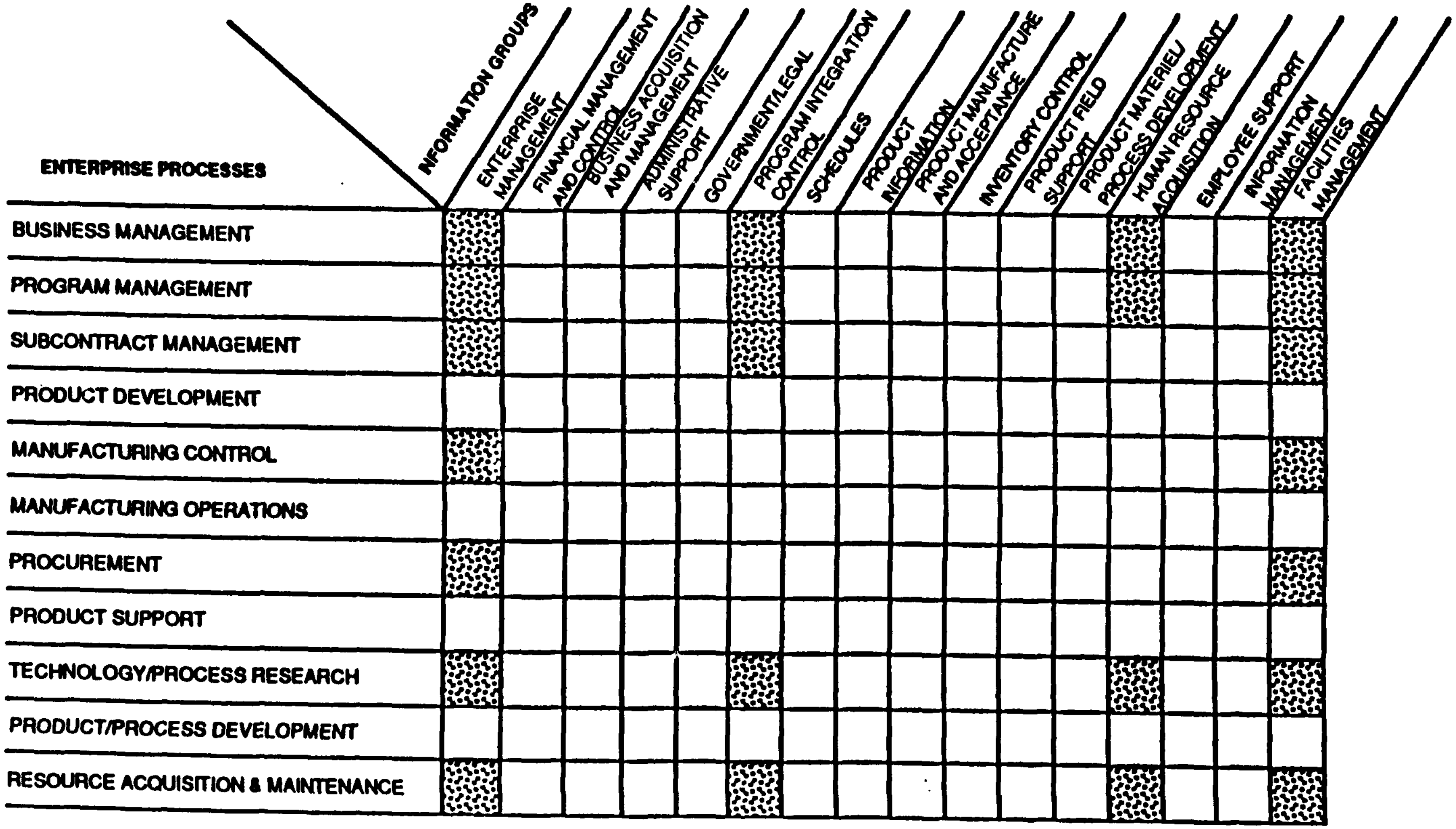

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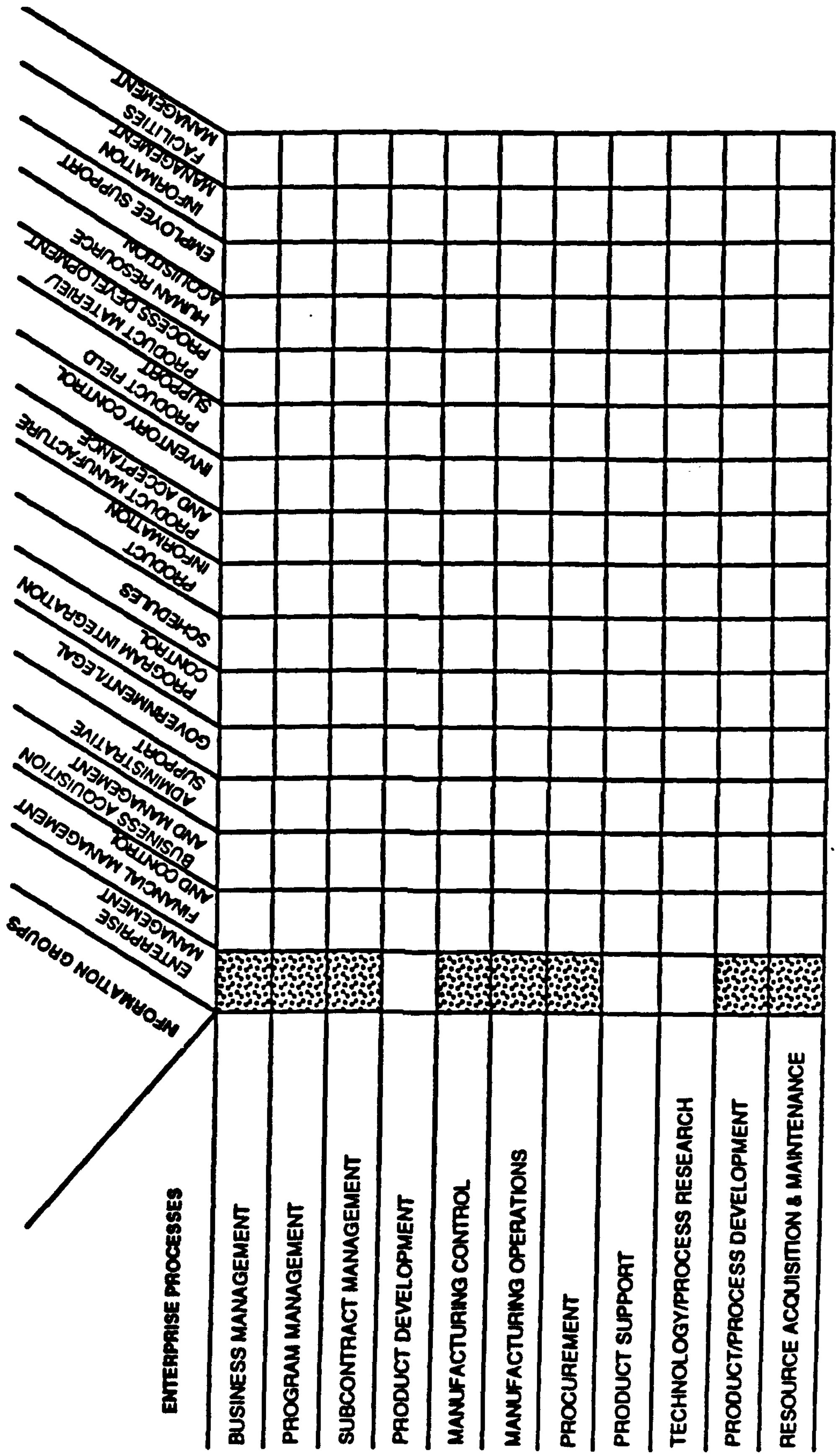

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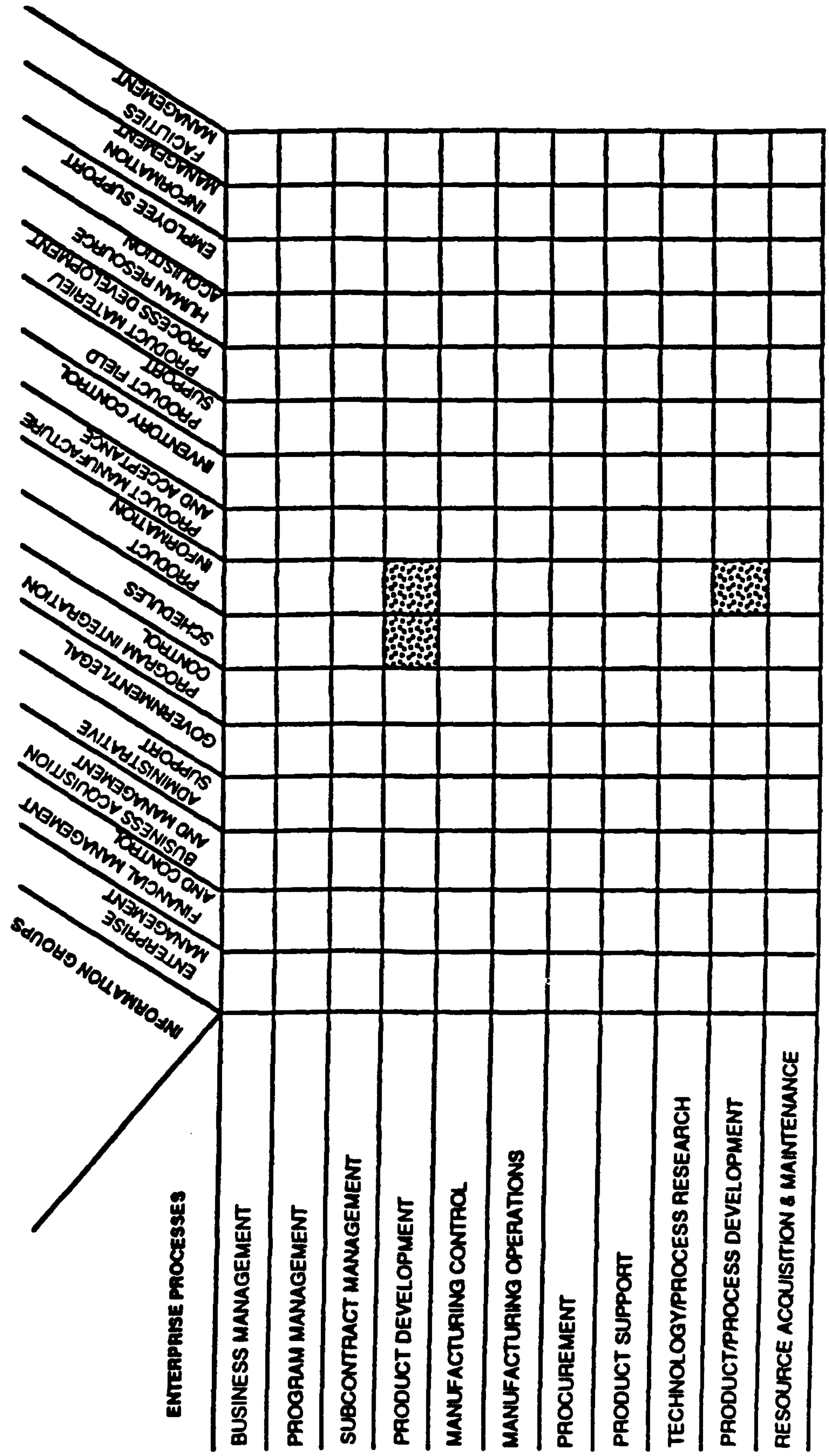

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ENTERPRISE MANAGEMENT											X
FINANCIAL MANAGEMENT AND CONTROL											
BUSINESS ACQUISITION AND MANAGEMENT											
ADMINISTRATIVE SUPPORT	X										
GOVERNMENT/LEGAL				X							
PROGRAM INTEGRATION CONTROL				X							
SCHEDULES		X		X				X	X	X	
PRODUCT INFORMATION											
PRODUCT MANUFACTURE AND ACCEPTANCE											
INVENTORY CONTROL											
PRODUCT FIELD SUPPORT					X				X	X	
PRODUCT MATERIEL/ PROCESS DEVELOPMENT											
HUMAN RESOURCE ACQUISITION											
EMPLOYEE SUPPORT											
INFORMATION MANAGEMENT											X
FACILITIES MANAGEMENT				X							X

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GMAP INFORMATION GROUP/PROCESS PLANNING MATRIX

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BUSINESS MANAGEMENT																
PROGRAM MANAGEMENT																
SUBCONTRACT MANAGEMENT																
PRODUCT DEVELOPMENT					■			■	■		■					■
MANUFACTURING CONTROL					■			■								
MANUFACTURING OPERATIONS					■			■	■							■
PROCUREMENT					■			■								
PRODUCT SUPPORT					■			■			■					■
TECHNOLOGY/PROCESS RESEARCH																
PRODUCT/PROCESS DEVELOPMENT																
RESOURCE ACQUISITION & MAINTENANCE																

PDES INFORMATION GROUP/PROCESS PLANNING MATRIX

ENTERPRISE PROCESSES \ INFORMATION GROUPS	ENTERPRISE MANAGEMENT	FINANCIAL MANAGEMENT AND CONTROL	BUSINESS ACQUISITION AND MANAGEMENT	ADMINISTRATIVE SUPPORT	GOVERNMENT/LEGAL	PROGRAM INTEGRATION CONTROL	SCHEDULES	PRODUCT INFORMATION	PRODUCT MANUFACTURE AND ACCEPTANCE	INVENTORY CONTROL	PRODUCT FIELD SUPPORT	PRODUCT MATERIEL/ PROCESS DEVELOPMENT	HUMAN RESOURCE ACQUISITION	EMPLOYEE SUPPORT	INFORMATION MANAGEMENT	FACILITIES MANAGEMENT
BUSINESS MANAGEMENT																
PROGRAM MANAGEMENT																
SUBCONTRACT MANAGEMENT																■
PRODUCT DEVELOPMENT						■		■	■		■					■
MANUFACTURING CONTROL						■		■								
MANUFACTURING OPERATIONS						■		■	■							■
PROCUREMENT						■		■								■
PRODUCT SUPPORT						■		■			■					■
TECHNOLOGY/PROCESS RESEARCH																
PRODUCT/PROCESS DEVELOPMENT																
RESOURCE ACQUISITION & MAINTENANCE																

PURDUE INFORMATION GROUP/PROCESS PLANNING MATRIX

ENTERPRISE PROCESSES \ INFORMATION GROUPS	ENTERPRISE MANAGEMENT	FINANCIAL MANAGEMENT AND CONTROL	BUSINESS ACQUISITION AND MANAGEMENT	ADMINISTRATIVE SUPPORT	GOVERNMENT/LEGAL	PROGRAM INTEGRATION CONTROL	SCHEDULES	PRODUCT INFORMATION	PRODUCT MANUFACTURE AND ACCEPTANCE	INVENTORY CONTROL	PRODUCT FIELD SUPPORT	PRODUCT MATERIEL/ PROCESS DEVELOPMENT	HUMAN RESOURCE ACQUISITION	EMPLOYEE SUPPORT	INFORMATION MANAGEMENT	FACILITIES MANAGEMENT
BUSINESS MANAGEMENT																
PROGRAM MANAGEMENT			■													
SUBCONTRACT MANAGEMENT																
PRODUCT DEVELOPMENT		■					■	■	■			■				
MANUFACTURING CONTROL																
MANUFACTURING OPERATIONS																
PROCUREMENT																
PRODUCT SUPPORT																
TECHNOLOGY/PROCESS RESEARCH								■								
PRODUCT/PROCESS DEVELOPMENT								■								
RESOURCE ACQUISITION & MAINTENANCE															■	■

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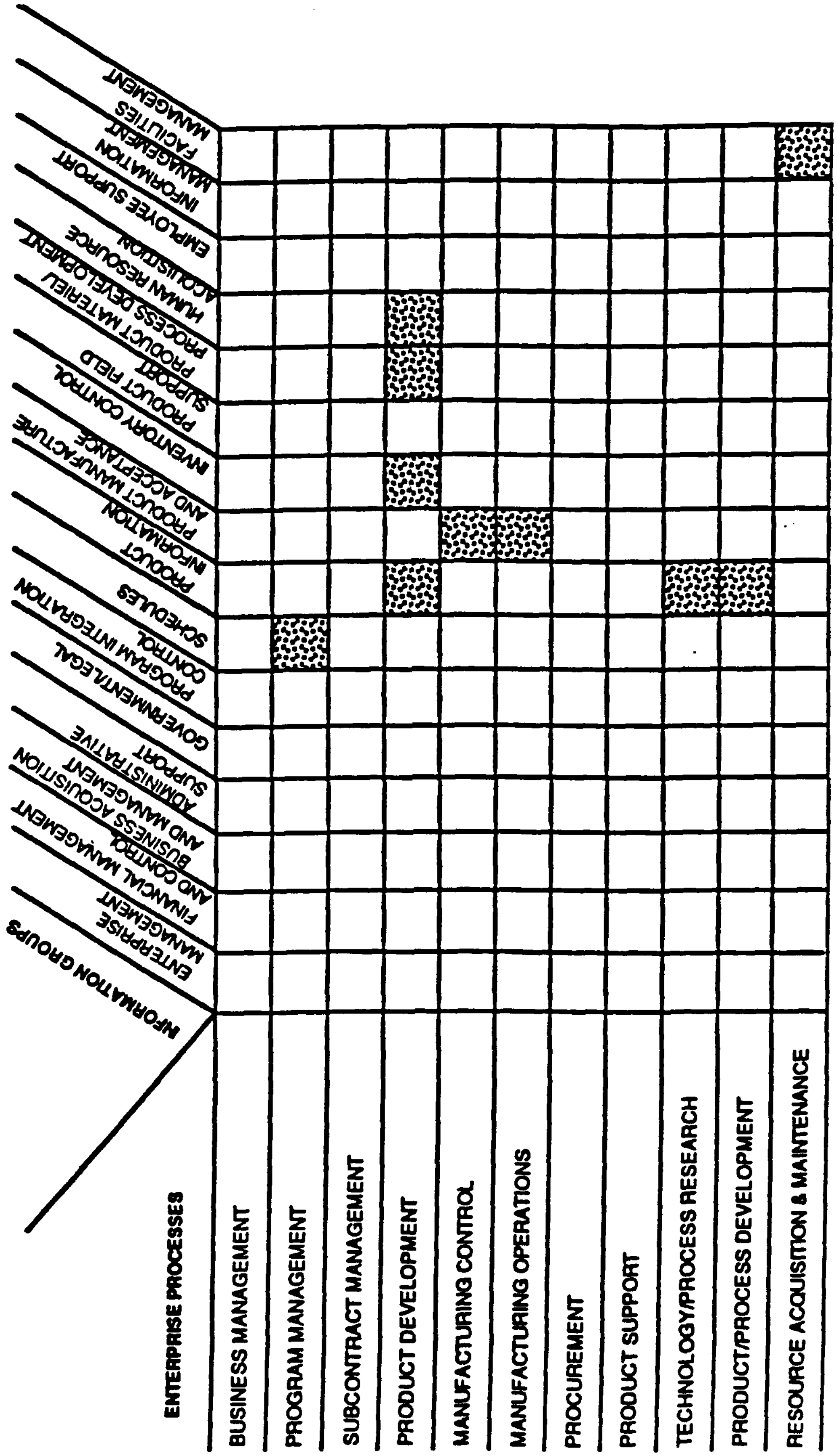

1C-EJG-843-050-006

SEMATECH INFORMATION GROUP/PROCESS PLANNING MATRIX

ENTERPRISE PROCESSES \ INFORMATION GROUPS	ENTERPRISE MANAGEMENT	FINANCIAL MANAGEMENT AND CONTROL	BUSINESS ACQUISITION AND MANAGEMENT	ADMINISTRATIVE SUPPORT	GOVERNMENT/LEGAL	PROGRAM INTEGRATION CONTROL	SCHEDULES	PRODUCT INFORMATION	PRODUCT MANUFACTURE AND ACCEPTANCE	INVENTORY CONTROL	PRODUCT FIELD SUPPORT	PRODUCT MATERIEL/ PROCESS DEVELOPMENT	HUMAN RESOURCE ACQUISITION	EMPLOYEE SUPPORT	INFORMATION MANAGEMENT	FACILITIES MANAGEMENT
BUSINESS MANAGEMENT																
PROGRAM MANAGEMENT																
SUBCONTRACT MANAGEMENT																
PRODUCT DEVELOPMENT																
MANUFACTURING CONTROL							■	■	■							
MANUFACTURING OPERATIONS							■									
PROCUREMENT							■	■								
PRODUCT SUPPORT																
TECHNOLOGY/PROCESS RESEARCH																
PRODUCT/PROCESS DEVELOPMENT								■	■			■				
RESOURCE ACQUISITION & MAINTENANCE																

APPENDIX C

EIF AEROSPACE STRAWMAN PROTOTYPE SIMULATION STUDY

EIF AEROSPACE STRAWMAN
PROTOTYPE SIMULATION STUDY

Prepared For:

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July, 1990

ENTERPRISE INTEGRATION FRAMEWORK
DAPRO CONTRACT #F 33600-87-C-0464
PHASE TWO

TASK 2.10

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EIF AEROSPACE STRAWMAN MODEL SIMULATION STUDY

PURPOSE

The purposes of the EIF aerospace strawman model prototyping effort are

- o to demonstrate the feasibility of developing a common language tool that facilitates multi-enterprise and multi-disciplined communications for program optimization and product cost, schedule, and quality improvement

- o to determine the benefits of management-level simulation in organizing and communicating enterprise operational data to management to support their decision making processes

- o to show the usefulness and applicability of the EIF aerospace strawman model in addressing management-level concerns

- o to provide a basis for a more detailed modeling effort that can expand the content, accuracy, and usefulness of the prototype for more general manufacturing enterprise and multi-enterprise applications

APPROACH

The basic approach taken in developing the simulation prototype was to develop a representative set of real, aerospace management business- and program-oriented concerns, and then determine if a simulation model could be developed (based on the Northrop EIF aerospace strawman) that could adequately address all or a selected subset of these concerns; i.e., build the minimum simulation model of the enterprise that could address the specific scenarios or concerns selected for the prototype demonstration. This approach permitted the development of a working prototype in the very limited time available to the effort. It had the disadvantage of not yielding a model, either in depth or breadth, that could be used to address more detailed questions or concerns of the user managers, or of being extended to scenarios that were beyond the programming goal. Those covered, however, were felt to be sufficiently representative, and would require modeling and exercising of enough the aerospace strawman to be indicative of whether the simulation could be effective and produce the desired results.

The approach taken for use of the simulation can be categorized into three basic steps, these being:

1. To display to the user all of the built-in model characteristics, including descriptions of the included enterprise processes, process relationships, and baseline (industry generalized) metrics and assumptions, the latter including overhead rates, hourly compensation rates, nominal processing times and time standards, and the like. The user will have the option at this point of modifying any of these metrics to better reflect their own enterprise's operations.

2. To display all of the program specific and dependent parameters that the user must supply, such as yearly production rates, length of product definition and delivery processes (i.e., program length and milestones), customer mandated or caused production breaks, and the like.

3. To exercise the model, display the results, and permit the user to reinitiate the simulation after modifying any of the enterprise or program parameters in building "what if" scenarios to see the effects of these changes on program and enterprise performance. Initially, such performance will be restricted to cost, but will eventually be extended (in follow-on efforts) to include schedule and output quality. For the cost performance, the displayed outputs will include total program cost, individual process cost (divided into direct and indirect charges), average cost of delivered unit, total cost of all units to date, and cost of the last unit.

MANAGEMENT SCENARIOS

A number of candidate management-level business and program scenarios were evaluated and considered for use in the simulation prototype. A subset of these was selected for current use based on:

a. the judged relative importance of the scenario (i.e., potential problem) on enterprise business and program performance,

b. how well the cause and effect relationships pertaining to the cost issues of each could be understood and simply described for use in the high-level, simplified type of prototype being constructed, and

c. the amount of time available to perform such modeling for this abbreviated, demonstration effort.

Based on these criteria, five scenarios were used to guide the prototype development; i.e., depending on the scenario and the algorithm(s) or equations developed for it, specific enterprise and program processes and parameters were added to the simulation model to permit it to address the scenario. The following five scenarios were chosen:

1. What are the program cost effects of the prime contractor implementing concurrent engineering to develop a contracted for product?

2. What are the program cost effects of one or more subcontractors also implementing concurrent engineering to develop their portion(s) of subcontracted for portions of the product?

3. How are program costs effected by changes in yearly production rates, both in terms of total levels and earlier or later peaks?

4. What is the cost effect of program delays or interruptions at various points in the program's production phase?

5. What is the program cost effect of changes in customer requirements at various stages of product develop (i.e., definition or delivery)?

MODEL

The simulation model developed for the EIF prototype is based on a portion of the Northrop aerospace strawman needed to adequately represent the enterprise's response to the above five scenarios. The resultant model contains nineteen (19) processes and subprocesses from the aerospace strawman. The processes and subprocesses encompassed in the first few levels of development of that strawman, as well as the subset selected for inclusion in the prototype simulation (shaded), are shown in Figure 1. The schematic diagram of the simulation model is shown in Figure 2. Almost without exception, a pair of information flow (or product flow) "pipelines" are used to interconnect and represent the closed-loop relationship that exists between pairs of interacting processes. Thus, for example, pipelines 1 and 2 represent this relationship between the Customer and the program's highest technology process, System Engineering. Similar pairs interconnect the Customer and Program Management, System Engineering and Subsystem Design, and so forth. Detailed descriptions of the responsibilities included within each of these processes, as well as the costing nature of each, is given in the material that follows.

The heavy or bold pipelines in Figure 2 represent busses that are used for two purposes. The first is to represent multiple inputs are summed from different processes for delivery to another process. Examples of this are the accumulation of product definition products from a half dozen processes for delivery to configuration management, and the accumulation of finished manufacturing WIP product for delivery to stores and the building of assembly kits. The second purpose of the buss is for representing the distribution of a single class of out-

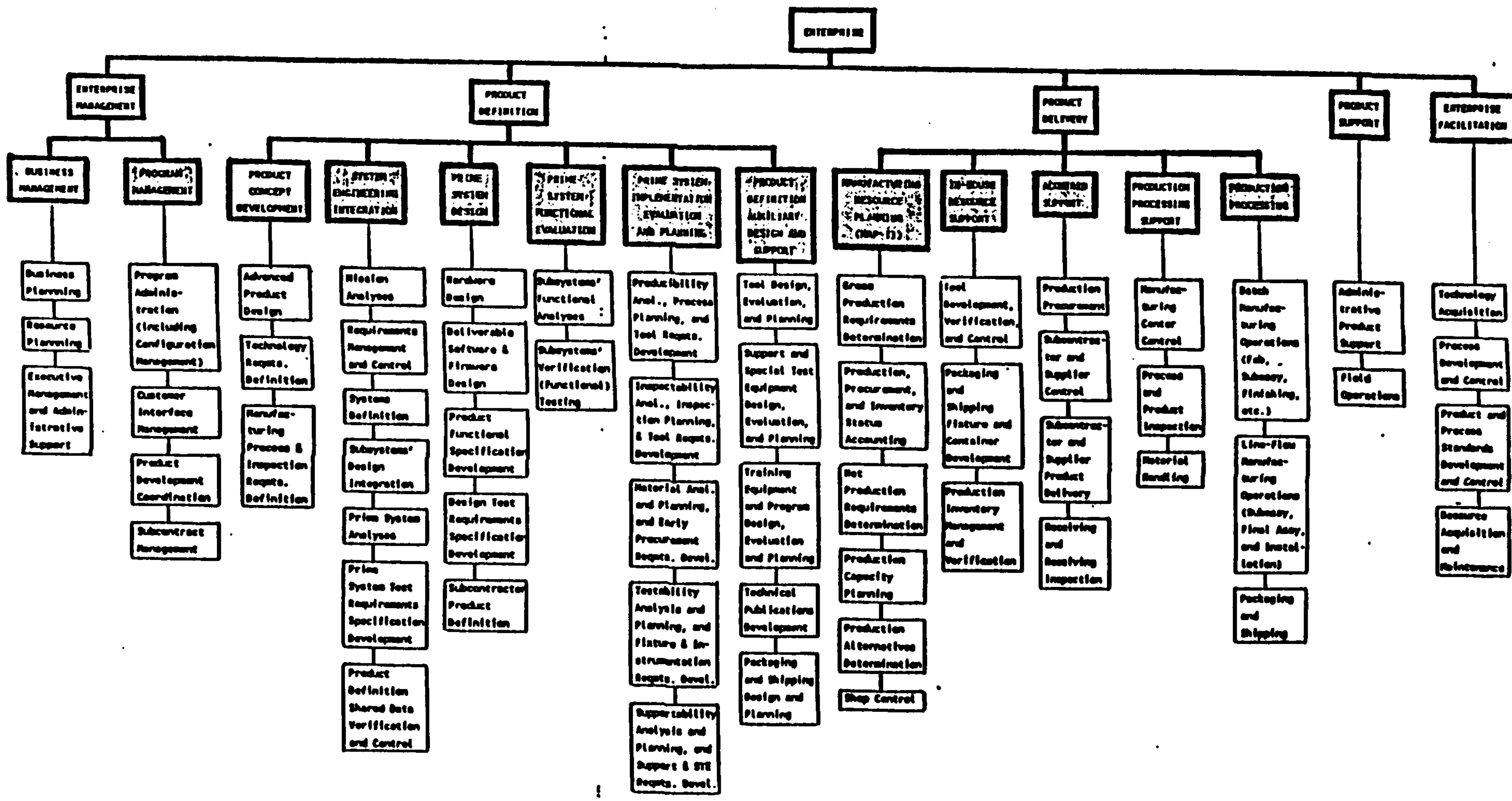

FIGURE 1 . EIF AEROSPACE STRAWMAN MODEL PROCESSES

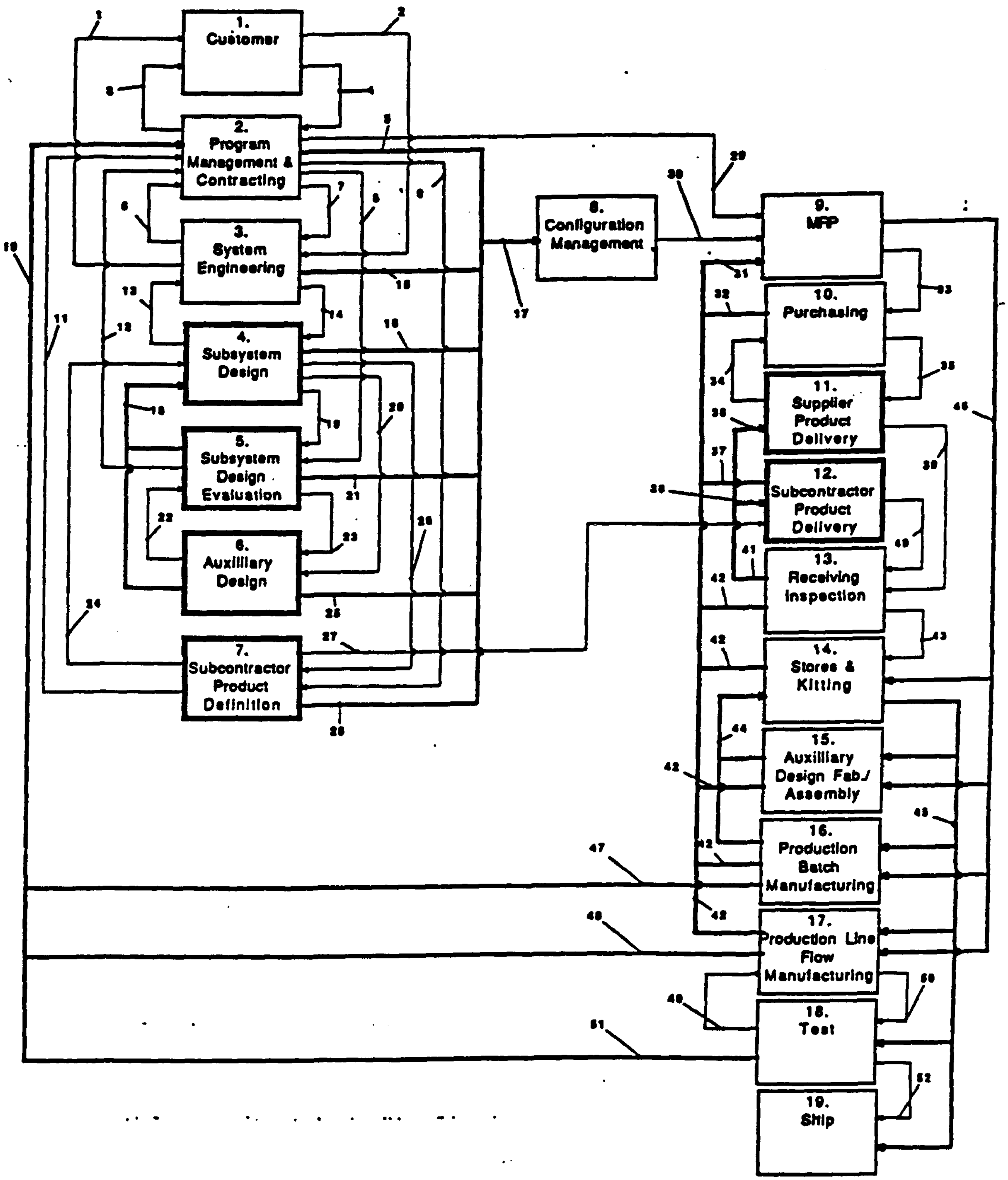

FIGURE 2 - SCHEMATIC DIAGRAM OF THE EIF PROTOTYPE SIMULATION MODEL

put to multiple using processes of that output. Examples of this are the distribution of processing orders by the MRP process to procurement, stores, and manufacturing, and the subsequent distribution of production kits to the various manufacturing tooling, fabrication, and assembly process centers. As in the case of the processes, a brief description of the principal content of each of these pipelines is also included in the material that follows.

The aerospace process simulated for the EIF program is a high level view of the aerospace design and production processes for the purpose of demonstrating feasibility rather than a being a complete process model used to test and evaluate program alternatives. The development of a complete and accurate process model and a full simulation of the effects of all variables can come with a more detailed study in a follow-on contract. In spite of the fact that the model was intended to only demonstrate feasibility, the authors of the model feel that the baseline numbers and variables are reasonably representative of reality and do roughly approximate actual trends.

For the purposes of this demonstration, the assumptions and parameters in this model are roughly based on the Northrop Aircraft Division's experience over the past twenty years with manned fighters for the Navy and Air Force. Converting the process model to another firm with another class of aircraft would require research into their history to collect detailed data on such things as change patterns and relationships between fabrication and assembly efforts for their class of aircraft.

The process model is controlled by varying a series of parameters that affect the outcome of the simulation. The parameters can be grouped into three classes. The first class is for customer controlled variables, such as production rate. The second are the prime contractor program specific variables that define the characteristics of the program such as assembly line production capacity. The third are the prime contractor's internal environment variables that are more enterprise driven than program driven. An example of this last variable is the enterprise's overhead burden rate. The second two classes of parameters define the characteristics of the enterprise for the class of program being studied. In this specific instance, the second two classes define NAD's experience with fighters. The three classes of parameters are as follows:

Parameter Class I, Customer Controlled Variables

1. What is the planned production life of the aircraft?

2. What is the planned number of production aircraft?

3. How long will it be before customer requirements mature and stabilize where no customer directed changes are implemented?

Parameter Class II, Prime Contractor Program Specific Variables

1. Will concurrent engineering operations be applied to the design and development of the product?

2. What percentage of program that will be subcontracted to major subcontractors and suppliers?

3. What is the assembly line maximum capacity with single set of tools?

4. How many months of product definition effort will it take before the completion of the first production unit?

5. How many months of product delivery will it take to produce an aircraft?

6. What does this program mean to the enterprise as a percentage of its total business?

Parameter Class III, Prime Contractor Enterprise Internal Variables

1. What is the historical distribution of changes per year from all sources?

2. What are the burden rates (both fixed and variable components)?

3. What is the total program and yearly distribution of non-recurring efforts to support the program?

4. What is the historical per vehicle cost of each aircraft for those activities whose costs are only influenced by the quantity of aircraft?

The aerospace process model addresses the interrelationships between the customer, program management, product design, implementation planning, and production. For the purposes of this high level simulation, the total process has been broken down into nineteen (sub)processes. The following material identifies those nineteen (sub)processes, explains their responsibilities, reviews the parameters that effect the cost of each of the (sub)processes, and defines the primary interprocess relationships (i.e., "pipelines") identified in Figure 2.

MODEL (SUB)PROCESSES

1. Customer

This process includes all of the customary activities normally engaged in by the Department of Defense or other military aircraft customer. This includes developing mission and performance profiles and requirements, soliciting and evaluating bids and proposals, reviewing contracted for work, evaluating and approving deviations and change requirements, and accepting and maintaining delivered products.

There is no cost that has been established for this node in the process. Instead, this node is treated as a collection point for customer determined parameters such as, program life in years, total production quantity, and year into program that the customer's requirements will be stabilized.

2. Program Management and Contracting

This process includes all of the customary activities normally engaged in by the program and contract management personnel assigned to a military aircraft program. This includes establishing and enforcing program policies and procedures, maintaining an interface with the customer, managing the development of company proposals associated with the program, chairing the various change and configuration review boards that evaluate change requests, developing and maintaining the integrated program schedule, qualification, solicitation, and selection of subcontractors, and support of the technical interface between them and the company's development personnel.

No cost has been determined for the overhead function of managing the program. All of its costs have been treated as part of the overhead rate used for all of the other nodes in the total process. Instead, this node is treated as a collection point for prime contractor determined parameters such as, capacity of assembly line, overhead rate, and program costs allocated to subcontractors.

3. System Engineering

This process includes performance of the airframe weapon-system level analyses, such as mission and performance analyses, overall vulnerability, reliability, maintainability, safety, and mass properties analyses. It also includes coordination, development, and negotiation of an integrated weapon system test plan, including all flight test planning. System engineering is also responsible for the definition of all major subsystems, the partitioning of weapon system-level requirements into subsystem interface and performance requirements, and the integration of subsystem design into the final weapon system configuration.

System Engineering has both a non-recurring and a recurring component with the non-recurring component associated with the initial design effort and the recurring component a function of the level of changes over the production life of the program. The use of concurrent engineering principles causes a growth in the level of effort during the initial design effort and a subsequent decrease as the reduced level of change minimizes the recurring sustaining efforts.

4. Subsystem Design

This process includes the detailed design of each of the major subsystems into which the weapon system has been physically and functionally subdivided. These include the vehicle's primary structure, the electronic vehicle control and maintenance systems, the propulsion system, the crew systems, the environmental system, the armament, the landing and arresting gear, and the secondary power, electrical, and hydraulic systems.

Subsystem Design, like System Engineering, has both a non-recurring and a recurring component, both of which behave in the same general manner as those in System Engineering.

5. Subsystem Design Evaluation

This process includes both the functional and downstream processing evaluation of design excellence, negotiating improvements to it with the various design teams, the definition of requirements for supporting hardware, electronics, and software tools and equipment needed to facilitate product manufacture and maintenance, and the development of detailed processing instructions for these two latter activities. Functional evaluation includes both analysis, such as loading, response, mass properties, and performance, and developmental and proof of engineering test, including wind tunnel, prototype, and laboratory testing. Downstream processing analyses include product producibility, testability, inspectability, procurement, and logistics support analyses. Support tools and equipment includes production and inspection tooling and equipment, handling equipment, storage and shipping containers, special test equipment, and field support equipment. Detailed processing instructions include manufacturing process, inspection, test, procurement, and support planning.

Subsystem Design Evaluation, like System Engineering, has both a non-recurring and a recurring component, both of which behave in the same general manner as those in System Engineering.

6. Auxiliary Design

This process includes the design of production and inspection tooling and all the special test, support, handling, storage, and shipping equipment whose requirements are defined in the design evaluation steps. This process also includes the development of non-hardware support products such as provisioning parts lists, technical publications, and customer training materials.

Auxiliary Design, like System Engineering, has both a non-recurring and a recurring component, both of which behave in the same general manner as those in System Engineering.

7. **Subcontractor Product Definition**

This process includes all the design, evaluation, and planning activities performed by the sum total of all the program's subcontractors who have design responsibilities.

Subcontractor product definition is controlled by a combination of the percentage of the contract performed by suppliers and the percentage of the suppliers effort where the supplier has design responsibility. The subcontractors level of effort is further controlled by the prime contractors and/or the subcontractors use of concurrent engineering principles.

8. **Configuration Management**

This process includes the activities performed to coordinate, verify, store, and disseminate product configuration data after completion of product definition. It is also responsible for maintaining the "as-built" configuration data from the procurement, fabrication, and assembly records.

Configuration management's level of effort is directly proportional to the number of new and change documents that they process. The number of change documents is effected by concurrent engineering principles in a very significant way.

9. **MRP (Material Requirements Planning)**

This process includes development of production gross (based solely on the product's design definition, production schedule, and manufacturing bill of materials) and net (based on work in process, material inventory status, and in-house and off-site production status) resource requirements, production capacity planning, development and issuance of procurement requisitions and shop orders, and development of alternatives to production plans when something goes wrong.

MRP's planning and order issuing level of effort is influenced by level of production and the number of changes. The level of production is a customer driven parameter in terms of the quantity of aircraft produced each year. The number of changes is influenced by the use of concurrent engineering principles.

10. **Purchasing**

This process includes qualification, solicitation, and selection of suppliers, negotiation of procurement terms and conditions, issuance of purchase orders, and tracking of procurement and off-site manufacturing status.

The cost of purchasing is influenced by the level of production and the number of design changes.

11. **Suppliers Product Delivery**

This process is responsible for all standard parts, raw material, and manufacture of prime contractor designed parts and subassemblies. In support of this, this process performs all manufacturing resource planning, procurement, tooling, fabrication, assembly, inspection, and test processes.

The cost of material provided by suppliers is influenced by the percentage of the contract allocated to suppliers, the total production rate, and the level of change created by the prime contractor. The cost of change shows up in the cost of unneeded material and scrap when the change makes the procured material's configuration unnecessary.

12. Subcontractors Product Delivery

This process is responsible for the production of all parts and subassemblies for which the subcontractor has design responsibility. In support of this, it performs all manufacturing resource planning, procurement, tooling, fabrication, assembly, inspection, and test processes.

The cost of material provided by subcontractors is influenced by the percentage of the contract allocated to subcontractors, the level of change created by either the prime contractor and subcontractor, the total production rate, and improvement in productivity as a result of assembly experience from previous units.

13. Receiving and Inspection

This process includes the receipt (logging in and cursory verification), detailed inspection and test, acceptance or rejection, and return shipment (where applicable) of incoming procurements.

The cost of receiving and inspection is influenced by the total production rate for the contract and the level of changes created by design. Changes result in reordering of material that became scrap as a result of change actions.

14. Stores and Kitting

This process includes all warehousing activities associated with inventory management, including storage, retrieval, kitting, dispersement, status accounting, and physical cycle counting and inventory audits.

The cost of stores and kitting is influenced by the total production rate for the contract and the level of changes created by design. Changes result in reordering of material, additional kits to rework or redo fabricated items and assemblies. The level of changes also influences the required frequency to analyze and purge excess inventory.

15. Auxiliary Designs' Fabrication and Assembly

This process includes the production and verification of manufacturing tooling, support and special test equipment, and shipping containers.

The cost of auxiliary design fabrication and assembly is influenced by the total production rate for the contract and the level of changes created by design. When changes occur, auxiliary products need to be reworked or remade.

16. Production Batch Manufacturing (Fabrication)

This process includes the batch or lot production (i.e., one set-up per production lot) of all fabricated parts and subassemblies consumed in the building of the product. It includes all production steps and proof of manufacturing tests and inspections.

The cost of production batch manufacturing and inspection is influenced by the total production rate for the contract and the level of change created by design. Changes creates rework and the fabrication of replacement parts for parts that needed to be scrapped.

17. Production Line Flow Manufacturing (Assembly Line)

This process includes the line flow production (i.e., one set-up per production run, which is the entire program without major production breaks) for all subassembly, assemblies, and installation activities made during the final assembly of the product. It includes all production steps and proof of manufacturing tests and inspections.

The cost of production line flow manufacturing is influenced by the level of change created by design, the total production rate, and improvement in productivity as a result of assembly experience from previous units.

18. Systems Test

This process includes all final product and system functional testing of the product (including flight testing) before packaging (as appropriate) and shipment to the customer site.

The cost of systems test is influenced by the level of change created by design, the total production rate, and improvement in productivity as a result of experience gained from testing previous units.

19. Packaging and Shipping

This process includes whatever packaging or crating is required to prepare deliverable product for shipment to the customer sites. This activity also includes any inspections of the results of the activity, as appropriate.

The cost of packaging and shipping is influenced by the level of change created by design, the total production rate, and improvement in productivity as a result of experience gained from packaging previous units.

MODEL (SUB)PROCESS RELATIONSHIPS (i.e., PIPELINES)

1. Informal Technical and Trade Study Analysis Results, Review Materials, Proposals, Technical Recommendations, and Discussions

2. Program Technical (Mission, Performance, and Environmental) Requirements, and Technical Review Results, Requests, Concerns, and Recommendations

3. Formal Review Materials and CDRL Items, Responses to RFIs and RFQs, Proposals, and Approval and Deviation/Waver Requests

4. Program (Business) Requirements, Requested Program (Business and Technical) Requirements Changes, Formal Review Results and Approvals for Requested Deviations and Changes

5. Program Configuration Management Plan

6. Trade Study Analysis Results, Technical Proposals, and Technical Development Status and Problems

7. Program Policies and Directives, Technical Development Budgets and Schedules, Change Review Board Requests and Decisions

8. Management Manufacturing Resource, Process, and Risk Decisions

9. RFIs, RFQs, Counterproposals and Negotiations, and Subcontracts

10. Formal Configuration Change Requests and Proposals

11. Subcontractor(s) Product Information, and Proposals

12. Proposed Production Plans and Resource Allocations

13. Subsystem(s) (Working and Releaseable) Designs, Information, Problems, Interface and Performance Requirement Change Requests, Subsystem(s) Trade Study Analysis Results, and Change Impact Analysis Results

14. Partitioned Subsystem(s) Responsibilities (Mission, Performance, Environmental, and Subsystem(s) Interface Requirements)

15. Weapon System Analysis Results and Test Plans, and Integrated Weapon System Configuration(s), including the Integrated Weapon System Indentured Parts List

16. Subsystem(s) Design Geometry, Parts Lists, Unit Test Specs, and Product Functional Specs (for Subcontracting)

17. Released Product Definition

18. Recommended or Needed Design Refinements/Changes,

19. Subsystem(s) Working and Releaseable Design Geometry, Intended and Implemented Design Changes

20. Subsystem(s) Working and Releaseable Design Geometry

21. Implementation (Production, Process, Inspection, Test, Support, and Packaging) Plans and Instructions, Logistics Support Analysis, Numerical Control (Production and Inspection) Programs, Manufacturing Bill(s) of Material, Make or Buy Decisions, and Functional and Qualification Test Reports, Implementation Plan and NC Program Changes

22. Tooling Policy and Requirements Problems and Recommendations, Support and Special Test Equipment Requirement Problems and Recommendations

23. Tooling Policy and Requirements, Support and Special Test Equipment Requirements, Customer Training Requirements, and Technical Publications Requirements

24. Subcontractor(s) Design Recommendations, (Working and Releaseable) Designs, Subsystem(s) Interface Problems, and Trade Study Analysis Results

25. Tool, Support, Special Test Equipment, and Packaging Designs and Part Lists, Provisioning Parts Lists, Customer Training Program(s), and Tooling and Auxiliary Equipment Design Changes

26. Subsystem(s) Working and Releaseable Design and Concepts, Unit Interface Requirements, Product Functional Specs, and (Interface and Functional) Design Requirement Changes

27. Subcontractor(s) Product Definition

28. Subcontractor(s) Design Definition

29. Contract Delivery Requirements (Schedule and Production Rates), Subcontracting and Off-Loading Requirements, and Integrated Program Schedules

30. Coordinated, Release Product Definition and Changes

31. Product Delivery Status

32. Procurement and Outside Manufacturing (Subcontractors and Suppliers) Status

33. Purchase Requisitions (with Relevant Product Definition)

34. Supplier(s) Product Delivery Status and Problems

35. Solicitations, Inquiries, and Purchase Orders (with Relevant Product Definition)

36. Rejected (and Returned) Supplier(s) Shipments

37. Subcontractor(s) Product Delivery Status and Problems

38. Rejected (and Returned) Subcontractor(s) Shipments

39. Delivered Shipments, Test Samples, and Reworked Procurements

40. Delivered Shipments, Test Samples, and Reworked Procurements

41. Rejected Incoming Shipments

42. In-House Inventory, Work-In-Process, and Production Status and Problems

43. Verified and Accepted Shipments

44. Completed Fabricated Parts, Assemblies, and Tools

45. Raw Materials, Tools, and Work-In-Process Kits

46. Shop Orders and Relevant Product Definition

47. Requested Batch Manufactured Product and Tooling Configuration Changes

48. Requested Line Flow Manufactured Product and Tooling Configuration Changes

49. Unshipable Final Products

50. Finished Product

51. Determine Product Performance and Production Quality Deficiencies and Deviations

52. Verified Product

ASSUMPTIONS

A number of assumptions had to be made to permit the degree of simplification needed to rapidly create algorithms that reasonably represented complex enterprise behavior for the abstract form of model developed. The principal assumptions made in designing the simulation prototype were:

1. Concurrent engineering can be simply and accurately simulated through a reduction in the number of post-design completion changes that have to be processed after initiation of implementation planning, tooling development, subcontractor development processes, issuance of procurement contracts, and in-house production. In other words, concurrent engineering could be simply represented by the reduction in change processing labor costs, both in design and all of the other affected "downstream" processes. This assumption neglects to account for time-wise or partial implementations of the many aspects of concurrent engineering, which can be accounted for through the selection of more conservative values for the percentage of change, and hence, of rework reduction. There was not simple way, however, developed or included to account for the smoother running, more efficient operations that would result in the reduced change processing environment. For the most part, the accounting for any scrappage reduction due to a corresponding change reduction is made through the reduced product delivery efforts and costs of the company's subcontractors and suppliers.

2. The implementation of concurrent engineering at any percentage of company subcontractors can be simply and accurately simulated by applying the same cost reduction factors determined for in-house implementation to that percentage of outside work also subjected to such an implementation.

3. A production rate change can be simply and accurately simulated by redistributing the fixed portion of business and program cost (i.e., the non-recurring process costs plus the non-variable portion of recurring costs, such as facilities and equipment, tooling, insurance, and so forth) over the smaller number of units to be produced.

4. A significant break in production activities could be simply and accurately simulated by reinitiation of the learning "experience" of direct labor personnel assigned to the production activities. In addition, in some cases, where the break was to be treated as so major as to require reassignment or attrition of the otherwise constant line flow production resources (facilities, equipment, tooling, and personnel), the simulation would be more appropriately modeled with the fixed cost of what is effectively the construction of a new start-up facility, including the acquisition and indoctrination of new employees to replace those lost during the interruption. Because each case would be unique, no provision is made for application of significant penalty costs to be paid to either the prime or subcontractors due to the interruption.

5. Instability in customer stated requirements (i.e., customer directed changes to contract and product requirements) could be simply and accurately simulated by requiring a percentage redoing of both product definition (at the prime and all subcontractors) and, depending on the timing of required changes, product delivery. The percentage of redoing of each would be different due to the different times of initiation and duration of the two major processes. As in the case of concurrent engineering, the accounting for any scrappage increases due to the introduction of additional change is made through the increased product delivery efforts and costs of the company's subcontractors and suppliers.

FINDINGS

The conclusions reached as a result of the simulation prototyping efforts have been reached from a combination of actual experience and the research into the work of others that has been extracted from the literature[1]. In general, these findings are:

1. High-level, management-type simulation modeling of complex manufacturing enterprises can effectively be performed in a top-down manner, wherein high-level (i.e., undecomposed) processes can be simply described and cause and effect relationships can be easily modeled using simplified algorithms that express the results of changes rather than how the changed processes work or how the changes are implemented.

2. More complex and accurate models can be evolved from these high-level models through decomposition of the high level processes, and continued research into and more precise understanding of the cause and effect relationships between process stimuli and enterprise and process performance.

3. A number of existing commercially available language packages appear to have all the necessary capabilities to perform complex manufacturing enterprise simulations; however, all contain their own language peculiarities and would require a different implementation of the same EIF developed industry "standard" process and technology descriptions.

4. The relatively simple, high-level management-type simulations can be performed on relatively small desktop type of computers or workstations; however, as such models are expanded to accommodate more detailed simulations to satisfy new process design development users, it is unlikely that such would continued to be the case. This could require transition to use of large mainframes on which to perform very (time-wise) lengthy computations, or would require partitioning and integration of smaller models used to simulated only portions of enterprise processes.

5. The easiest part of performing complex enterprise and process simulation is the construction of the model on the simulation tool. By far the more challenging, time consuming, and costly part of the task involves first, study and understanding of the complex cause and effect relationships that actually exist in such enterprise operations; second, the design of the simulation model to accurately and, as simply as possible, algorithmically represent these relationships; and finally, the compiling of accurate, discrete statistics (i.e., metrics) from enterprise historical and current operations records with which to populate the designed model. This latter step may, in fact, be the most difficult of all.

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RECOMMENDATIONS

The development of the management-level prototype shows much promise in being able to effectively simulate and project enterprise performance for critical business and program decision making support. The modeling done thus far, however, only scratches the surface, even insofar as demonstrating feasibility is concerned. For example, only the effects on cost have been included, and yet those on schedule and output or product quality are equally important in helping managers make informed decisions. Therefore, the following recommendations are made for further EIF related simulation studies:

1. Continue the development of the management-level prototype, expanding it to include development schedule, product quality, resource requirements effects, and a much broader range of management critical scenarios. These would include the effects of subcontract structure (i.e., terms and conditions), the quality of product functional specifications applied to such subcontracts, the failure of the prime or subcontractors' products to meet any of their respective functional obligations, and so forth.

2. Determine the effective limits of management-type simulations on commercially available software based on small computers, such as personal and desk top computers.

3. Support the development and industry acceptance of a "standard" simulation language that would permit portability of EIF simulation and model development results to potential users throughout the united States manufacturing industry; the CIM-OSA standard, already under development for use in the European manufacturing community, would be an appropriate and recommended vehicle for such development.

4. Expand the development of the management-level model to the greater depth required to support process analysis, design, and implementation by decomposing the EIF aerospace processes from one to two or more, as found appropriate, levels of detail, including development of the greater number of process (or subprocess, as the case will be) relationships and algorithms to mathematically represent these relationships. Such detail should include such factors as the impacts of personnel skill mix, funding profile, manpower loading, task definition, task initiation and completion criteria, facility, equipment, tool capabilities, level and effectiveness of process and subprocess control, level of required documentation, and the like.

SECTION FIVE

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