Control of Manufacturing Processes with MRP II: Benefits and Barriers in the Defense Aerospace Industry

by RENATA ALMA POMPONI

S.B., Physics with Electrical Engineering; S.B., Humanities and Science
Massachusetts Institute of Technology, 1990

Submitted to the Department of Aeronautics and Astronautics
in Partial Fulfillment of the Requirements for the Degrees of

MASTER OF SCIENCE in TECHNOLOGY AND POLICY

and

MASTER OF SCIENCE in AERONAUTICS AND ASTRONAUTICS

at the
Massachusetts Institute of Technology

February 1995

Signature of Author ....
July 25, 1994

Certified by ....
Dr. James G. Ling
Center for Technology, Policy, and Industrial Development
Thesis Supervisor

Certified by ....
Professor Stanley I. Weiss
Department of Aeronautics and Astronautics
Thesis Reader

Accepted by ....
Professor Richard de Neufville
Chairman, Technology and Policy Program

Accepted by ....
Professor Harold Y. Wachman
Chairman, Department Graduate Committee

Control of Manufacturing Processes with MRP II: Benefits and Barriers in the Defense Aerospace Industry

by RENATA ALMA POMPONI

Submitted to the Department of Aeronautics and Astronautics on July 25, 1994 in partial fulfillment of the requirements for the Degrees of Master of Science in Technology and Policy and Master of Science in Aeronautics and Astronautics

ABSTRACT

The defense aerospace industry currently faces a crisis in dealing with a decreasing and uncertain military threat accompanied by shrinking procurement budgets, challenging the government and industry to do more with less. One path to meeting this challenge lies in lean manufacturing techniques. The use of computer simulation tools to manage and track inventory is one of the more notable examples of material planning and handling that exhibit a wide range of practices among defense aerospace firms. While the majority of companies employ some sort of simulation tool for production planning and scheduling, many have surprisingly little control over inventory and production processes, demonstrating approaches more typical of 1940s production techniques than of state-of-the-art process control. Last-minute changes to designs also jeopardize schedule and inventory management to a great degree.

The juncture between these two identified leverage points, inventory management and engineering change, is an ideal location in which to incorporate lean practices. In particular, the Manufacturing Resource Planning (MRP II) system provides a way to create a seamless interface between engineering and manufacture. In brief, MRP II combines inventory ordering and distribution with timing and capacity requirements to form an integrated system across the company. Although the roots of MRP philosophy were developed almost three decades ago, few aerospace manufacturers have employed the technique to its fullest, especially at the product development/fabrication interface. This thesis examines how the use of MRP II can improve manufacturing processes and smooth the impact of engineering changes, thereby preventing schedule slips and reducing inventory. Of special interest is the development of implementable improvements for the defense aerospace industry. Crucial factors that should be present to insure a successful MRP II implementation include:

- Commitment to change and improvement
- Serious evaluation of current situation and future goals
- Active support from top-management
- Full-time dedicated program manager
- Cross-functional implementation team
- Methodical implementation plan
- Implementation schedule that is long enough to be thorough but short enough to sustain momentum
- Unmodified off-the-shelf software package (with available support and upgrades)
- Database integrity before implementation begins
- Pilot program before gradual cutover
- Company-wide training and education (focus on people, not computers)
- Up-front customer interaction (focus on compliance with government standards)
- Minimal reliance on consultants once system is operational
- Perseverance to overcome the cultural barrier

Unless circumstances are extremely divergent from the typical manufacturing organization, chances are extremely good that the introduction of MRP II will have a net positive effect at most defense companies. Primary benefits, the extent of which depends on the dedication and perseverance of the implementation team and the company's top management, include:

- Increased direct labor productivity (fewer people can do more)
- Reduction of inventory (less work in process, less stock, less floor space, less overhead for upkeep)
- High inventory accuracy
- Reduced volume, quicker review time, and improved introduction of engineering changes
- Facilitated interaction within and among function due to common reliable database and improved information flow
- Simulation capability to test "what-if" scenarios in a risk-free environment
- Simplified accounting for transfer of inventory between contracts
- Easier compliance with government inventory accounting standards
- Improved "quality of life" (company focus shifts from crisis management to process control)

A case study of the MRP II implementation at AIL Systems Incorporated is also presented to mark a path for other companies to follow and to give testimony that the benefits gained from the system can outweigh the barriers to its introduction and use. At AIL, reduced material costs paid for their system in one year. Both inventory and kitting accuracy now measure over 99 percent, reducing the time it takes to request a kit from the stockroom from 13 weeks to 1 day. Approximately 70 percent of the material signaled for purchase each year is transferred from existing excess inventory, and inventory floorspace was reduced by 43 percent. The benefits of improved control over the manufacturing process will continue to make the company competitive in the years to come. The more efficient interface between manufacturing and engineering that MRP II also provides will lead to further cost reductions and the ability to do more with less, both important characteristics of lean manufacturing.

Thesis Supervisor: Dr. James G. Ling, Research Associate

Table of Contents

List of Figures

List of Tables

List of Acronyms

ABC	Activity Based Costing
ACSN	Advance Change Study Notice
APICS	American Production and Inventory Control Society
ASC	Aeronautical Systems Center (U.S. Air Force)
BOM	Bill of Material
C/PIOS	Contract/Production Inventory Optimization System
C/SCSC	Cost/Schedule Control Systems Criteria
CCB	Configuration Control Board
CDR	Critical Design Review
CPM	Critical Path Method
CRP	Capacity Requirements Planning
DCAA	Defense Contract Audit Agency
DCMAO	Defense Contract Management Area Operations
DFARS	Defense Federal Acquisition Requirements Supplement
DOD	Department of Defense
DPM	Defects per Million
DPRO	Defense Plant Representative Office
ECN	Engineering Change Notice
ECP	Engineering Change Proposal
ERP	Engineering Resource Planning
FCA	Functional Configuration Audit
FIFO	First-In, First-Out
GFE	Government Furnished Equipment
GM	General Motors
GUI	Graphical User Interface
ILS	Integrated Logistics Support
IMVP	International Motor Vehicle Program
IPD	Integrated Product Development
JIT	Just-in-Time
LAI	Lean Aircraft Initiative
LIFO	Last-In, First-Out
M.I.T.	Massachusetts Institute of Technology
MIL-Q	Military Quality Program Requirements Specification
MIL-STD	Military Standard

MMAS	Materials Management and Accounting System
MO	Manufacturing Order
MPS	Master Production Schedule
MRP II	Manufacturing Resource Planning
MRP	Material Requirements Planning
NTU	National Technological University
OPT	Optimized Production Technology
PCA	Physical Configuration Audit
PDR	Preliminary Design Review
PERT	Program Evaluation and Review Technique
PM	Project Manager
PO	Purchase Order
PWB	Printed Wiring Board
R&D	Research and Development
SFC	Shop Floor Control
SPC	Statistical Process Control
SRR	Scrap, Rework, and Repair
TEM	Temporary Equipment Modification
TQM	Total Quality Management
U.S.	United States
UE	Universal Exciter
WIP	Work in Process

Chapter 1 Introduction

The defense aerospace industry currently faces a crisis in dealing with a decreasing and uncertain military threat accompanied by shrinking procurement budgets, challenging the government and industry to do more with less. One solution to this end lies within industry manufacturing practices. In the boom years of the defense industry, from World War II through the recent end of the Cold War, emphasis rested on producing designs with more and more sophisticated technology and performance capability. Cost, and therefore manufacturability, was not a driving factor for success in the industry given the guaranteed market from the single government customer.[1] Unlike the commercial sector, where a long standing bottom line of profitability led to early insertion of state-of-the-art manufacturing processes, defense contractors did not feel the same imperative to reduce costs and schedules until the guaranteed market began to crumble. Now that defense spending is in drastic decline and shows no signs of rebounding anywhere near the apex of mid-1980s levels, attention has gradually shifted towards bringing the industry up to modern manufacturing standards. Continued reliance on the mass production techniques that were adequate during times of high volume demand will not be possible in the new cost-conscious environment where rapid development and prototyping ability must be accompanied by a low price tag.

One path to meeting this challenge lies with the lean manufacturing techniques first exhibited in the Japanese automotive industry. Searching for ways to apply lean principles to the problematic aspects of the defense aerospace industry, the United States Air Force looked to M.I.T. to extend its research into this area. The result is a consortium of aerospace industry members, led by M.I.T. researchers and co-sponsored by the Air Force Aeronautical Systems Center (ASC), known as the Lean Aircraft Initiative (LAI).

1.1 Identification of Leverage Points

The first hurdle facing a project of such magnitude, namely the reformation of the aerospace industry from "fat" to "lean," is in the selection of specific areas of attack. Since no program can adequately address all potential elements, care must be taken in identifying those leverage points that have the most significant impact and greatest

---

[1] For a more detailed description of the history of the government/industry relationship, see Chapter 1 of Houlahan, Christina J., *Reduction of Front-End Loading of Inventory: Making the Airframe Industry Lean Through Better Inventory Management*, M.I.T. Master's Thesis, May 1994.

potential for improvement. This thesis examines the relationship between two areas perceived as critical for industry improvement: inventory management and engineering change.

1.1.1 Inventory Practices

The LAI pilot project called for an investigation into a vital business issue challenging the defense aerospace industry: inventory management. This interest led to the creation of the Inventory Practice Survey, a comprehensive examination of nine key facets of materials management. Preliminary results from the survey pointed to several areas in need of further examination. The use of computer simulation tools to manage and track inventory is one of the more notable examples of material planning and handling that exhibited a wide range of practices among the responding companies. While nearly two-thirds of the companies surveyed claimed to be employing some sort of simulation tool for production planning and scheduling, many of thèm have surprisingly little control over inventory and production processes, demonstrating approaches more typical of 1940s production techniques than of state-of-the-art process control.

1.1.2 Engineering Change

While inventory management is recognized as a key area in need of improvement, the issue does not stand alone in the minds of industry managers. Harking back to the wartime mentality of cutting-edge designs focusing on high performance above all else, the industry continues to place tremendous importance on product development. Inherent in the development process are the numerous changes that occur along the way to a completed system design. The benefits of early detection and the problems associated with errors have strong consequences in this phase that in turn affect the manufacturing stages that follow. Engineering change orders to correct or modify previously-completed designs occur on government contracts well into the scheduled production phase, resulting in difficult rework and poor systems integration. Last-minute changes to designs also jeopardize schedule and inventory management to a great degree. Changes in the product design can result in changes to the part list, which lead to delays in the purchasing and delivery of inventory and ultimately to manufacturing schedule slips. In addition, previously purchased inventory becomes obsolete unless modifications, a costly option, are possible.

1.2 The MRP II Interface

The juncture between these two identified leverage points, inventory management and engineering change, appears to be an ideal location in which to incorporate lean practices. In particular, the Manufacturing Resource Planning (MRP II) system provides a way to create a seamless interface between engineering and manufacturing. In brief, MRP II controls inventory ordering and distribution through a simple set of questions:

- What are we going to make?
- What does it take to make it?
- What have we got?
- What do we have to get?[2]

MRP II combines this calculation with timing and capacity requirements to form an integrated system across the company. The basic goal is prevention of shortages and excess, leading the way to a streamlined flow of inventory through the process.

Although the roots of the MRP II philosophy were developed almost three decades ago, few aerospace manufacturers have employed the technique to its fullest, especially at the product development/fabrication interface. Often, each functional department has its own computer system, with little interaction between them even when they are monitoring the same material. MRP II provides consistency across the company, integrating all systems so that changes in one department are immediately reflected in the parameters concerning the others. This thesis examines how the use of MRP II can improve manufacturing processes and smooth the impact of engineering changes, thereby preventing schedule slips and reducing inventory. Of special interest is the development of implementable improvements for the defense aerospace industry. Questions to be addressed include:

- What is the current state of inventory management practices in the defense aerospace industry?
- What is MRP II? To what extent is it currently implemented in the industry? What are the barriers to its use? What are the benefits?
- What is the nature of engineering change? Where do changes originate? What is the impact on schedule and inventory management?
- How can MRP II help to alleviate the problems associated with engineering changes? How best to implement MRP II in the industry?

---

2 Wight, Oliver W., *MRP II: Unlocking America's Productivity Potential*; CBI Publishing Co., Inc., Boston, 1981, p. 50.

1.3 Research Methods

The research plan designed to answer these questions consisted of three steps: an industry-wide survey, a case study of a single company, and a conference with industry representatives. This arrangement facilitated both the construction of an accurate representation of the industry as a whole and the insight gained from intimate knowledge of a single site. Each step is outlined briefly below; details are provided in later chapters.

1) A survey of aerospace industry inventory practices was completed by the LAI sponsor companies. The initial results were analyzed, leading to the general conclusions pointing to a need for further study in the area of MRP II. Many of the 40 percent of survey respondents who use MRP II describe their system as a tool for inventory reduction. Since a majority of all respondents consider inventory reduction to be an important descriptor of company health, this raises the question of why more of them aren't using MRP II. Data interpretation from the survey is ongoing, and additional analysis was conducted as necessary. Details can be found in Chapter 3.

2) A case study of AIL Systems Inc. (Deer Park, NY) was performed, concentrating on AIL's success in implementing an MRP II program while simultaneously meeting their largest-ever government contract. While the program was not without problems, the history of the AIL implementation marks a path for other companies to follow and gives testimony that the benefits gained from the system can outweigh the barriers to its introduction and use. Details can be found in Chapters 6 and 7.

3) Initial conclusions from the survey and the case study were presented to LAI company representatives in an informal conference, the purpose of which was to evaluate the applicability of case-study specific recommendations to the industry at large and to judge the practicality of implementing recommendations. Details can be found in Chapter 8.

1.4 Outline of Chapters

The eight chapters of this thesis attempt to delineate a clear picture of the state of the industry with regard the potential role of MRP II systems in managing the manufacturing process. Chapter 2 relates the history the of the Lean Aircraft Initiative, including its mission, sponsors, and program structure. A summary of "lean manufacturing" principles is also given. Chapter 3 introduces the LAI pilot project through an overview of the analysis of the Inventory Practices Survey. Key results from areas relating to MRP II use are given, while complete results are found in the appendices. Chapter 4 examines the foundations of MRP II. A discussion of the nature of engineering change is found in Chapter 5, which attempts to determine the treatment of configuration change in the defense aerospace industry and its effect on cost, schedule, and inventory management. The relationship between engineering change and MRP II is also considered, focusing on the application of MRP II to product development. A case study of AIL Systems Inc. is found in Chapter 6, documenting their experience with implementing an MRP II system in conjunction with an intense production work load. Chapter 7 augments the case study by exploring the effects of the MRP II implementation on engineering change control at the company. The benefits of the system exhibited in the case study, along with a look at the barriers overcome in implementing it, form a basis for Chapter 8, which raises issues in regard to the applicability of MRP II for industry-wide use.

Chapter 2 Background of The Lean Aircraft Initiative[1]

The foundations of the Lean Aircraft Initiative (LAI) lie in the lean manufacturing methods first identified in the Japanese automobile industry. The principles behind this revolutionary approach to business are beginning to be implemented in many other industries as well. This chapter outlines the basic premise of lean manufacturing and discusses its use as related to the domestic military aerospace industry through LAI.

2.1 What is Lean?

The term "lean manufacturing"[2] was coined during the early phase of the M.I.T. International Motor Vehicle Program (IMVP) as a way to indicate the marked difference between the revolutionary approach to manufacturing observed in the study and the mass production tradition. The concept encompasses many of the current "hot topics" of management practice, such as total quality, process improvement, integrated product development, and just-in-time (JIT). The key difference between these various single-focus topics and the lean philosophy is the way lean manufacturing works to combine these disparate concepts into one direct focus for improved operation. Numerous surveys of and site visits to the Japanese automobile factories and their American and European counterparts formed the basis of the IMVP work between 1985 and 1990. M.I.T. began its second major study of lean manufacturing with LAI. A brief description of the relationship between the two studies and a discussion of the foundation of lean manufacturing principles follows.

2.1.1 IMVP Beginnings

The original study of lean manufacturing (IMVP) was a five-year, five million dollar project conducted by a world-wide team of researchers based at the M.I.T. Center for Technology, Policy, and Industrial Development. IMVP consisted of a comprehensive study of the auto industry with emphasis on the Japanese development and implementation of lean manufacturing. Major results of the program are documented in

---

1 This chapter was co-authored by Christina Houlahan, LAI Research Assistant.

2 Note: the terms "lean manufacturing" and "lean production" will be used interchangeably throughout the text to refer to the concepts described in the IMVP study.

The Machine That Changed the World.[3] The program was highly successful in earning major visibility among an international competitive manufacturing community largely unaware of the huge disparity of cost and schedule metrics between Japanese and Western car manufacturers. As *The Machine That Changed the World* became a national bestseller, its popularity and influence spread throughout the manufacturing world, eventually bringing lean production ideas to the attention of top officials at the United States Air Force Aeronautical Systems Center (ASC) in 1992. As mentioned in Chapter 1, following the collapse of the Soviet Union, the defense aircraft industry was faced with a crisis in dealing with a decreasing and uncertain threat accompanied by shrinking procurement budgets. In short, the government and industry were challenged to do more with less. Searching for ways to apply lean manufacturing principles to these problematic aspects of the defense aerospace industry, ASC looked to M.I.T. to extend its research into this area. Continuity between IMVP and LAI is provided by former IMVP Director Daniel Roos, who was appointed LAI Co-Principal Investigator.

2.1.2 Lean Principles

Lean production is fundamentally different from mass production, having a different operational framework, corporate culture, and organizational structure.[4] The term "lean" manufacturing was selected because the associated techniques require significantly fewer resources than previous methods. For instance, compared to mass production, lean manufacturing uses less human effort in the factory, less manufacturing space, a smaller investment in tools, fewer engineering hours to develop new products, and less inventory on-site.[5] In addition, lean production results in many fewer defects while producing a greater variety of products. From a philosophical perspective, practitioners of mass production set limited goals for "good enough" performance, while lean producers set their sights on perfection.[6] This attitude is evidenced by the major goals of lean production, namely, perfect first-time quality, waste minimization, and continuous improvement. The corresponding desired outcome is lower production cost, improved

---

3 Womack, James P., Daniel T. Jones, and Daniel Roos, *The Machine That Changed the World*; Rawson Associates, 1990.

4 Weiss, Stanley I., "Lean Aircraft Initiative," National Technological University (NTU) presentation, Washington, D.C., July 26, 1993, p. 15.

5 *The Machine*, p. 13.

6 *The Machine*, p. 14.

product quality, higher productivity, efficiency at a lower scale of production, rapid product development cycle, and product mix diversity.[7]

To accomplish these lofty goals, lean manufacturing amalgamates the best features of craft production (high quality, custom-made products) with those of mass production (large quantities to satisfy broad customer needs at lower price).[8] Here is where many of the management concepts that have emerged from Japanese business come into play in the lean arena. One of the most notable distinctions of lean production is the ability of any worker to stop the line to fix problems, unlike the rigid structure found in mass production factories where the continuity of the line is maintained at the expense of increased amounts of re-work to be corrected in the finished product. The Japanese *kaizen* principle (continuous incremental quality improvement), which has come into vogue in Western plants as of late, demands this flexibility and empowerment of the line workers to reduce defects by catching problems where they occur instead of later in the process when the value-added is much higher and errors are buried beneath complex layers of later-installed parts. The effect of errors is therefore reduced, while the probability of correcting the source malfunction is significantly improved. The concept of design for manufacture complements this error-reduction strategy by aiming at designs with fewer parts and better fit.

The *kanban*/just-in-time (JIT) method is also incorporated into lean manufacturing principles. By coordinating the flow of parts within their supply system, lean producers are able to reduce inventories and speed manufacturing cycle times. They generally have a much better understanding of their process flow through the use of "value engineering" to break down the costs of each stage of production so as to identify factors that could lower part cost.

The IMVP researchers found the Toyota Production System to typify lean production principles. The most graphic testimony to the effectiveness of lean production in improving plant operational efficiency is evidenced by a comparison of various operational statistics for the General Motors (GM) Framingham Assembly Plant (now closed) and the Toyota Takaoka Assembly Plant (see table 2.1). The data refer to the production of a "standard car" defined by IMVP to allow comparisons between disparate plant sizes and product configurations.

---

7 Ling, James G., "Lean Production," LAI Internal Memorandum, October 1993.
8 Weiss, NTU presentation, p. 17.

Table 2.1: Comparison of General Motors (GM) Framingham Assembly Plant and the Toyota Takaoka Assembly Plant (1986 figures)
Source: IMVP World Assembly Plant Survey[9]

	GM	Toyota
Gross Assembly Hours per Car:	40.7	18.0
Assembly Defects per 100 Cars:	130	45
Assembly Space per Car (sq. ft.):	8.1	4.8
Inventories of Parts (average):	2 weeks	2 hours

As these figures demonstrate, the Toyota plant was more than twice as productive and almost three times as accurate as the GM plant. In general, the IMVP study found that Western auto companies misunderstood the reasons for the Japanese business advantage and were unwilling and unable to diagnose their own problems. The first precise definition and evaluation of lean production helped to clarify the competitive situation and identify key areas for improvement.

2.2 What Is LAI?

The often-quoted statistics from *The Machine That Changed the World* GM/Toyota survey brought the benefits of lean production to light for many American businesses and aided in creating the impetus for LAI. This section contains a discussion of the LAI mission and its organizational structure. A description of the inventory pilot project is also included.

2.2.1 Mission

The formal mission of the Lean Aircraft Initiative is "to spearhead an organized process of research and action leading to a fundamental transition of the defense aircraft industry over the next decade by instituting substantial improvements in both industry and government practices."[10] Major goals include the identification of "roadmaps for change" to lead to better, faster, and cheaper manufacturing, searching for best practices to use as models for comparison along the way. The program is designed to build upon the IMVP work but treats the aerospace industry as its own entity, lending special consideration to the unique customer relationship between defense manufacturers and the

---

9 *The Machine*, IMVP World Assembly Plant Survey, p. 81.
10 Bozdogan, Kirkor, "Lean Aircraft Initiative Mission," LAI Internal Memorandum, March 26, 1993.

government. As in the auto industry, lean manufacturing appears to be a good fit with the traditional aerospace environment of high-tech craft managed as mass production.[11]

The approach to LAI differs from the usual mode of industry research in that the focus is on implementation of real-world concepts and strategies rather than academic theorization. Researchers work closely with industry and government representatives to insure the selection of near-term implementable goals and plans. The final main objective is to identify and validate areas of the government acquisition process (i.e., regulations and procedures) that impair efficiency for industry producers.

2.2.2 Sponsors

LAI is under the joint sponsorship of the United States Air Force and 21 aerospace industry corporations whose membership includes all sectors of the industry -- airframe, avionics/electronics, engines, subsystems, and others. A financial contribution of $50,000 per year from each industry participant is matched by one-third government funding through ASC. Commitment to the program is demonstrated by the high-level of support and participation at ASC (general officer level) and the companies (corporate level). Total program funding is $1.8M per year for three years, with a possibility for follow-on work. Current sponsors are shown in table 2.2.

Table 2.2: LAI Sponsors

Air Force Aeronautical Systems Center (ASC)		
AIL Systems Inc.	Lockheed Aeronautical Systems	Rohr Industries
Allied-Signal	Lockheed-Fort Worth	Sundstrand
Boeing Defense & Space	Martin Marietta	Texas Instruments
GE Aircraft Engines	McDonnell Douglas	Textron Defense Systems
Grumman/Northrop	Northrop	TRW
Hughes Aircraft	Pratt & Whitney	Vought Aircraft
IBM Federal Systems/LORAL	Rockwell-North American	Westinghouse Electronic Systems

[11] Weiss, NTU presentation, p. 23.

2.2.3 Program Structure

LAI is structured with M.I.T. serving as the "honest broker," allowing tight interaction with sponsors to guarantee a useful path of research and a reliable supply of unbiased data. Sponsor interaction occurs at many levels, and industry participants are expected to expend approximately six person-months of effort annually for meetings, site visits, and data collection support. The upper-most level of direction is provided by an Advisory Board comprised of roughly 20 president-level industry representatives and high-ranking government military and civilian personnel. Industry Board membership is chosen from among the sponsor companies on a rotating basis. The Advisory Board meets three times per year at M.I.T. and is responsible for guiding the overarching direction of research and for setting program policies. A Working Group made up of subordinate staff from the same organizations is tasked to set agendas for Board action items and to carry out any subsequent mandates. M.I.T. has its own Internal Advisory Board to handle Institute-specific issues.

Representatives from all the sponsors gather quarterly at M.I.T. for Workshops whose purpose is to report on LAI progress, disseminate current research results, present case studies of lean practices, and identify issues for further consideration. At this time, Focus Groups are convened in each of the five major areas of research: fabrication and assembly, product development, supplier relations, human resource management, and policy and external environment. A cross-section of participants from industry, government, and academia attend each Focus session to discuss specific research progress and goals. The Focus Groups are also a vehicle for direct sponsor interactions with the M.I.T. team which often result in individual company case studies and site visits. The Workshop also hosts Sector Group meetings, where company representatives from each industry sector -- airframe, avionics/electronics, engines, or subsystems -- confer to discuss issues relevant to their particular specialties. The most comprehensive level of sponsor/researcher interaction takes place during intensive mini-workshops throughout the year, during which M.I.T., industry, and government specialists meet to discuss detailed research methodology and results.

The five Focus Groups indicate the main organizational categories for LAI research. Each topic is under the direction of M.I.T. faculty and research staff, with a complement of graduate research assistants. Plans call for a series of M.I.T.-conducted surveys, to be completed by the industry sponsors, which examine specific practices relating to each topic. The goal is to look at industry and government attitudes and practices relating to the focus area and then to identify best practices and opportunities for improvement. The first LAI focus team concentrated on aerospace inventory practices, a subcategory of fabrication and assembly. The pilot project is described in Chapter 3.

Chapter 3 The Inventory Pilot Project Survey[1]

Fabrication and Assembly was singled out from the start of the LAI program as a major area of current difficulty with good possibilities for successful implementation of change. In particular, inventory control processes were cited by the industry participants as having a significant impact on company viability and also as needing improvement. Inventory is pervasive throughout an organization, masking many problems inherent to its manufacturing operation. As figure 3.1 shows, the presence of inventory affects and is affected by a great many aspects of a manufacturing operation: facilities management, supplier relations, quality, purchasing, etc. Starting the research plan with an examination of inventory provides a good snapshot of the state of the industry and of individual companies, along with ideas for a number of areas for future study. Key questions to be answered included:

- How much capital is tied up in inventory?
- How much does it cost to carry inventory?
- How fast does inventory turn over?
- What factors drive inventory levels and turns?
- How do inventory levels affect ability to meet production schedules?
- What do inventory practices reveal about the company's control over process flow?
- What improvements can be made?

This chapter contains background on the format of the survey, the characteristics of the database, the requirements for "valid" data, and lastly some of the salient results from the section of the survey relating to industry use of MRP II. Complete results of the survey are found in appendix A.

---

[1] This chapter was co-authored by Christina Houlahan, LAI Research Assistant.

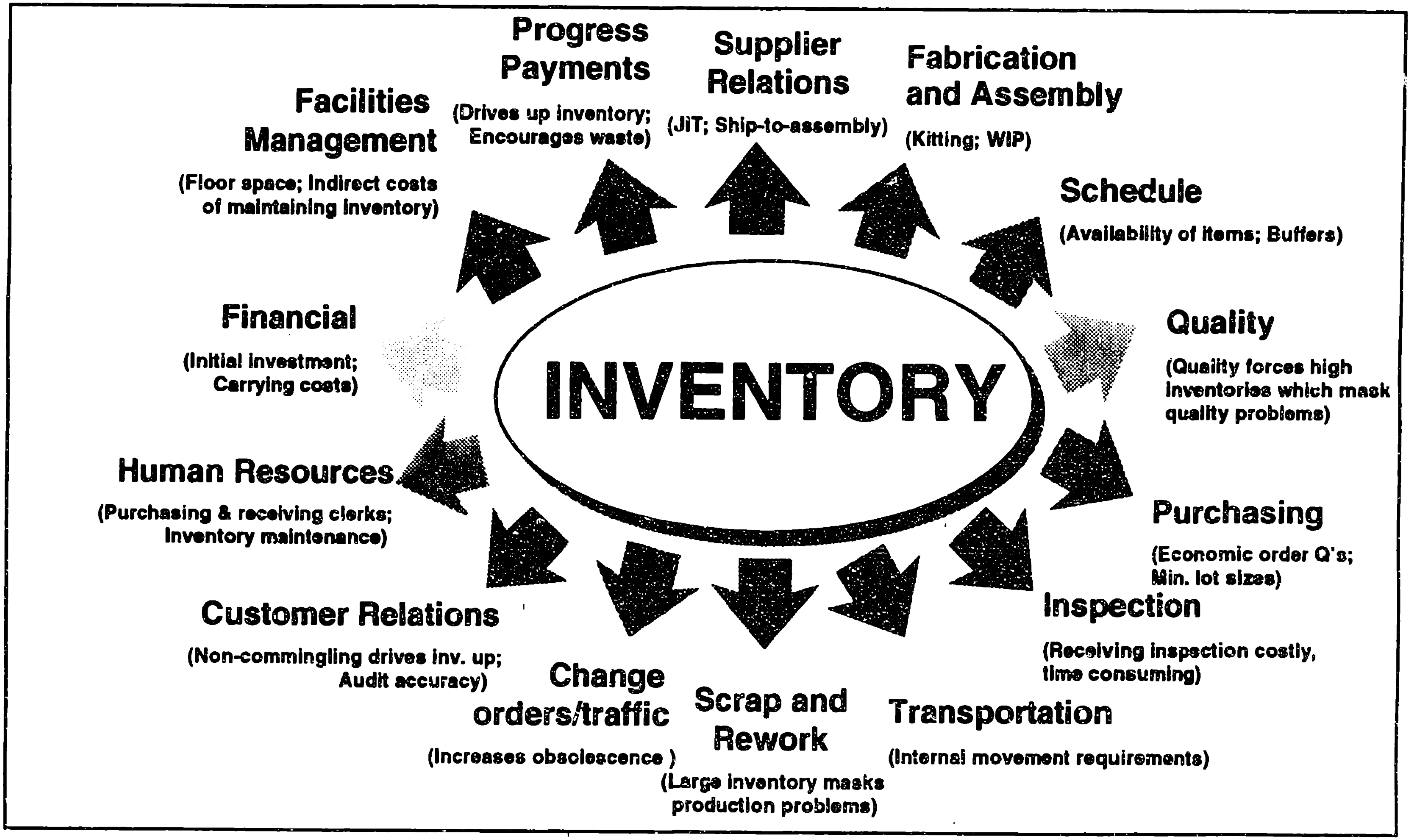

Figure 3.1: Pervasiveness of Inventory

3.1 Research Plan of Attack

The pilot project process flow is detailed in figure 3.2. Once the inventory topic was selected, the first step in examining industry practices was a series of seven site visits to LAI member companies during the spring of 1993. Researchers prepared a list of approximately 60 inventory-related questions, derived from initial research, to serve as a basis for discussion at the visits. Site hosts typically provided two days of presentations by inventory control management personnel and a factory tour, followed by a question and answer session. General impressions from site visits concluded that many opportunities for the introduction of lean practices exist in aircraft manufacturing, especially in fabrication, scheduling, and parts distribution. There is a clear recognition among top management of the need for leanness, as well as an existing visible movement toward teaming and integrated product development. Researchers also saw variability of government oversight coupled with a gradual change in government approach, shifting towards process verification. In the specific area of inventory control, a wide range of practices were found, from 1940's approaches to 1990's world-class. Excess inventory was found to cause problems in four ways: up front capital investment, carrying costs, scrap and rework costs, and masking of production problems. On the government side, progress payments and fiscal year buys seemed to encourage excess inventory. All in all, the evidence pointed out that companies are trying to reduce inventory, but the process is slow at current production rates.

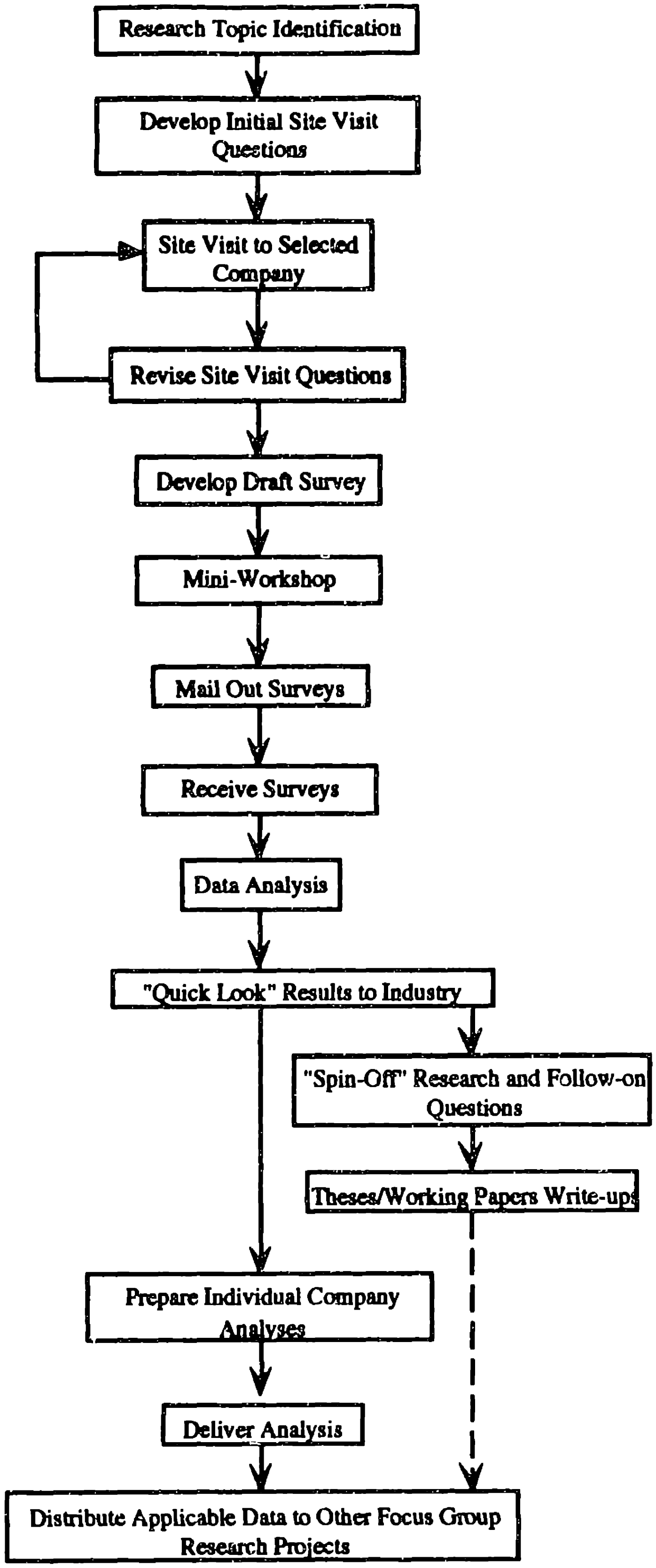

Figure 3.2: Inventory Pilot Project Process Flow

The results of the site visits were used to fine tune the initial set of questions and to convert them into a draft questionnaire. Attention was paid to developing a consistent survey format so as to increase response accuracy. A mini-workshop was then held at M.I.T. in June to revise the survey. A panel of industry and government inventory specialists, selected as a representative sample of the sponsoring organizations, was invited to the intensive two-day meeting. The goal of the mini-workshop was to address outstanding global issues, including the definition of the scope of analysis, response protocol, and results/output. Small groups examined each section of the survey to modify format and content. To insure consistent terminology within the survey across industry segments, the group prepared standard industry production and planning models (figures 3.3 and 3.4) and a glossary of terms. Most questions were based on the acceptance of these models as accurate representations of the responding company's system. The survey also included space for the company to describe its own system if it differed substantially from the standard model.

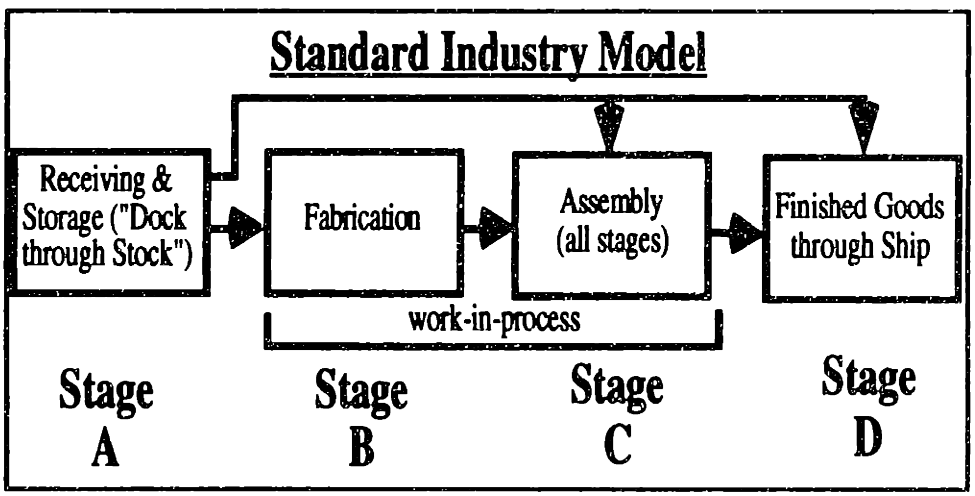

Figure 3.3: Standard Industry Model

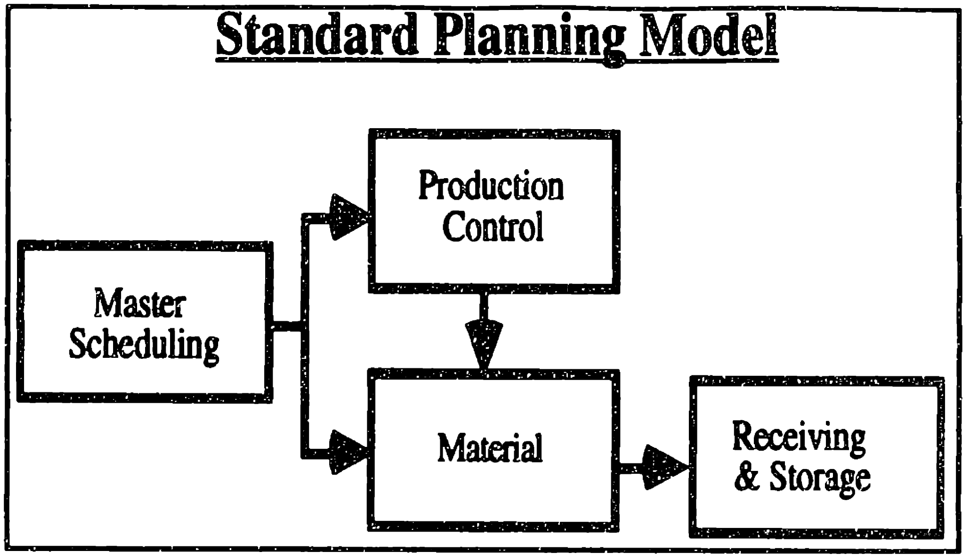

Figure 3.4: Standard Planning Model

3.2 Survey Format and Database Characteristics

The output of the mini-workshop was a final version of the survey, a 60-page questionnaire containing numerical, yes/no, and essay questions in nine areas:

- Section O: Company Overview and General Statistics
- Section A: Organization and Management Policy
- Section B: Metrics
- Section C: Accounting Practices
- Section D: Inventory Handling and Facility Management
- Section E: Planning and Simulation
- Section F: Inspection and Defects
- Section G: Government Relations
- Section H: Final Comments

The final inventory practices survey was distributed to the member companies in late June 1993. Respondents were given one month to respond. Appended to the survey was a tracking sheet so that companies could note individual company representatives to be contacted should questions arise during the course of the analysis. Each company was asked to complete surveys for those internal organizations having more than 200 employees that in total comprised 80 percent or more of its annual DOD business. Thirty-six valid surveys were returned, representing 20 companies (six companies surveyed multiple plants/divisions).

Respondents were grouped into the following major sectors (the number of surveys within each category is indicated after the colon):

- Airframe (major assemblies, fuselage sections, structures or skins): 10
- Engines (aircraft primary power plants): 3
- Electronics (avionics, flight computers, guidance equipment, etc.): 13
- Systems (electro-mechanical systems and components): 4
- "Others" (missiles, satellites, communications, etc.): 6

Data were analyzed for the industry as a whole, as well as for individual sectors.

3.3 Analysis Methodology

Response data were compiled in a Microsoft Excel™ spreadsheet database format running on a Macintosh personal computer. Initial analysis included the calculation of averages and statistical information on numerical data and percentages on Boolean responses. Researchers assessed the data as it was entered to verify reasonableness, check for outliers, and correct technical errors. A second more in-depth analysis consisting of data evaluation and manipulation resulted in the creation of graphics describing general results. Quantitative information was combined with written answers to essay questions in order to assemble a snapshot picture of the state of the industry. Presentations on initial results were made at the Workshop and Sector Group level, while individual reports were prepared for respondents showing how they measured up to industry norms. Ongoing data interpretation involves the search for internal and external benchmarks related to inventory and production management practices, which will be documented in subsequent student theses and M.I.T. working papers.

3.4 Survey Evidence of MRP II Use

The "Planning and Simulation" section was designed to gauge the extent to which companies had utilized and implemented common production techniques and accepted simulation tools into their everyday operations. Respondents were first asked whether they have a master production schedule (MPS), and, if so, if that schedule is automated. Most companies (94 percent) do have master schedules, and nearly three-quarters of them are fully automated. Results by sector are given in table 3.1. The survey analysis also showed that 78 percent use the MPS as the principal determinant of inventory levels.

Table 3.1: Percentage of Companies Using a Master Production Schedule (MPS)

	MPS in use	MPS automated
Airframe	90%	80%
Electronics	100	62
Systems	100	100
Engines	100	67
"Others"	83	58
Industry	**94%**	**71%**

A computerized master schedule is one of the cornerstones of the MRP II technique (see section 4.2). These statistics indicate that a majority of the industry has advanced beyond manual inventory control systems and is at least somewhat prepared to implement an MRP II system.

More than 60 percent of the companies use some sort of simulation tool for production planning and scheduling (see figure 3.5), most often to evaluate shop floor control and the downstream impact of schedule changes. Other uses include the simulation of capacity constraints, such as limits in manpower and machine availability. Companies were also asked to identify the specific tools used in their operations. The results are sector dependent, but MRP II ranks highest in all cases (44% industry-wide), followed by the Critical Path Method (CPM, 20%) and then Program Evaluation and Review Technique (PERT, 14%). Some sectors show more advanced use than others for tools such as MRP II (see "Others" specifically). This conclusion comes with the caveat that the sample size for the "Others" sector is smaller than that for sectors such as Electronics and Airframes. The Engine group uses none of the three tools found in other sectors.

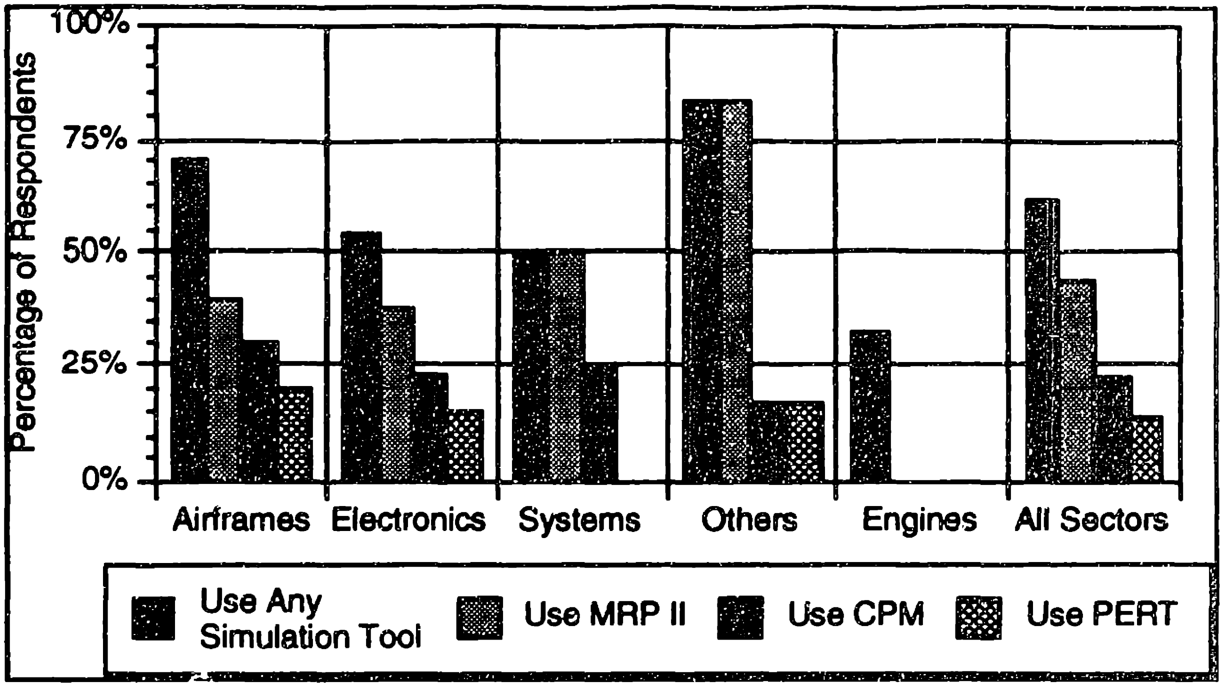

Figure 3.5: Use of Simulation Tools

Use of an automated process flow scheduling and planning system along with simulation modeling is considered to be an essential element in a company's progress towards lean manufacturing. Although 44 percent of the industry does have an MRP II system in place, this figure is not as high as would be expected among modern manufacturing facilities. Subsequent chapters attempt to discover whether the perceived barriers to MRP II use are justifiable in light of the potential benefits.

Chapter 4 Foundations of MRP II

While the state-of-the-art in computer software advances at a rapid pace, the fundamental principles of MRP II remain. MRP II is therefore more appropriately considered a dynamic and flexible technique than a static computer program. At its most basic, the philosophy behind MRP II can be summarized as, "Produce only what the customer wants, when he wants it."[1] The preeminent MRP II consulting organization, the Oliver Wight group, prefers the succinct phrase, "organized common sense."[2] Even formal definitions of MRP II tend towards vagueness, most including some notion of effective planning of manufacturing resources based on company-wide networked scheduling. Major characteristics include the integration of a master schedule with capacity and material requirements, the ability to reconcile an operational plan detailing production in terms of part units with a financial plan calculated in dollars, and simulation capability to answer "what if" planning questions.[3] The latter feature, which links present inventory levels to future requirements, distinguishes MRP II from earlier backward-looking systems that merely acted to replace material stores when they had been exhausted.[4] While MRP II is similar to other modern planning techniques, such as PERT and CPM, in that they all represent network scheduling systems, MRP II's comparative simplicity make it easier to keep records up to date. In this way, its straightforward nature makes it more valuable to users than the additional sophistication offered by more complex systems.[5] This chapter discusses the development of MRP II and the basic principles of the system. A sample implementation plan, endorsed by the Oliver Wight group, is also included. The discussion concludes with a brief overview of enhancements to MRP II applications expected in the future.

---

1 Chamberlain, Woodrow, "MRP II: Don't Write It Off Yet! Myths and Near Myths," *APICS - The Performance Advantage*, American Production and Inventory Control Society, Falls Church, VA, Vol. 4, No. 3, March 1994, p. 27.

2 Wallace, Thomas F., *MRP II: Making It Happen*, Oliver Wight Limited Publications, Inc., Essex Junction, VT, 1990, p. 3.

3 Wallace, p. 310.

4 Turbide, David A., "This Is Not Your Father's MRP!" *APICS - The Performance Advantage*, American Production and Inventory Control Society, Falls Church, VA, Vol. 4, No. 3, March 1994, p. 28.

5 Wight, Oliver, *The Executive's Guide to Successful MRP II*, Oliver Wight Limited Publications, Inc., Essex Junction, VT, 1982, pp. 12-13.

4.1 Development Background

From the 1940s to the early 1960s, material control consisted of basic "order point" formulae used to maintain a level average inventory balance.[6] As manufacturing complexity increased, so did the demand for a more sophisticated method of inventory control. Material Requirements Planning (MRP, not to be confused with its successor, MRP II) was developed in 1965 to serve as a platform to answer four questions, known as the "Universal Manufacturing Equation":

- What are we going to make?
- What does it take to make it?
- What do we have?
- What do we have to get?[7]

The respective answers to the first three questions lie in the blueprints of the production plan: the master production schedule (MPS), the bill of material (BOM), and the physical inventory records themselves. When taken together, these can be used to determine the solution to the final query: future requirements. MRP's most prized ability lay in the coordination of dynamic timing requirements; the supplier's raw material delivery date, the company's production date, and the customer's receipt date were all considered in the determination of priorities.[8] This feature propelled MRP into widespread use among commercial manufacturers, although limitations in computer processing power and memory size at that time restricted its applicability to smaller firms.

While MRP was certainly a vast improvement over simple manual methods, the potential to stretch its boundaries even further was soon recognized. A company's production is constrained not only by inventory needs but also by equipment and personnel capacity, facets of the plant not considered in the Universal Manufacturing Equation. In 1975 the next generation system, Closed-Loop MRP, integrated capacity factors into the MRP structure and used feedback on production status to maintain the validity of planning decisions as requirements changed.[9]

---

6 Goldratt, Eliyahu M. and Robert E. Fox, *The Race*, North River Press, Inc., Croton-on-Hudson, NY, 1986, p. 10.

7 Wallace, p. 5.

8 Wallace, p. 5.

9 Wallace, p. 6.

One crucial link in the manufacturing decision chain was still missing -- the financial point of view. The introduction of MRP II five years later served to bridge this gap. The operational Closed-Loop MRP plan, represented in material units such as pieces and pounds, was translated into financial dollar terms, enabling the entire organization to work off a single set of data. Simulation capability was also developed in order to answer "what if" planning questions with action-oriented replies.[10] Thus the system truly encompassed *manufacturing resources* instead of merely material requirements, justifying the addition of the version number "II." Dramatic improvements in computing power over the past decade have made MRP II a viable option for even the largest data needs.

4.2 Major Principles: The MRP II Flow

The logic behind MRP II can be described as a flow of information through the various factory operations, as depicted in figure 4.1. The system is comprised of eight primary areas of control: business planning, sales and operations planning, demand management, rough-cut capacity planning, master scheduling, detailed material and capacity planning, plant and supplier scheduling, and execution.[11] The first five elements consist of company inputs to the MRP II computer program, and all require in-depth planning on the part of management and coordination across functional areas. The last three blocks of the flow are the essential outputs of MRP II but should not be thought of as the "black box" result of mystical computer processing. All of the steps along the flow require constant feedback and interaction throughout the company, as indicated by the two-way arrows connecting each phase. The details of the processes behind each step are outlined below.[12]

The source of the flow is the company business plan, a overarching scheme that considers the market, company resources, and financial requirements to formulate long-range strategic goals (in dollars). One important aspect of the business plan is sales and operations. As its name suggests, this sub-plan contains details on the production schedules designed o meet the business plan objectives and is measured in personnel hours and product units.

---

10 Wallace, p. 8.

11 A detailed description of the MRP II flow can be found in Wallace, pp. 254-262.

12 Note: While the exact operating procedures of specific MRP II software packages will vary, these steps serve to illustrate the capabilities of a typical system operating according to "classic" MRP II principles.

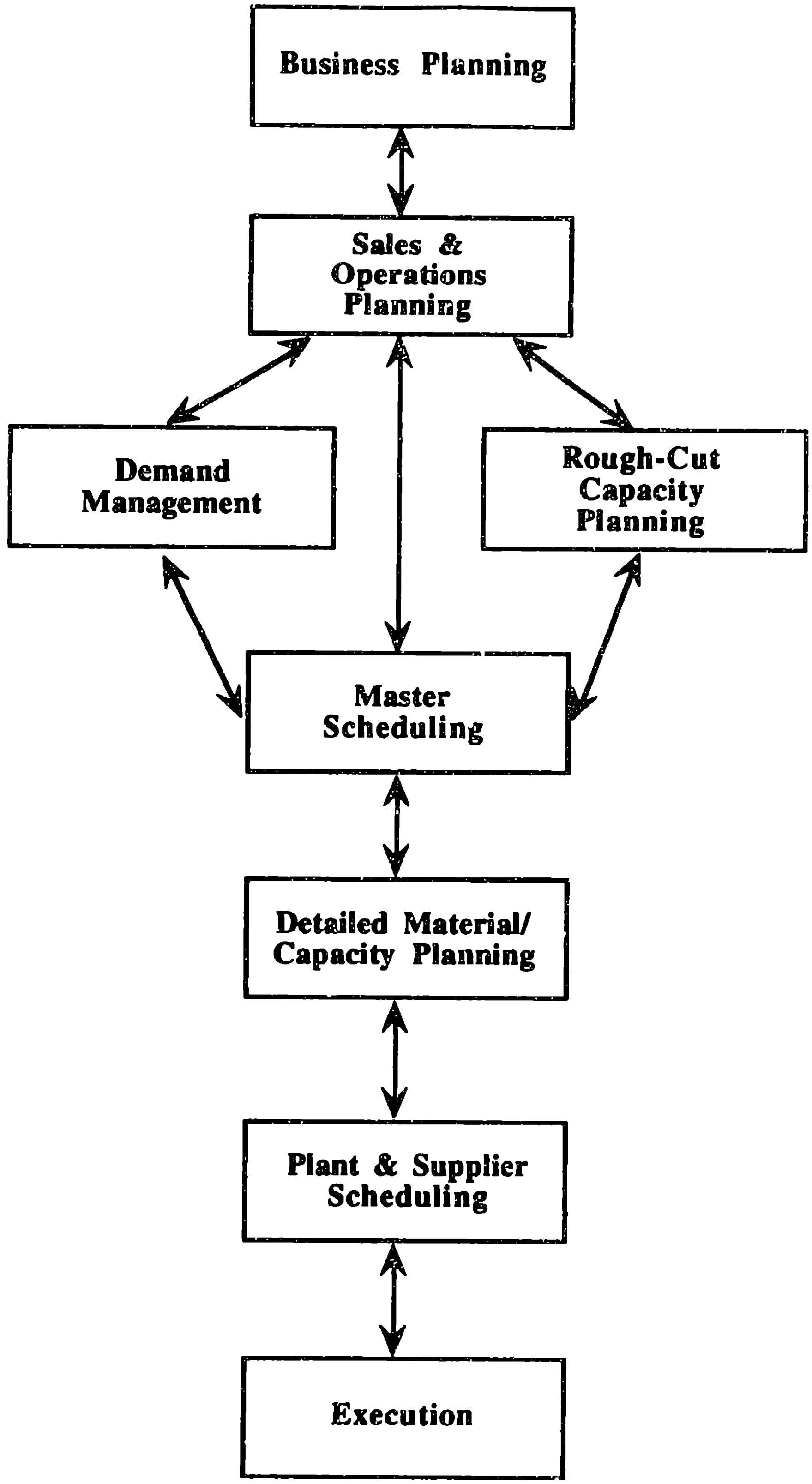

Figure 4.1: Manufacturing Resource Planning (MRP II) Flow Chart
Source: Wallace, p. 5.

The next steps, demand management and rough-cut capacity planning, elaborate on the sales and operations planning scheme. Demand management is made up of two segments. Forecasting and sales planning describes what the company is planning to sell (in units and in dollars) and what steps are needed to realize this goal. The other segment, customer order entry and promising, involves taking incoming orders, determining availability, and calculating realistic delivery dates. Rough-cut capacity planning judges whether the plant resources needed to achieve the sales and operations goals are realistic given the company profile.

The final and most critical input, the master production schedule (MPS, also known simply as the "master schedule"), is a detailed statement of what the company will produce (by individual item) and when. The MPS must consider existing and forecast orders as well as current inventory and available capacities. The most challenging step for management is to generate detailed priority plans for each production department to follow.

The first step of the flow to involve computer data manipulation is the detailed material and capacity planning segment. This step is an amalgamation of traditional MRP (Material Requirements Planning) and its counterpart, CRP (Capacity Requirements Planning). As described above in the development history, MRP uses the MPS, BOM, and inventory records to determine what new material must be ordered and when. Similarly, CRP uses the MRP output and a routing list for each product to predict how much capacity will be needed and when.

Plant and supplier scheduling provides both internal and external communication links for the company. The plant schedule lists exactly which jobs are scheduled on a given date for each production shop and indicates the priority of each in the overall company business plan. This phase is truly an interactive one, since the system monitors the flow of capacity by comparing scheduled work to actual completed work as a form of input-output control. The MRP output for purchased items is summarized and can be sent directly to vendors, eliminating the need for purchase requisitions and purchase orders. The long term supplier schedules authorize weekly deliveries and include forecasts of future orders and changes to current priorities so that the supplier acts as a well-informed company resource instead of an external uncontrolled variable. Material with a long supplier or production lead-time is placed on order according to the forecast, with the actual receipt schedule adjusted to match actual demand as the date approaches.[13]

The heart of MRP II lies in the execution and feedback phase. Conflicts in material or capacity requirements are resolved via feedback to the planning department from all production areas. Any changes are reflected in the MPS, with updates communicated to the customer if delivery dates will be missed. This phase provides the many substantial links required for integrated operations, including the coordination of general long range plans for the business with short term detailed plans for the shop floor. As explained above, the inclusion of both unit and dollar data allows a direct connection between the operational and financial departments. This ensures that the right people have the right data to analyze the situation and make informed choices. The decision-making process is enhanced by the ability to evaluate simulated situations regarding changes in market demand, costs, and capacity without a direct risk to company operations.

4.3 Typical Implementation Plan

Implementing an MRP II system can be an extremely involved process, one that must be taken seriously if the company is to obtain the maximum benefit. It is a simple task to install a stand-alone computer program and let it run in the background, but true control of factory operations requires a strong commitment to change and to the implementation effort. This section describes an MRP II implementation process endorsed by consultants and software developers as the result of 25 years of trial and error at thousands of sites. The "Proven Path" described below has been followed innumerable times with success and is accompanied by a Wight group guarantee: "If you do it right, it will work. Period."[14] While this is certainly not the sole route to MRP II mastery, it is provided as a example of a proven core methodology.

4.3.1 General Goals

The extent to which MRP II pervades a company's business operations can be categorized in four grades: Class A through Class D.[15] In general, the level of dedication and education put into the implementation process determines the extent of the benefits.

---

13 Chamberlain, p. 26.
14 Wallace, p. 20.
15 Wallace, p. 9.

At the low end of the scale, MRP II in the Class D environment is thought of as just another computer program. Since the system is poorly understood by users, it provides little aid to company operations. The Class C MRP II user employs the system primarily as a material ordering method. Some reduction of inventory may result, but fundamental business practices are unchanged. In a Class B organization, measurable improvements in operational metrics and the ability to cope with change are evident, but not quite to the extent exhibited in a Class A environment. The top level of achievement represents an organization that uses the system effectively company-wide. The Class A company receives substantial improvements in customer service, productivity, inventory, and costs as a result. The system is used to run all aspects of daily operations, and extensive simulation is employed.

Even the lowest level of MRP II implementation will probably be of some value to the company, but, obviously, striving to invoke the full benefits of the system should be the ultimate goal. Achieving Class A status is an extremely people-intensive effort. Active participation from top management is an absolute necessity, since the implementation must be assured high priority in the company. Cooperation among all departments is also required, and all employees must be willing to change some of the basic ways they do their jobs.[16]

An aggressive schedule is often the key, so that the high level of resources that implementation requires doesn't distract too long from the primary goal of running the business. Typically, a schedule of less than one year is not long enough to complete the educational and informational requirements or instill fundamental change. At the same time, the company will find it arduous to sustain momentum and priority for longer than two years. A schedule of roughly 15 months from the decision to begin implementation to the installation of a pilot project is therefore suggested as a compromise.[17] In this format, the implementation is accomplished in stages that correspond to the development history of the system: MRP is established in the first ten months, closed-loop MRP in the next three months, and full-fledged MRP II in the last two. If the length of this schedule presents a problem, the company may opt to perform a "Quick-Slice" implementation such that the majority of MRP II functions are employed for one or more high-profile product lines instead of in the entire company. This mini-implementation can be

---

[16] Wallace, pp. 14-15.
[17] Wallace, pp. 16-17.

performed in only three to five months and may be repeated as resources allow to broaden the extent of MRP II control.[18]

4.3.2 The Proven Path

Several versions of the Proven Path have been developed by MRP II specialists since the central properties of the system were established. The particular method described below emerged in the mid- to late-1980s and involves 16 steps, as shown in figure 4.2.[19] The first four steps of the Proven Path are an organized approach to guide top management in deciding whether or not MRP II is the best way to solve the company's problems. The initial audit and assessment activity is an analysis of the current business situation, its end result being the creation of a short term action plan. Educational preparation is divided into three phases spread along the course of the implementation. The goal of the first-cut education is to inform the corporate decision makers as to the fundamental structure of the system, along the lines of the summary material presented in section 4.2. The managers then work to formulate a vision statement indicating how the company should look post-implementation. Once a concrete picture of the current situation and future goals is established, a cost/benefit analysis (see chapter 8) is performed to justify a formal decision to proceed with the implementation.

---

18 For more information on the Quick-Slice implementation, see Wallace, Chapters 11-12, pp. 209-237.

19 A detailed task list for the Proven Path can be found in Wallace, Appendices C-D, pp. 273-292.

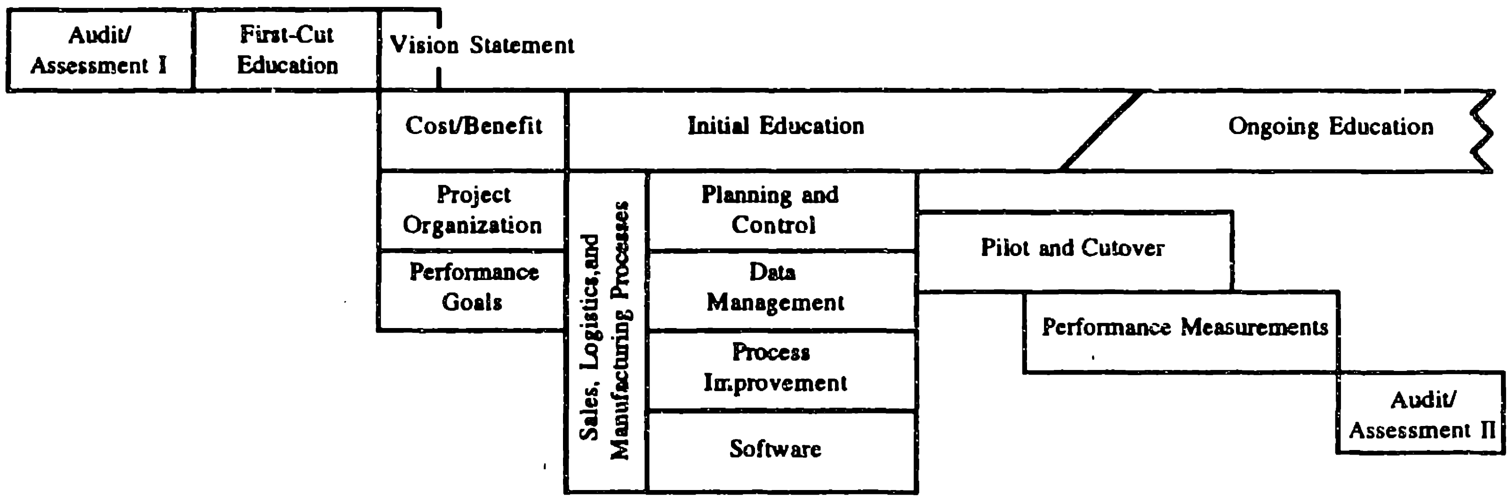

Figure 4.2: The Proven Path
Source: Wallace, p. 44.

Since MRP II depends on people to reach its full potential, the project organization is crucial to the ultimate success of the implementation.[20] Human resources for the implementation team can be group roughly into two spheres, management and operations, as shown in figure 4.3. An Executive Steering Committee should be convened approximately one hour per month to oversee progress from a broad perspective. This top management effort is spearheaded by one enthusiastic individual known as the "torchbearer" (often the company General Manager or equivalent). It is usually the torchbearer who has brought MRP II to corporate attention, who is a dedicated proponent of its invaluable nature, and who rallies support from other managers. This role is intrinsic to a successful implementation, as it provides the requisite weight from top management to get things done at lower levels in the company, as well as the leadership support to instill a new set of values. The torchbearer must manage by setting objectives, establishing accountability, educating people, giving them the tools to do their jobs effectively, and then measuring their performance in a constructive manner that charts progress towards planned company goals. It is very much a "hands on" position and requires detailed knowledge and interaction with the operation of the MRP II system in order to be fully effective.

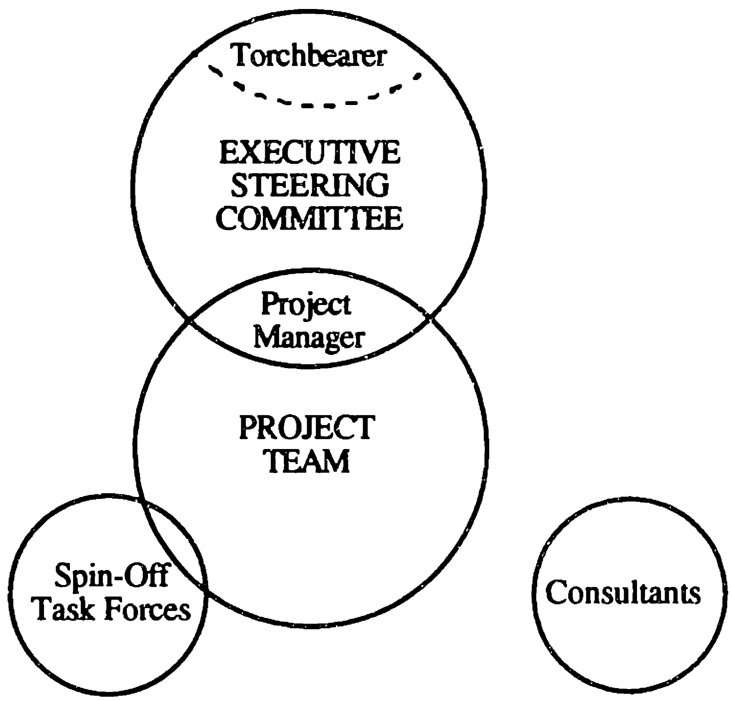

Figure 4.3: Recommended Organizational Arrangement of Implementation Team
Source: Wallace, p. 81; with additions.

---

[20] Further suggestions for the composition of the implementation team can be found in Wallace, pp. 77-85.

Rounding out the management level, but coexisting in the labor sphere, the project manager (PM) is a full-time position that reports directly to the torchbearer. The PM's basic job description is "to get things done." In selecting the PM, the Steering Committee should look for a veteran employee with a firm background in all areas of company operation who is also an excellent personnel manager. The PM supervises the activities of the project implementation team itself, which should include high-grade people from the primary company departments, including marketing/sales, purchasing, finance/accounting, information services, human resources, production control, manufacturing, engineering, and research and development (R&D). The project team should hold weekly meetings, although not all team members may need to be full-time dedicated resources.

If necessary, ad hoc spin-off task forces made up of cross-functional team members and other relevant company personnel can be assembled to perform specific jobs. Areas which might warrant temporary skill bases acting as resources to the team include the handling of software selection or engineering change procedures. In addition, outside professional guidance from consultants may be advisable to coach management, ask probing questions related to the detailed workings of the system, and to keep the project on track. Care should be taken to prevent overeager consultants from usurping the role of the project team, since an in-house perspective is required to assemble a system that will work within the company framework. The users should also feel a sense of ownership for the system and not rely on outside crutches to provide day-to-day operation support.

The final step in gearing up for MRP II implementation is to set performance goals. Specific improvements in key metrics, such as inventory accuracy and labor productivity, should be determined before the project sets out so that the near term goals are clear and progress can be evaluated in an objective manner. This concludes the company preparation and leads into "Month Zero" of the actual 15 month installation.

As stated above, the focus of the effort should lie with the people, not the computer program. The most thorough method of accomplishing this is through education of the entire workforce. All employees need to understand how their jobs will change as a result of the new system, especially managers who need to develop informed leadership. The initial education phase should involve both fact transfer and some impetus for behavioral change. Later, ongoing education should be developed to introduce new employees to the system and to refresh the skills of veteran workers so that the company talent base can continue to gain strength.

At the heart of the implementation path, the definition of sales, logistics, and manufacturing processes comprises a detailed description of how the company will function under MRP II. The average company will most likely construct a list on the order of 500 tasks required to accomplish this. The Steering Committee simultaneously works to develop revisions to company policies and procedures for planning and control that must accompany any changes in operations.

Data management is also an important aspect of the implementation. Without a high level of record accuracy, MRP II's sophisticated material and schedule manipulation will be meaningless. Inventory accuracy (that is, the computer balance sheet matched to a physical count) of at least 95 percent is required to generate useful MPS and MRP results, while the minimum BOM accuracy is 98 percent.[21] During the arduous task of reconciling inventory counts, opportunities for the improvement of physical processes, such as in bin location and addressing, should be considered if possible to aid future inventory control.

Software acquisition, installation, and maintenance can consume a considerable amount of time in the schedule if the company allows it to. The simplest way to avoid unnecessary repetition of existing effort is to purchase an off-the-shelf commercial product designed for MRP II use in the particular company environment. In-house software development usually ends up being excessively costly, time-consuming, and risky, all factors that hinder the program's eventual success. Instead, energy should be focused on determining software requirements. This analysis should generate a list of criteria to evaluate each package, considering individual company profile factors such as business volume, product complexity (in terms of number of parts and number of part numbers), production variability, and the need for integration with existing systems. The aerospace and defense sector's unique cost reporting requirements must also be addressed in order for the system to be useful for doing business with a government customer (see section 8.3.2). So many adequate commercial software packages are on the market today (nearly 300), with options changing so rapidly, that a recommendation of a specific product is futile and would be hopelessly out of date within a short time. In general, the

---

21 Wallace, pp. 129, 137.

choice of an off-the-shelf program should involve requests for quotes, visits to vendors, and discussions with current users at reference sites. Each option should then be evaluated according to the list of predetermined criteria.[22] A range of products will probably fit the company's needs, so the final selection should focus on a software firm with a proven track record that will be able to provide customer support and ongoing update releases.

Once the software is installed, the data integrity established, and the other numerous process planning tasks addressed, the company is ready to initiate actual MRP II operation. Beginning with a reduced scale "conference room" pilot allows the team to test as many process transactions and scenarios as possible with "dummy" data so as not to disrupt company operations. A full computer test should also be performed to assure that the software is functioning correctly and that all bugs have been removed. Only upon successful completion of as much testing as the schedule will allow should MRP II be introduced to "live" data from a selected pilot program. This phase is often the most frustrating, since the introduction of live data will no doubt bring about unanticipated problems, and at the same time the most exciting, since the rewards of the implementation process will begin to be apparent.

After this substantial effort is completed, the team should continue to percolate MRP II throughout the company via systematic introduction of the system to one program at a time, a process known as "cutover." The performance measures determined in the early stages of the implementation should be used to track actual results and compare them to the company goals. Another audit and assessment, evaluating the new company situation, brings the Proven Path full circle and provides an opportunity to move towards future improvement initiatives.

Virtually all companies who follow the Proven Path diligently should end up with a Class A or Class B implementation.[23] The exact timing and sequence of the method elements depends on the current state of the company, for instance, if some steps are already in adequate shape. While the fundamental premises of MRP II should remain inviolate no matter what the company particulars, the set of tools used to implement the system can be

---

22 Lengyel, Alexander and B.J. Bastow, "Key Issues Needing Resolution During MRP II Implementing in Aerospace and Defense Companies," *Thriving on Change*, Proceedings of the APICS Los Angeles - Aerospace and Defense Special Interest Group 1991 Annual Conference, Los Angeles, CA, May 13-15, 1991, pp. 284-285.

23 Wallace, p. 26.

tailored to fit individual characteristics. Examples of situations that would warrant adaptation of the Proven Path include flow shops, in which operations consist solely of processing instead of manufacturing (i.e. chemicals, food) or are highly repetitive (i.e., automobiles). In this case, detailed operation-by-operation job shop scheduling can be eliminated. Companies that are re-implementing MRP II to move from Class C/D to Class A/B may skip steps which are already under control. Likewise, multi-plant operations seeking to implement MRP II at more than one site can overlap steps but should avoid having more than one pilot or cutover at a time. As mentioned above, companies specializing in non-standard manufacturing functions (i.e., pharmaceuticals, defense, shelf life products) may need to modify or expand the software to account for their specific needs.[24]

4.4 MRP II in the Future

Despite its longevity as a manufacturing tool, MRP II software functionality is anything but stagnant; many exciting advancements to improve use are on the horizon. Future MRP II systems will be much better at addressing current business needs than their predecessors, and the software will continue to grow to accommodate new needs as they become identified. For example, the ability to perform batch processing every hour will get managers the information they need for strategic decision-making in a much more timely manner than today's nightly or weekly runtime limitations. Software developers are working to incorporate recent advances in database client/server technology to promote the free flow of data across organizations. The addition of a graphical user interface (GUI) to replace the highly technical and cumbersome front-end found in some current packages will make MRP II more user friendly and promote acceptance among employees without previous computer experience.[25] New tools for total quality management (TQM) and continuous process improvement will be incorporated into the MRP II framework, while systems built around "expert system shells" will use artificial intelligence to adapt the system to how the company does business.[26]

---

24 Wallace, pp. 36-40.
25 Chamberlain, p. 27.
26 Haupt, p. 114.

Chapter 5 Relationship Between Engineering Change and MRP II

Engineering change can never be completely eliminated from the design process since all development efforts will encounter unforeseen events on the path from the drawing board to the finished product. The experimental nature of engineering design lends itself to a cycle of testing and rework as the design matures. However, the later that a change occurs in the development timeline, the larger the impact it will have. Manufacturers must learn to manage unavoidable changes so that their effects on cost and schedule are minimal. With each change order summing to upwards of several tens of thousands of dollars in administrative costs alone, any avoidable changes should certainly be eliminated. The defense contractor has the added challenge of meeting strict government guidelines on the treatment of changes. An efficient material control system, such as MRP II, can permit changes to be accomplished with as little disruption and burden as possible. This chapter addresses the character of engineering changes in military contracts, paying special attention to means for incorporating the process into the company's MRP II system to smooth the impact of configuration changes.

5.1 Engineering Change in Government Contracts

The Department of Defense Military Standard for Configuration Management (MIL-STD-973[1]) defines the requirements for engineering changes in government contracts. An engineering change proposal (ECP) must be submitted and accepted before any changes are made to the current approved configuration documentation. This includes changes generated by either the contractor or the customer. If the contract is segmented in a prime/associate relationship, companion ECPs may be needed to coordinate changes to one system driven by changes in other subsystems. This section describes the nature of engineering changes in military contracts in terms of the types of changes typically encountered, the effects of timing, and the government requirements for configuration management and documentation.

---

[1] U.S. Department of Defense, *Military Standard: Configuration Management (MIL-STD-973)*, Section 5.4.2: "Requirements for Engineering Changes," April 17, 1992, pp. 34-51.

5.1.1 The Nature of Changes

The mix of changes originated by the customer versus by the contractor is highly program dependent. Typically, true "engineering" changes involving part functionality come from the company, while variations in the scope of work originate with the government. The timing of changes greatly affects the extent of their impact on cost, schedule, and manufacturability. During the development phase, before the Critical Design Review (CDR) milestone, designs are still flexible, and changes, for the most part, impact only the internal workings of the engineering department. The most common development changes concern modifications to the contract specification, such as customer requests for a particular configuration not envisioned during the design process. Limitations in the capabilities of selected vendors may also require rework. System integration, the assembling of components and subsystems into a workable unit, can also produce changes involving the interface between various pieces. Many of these problems emerge during testing. For example, fit problems in the wire harness of an electronic device are often discovered during the testing of prototype hardware, such that adjustments have to be made in wire lengths, signal routing, or power supply interference patterns.

After the customer has approved the prototype operation and production has begun, however, changes are much more difficult to accomplish. A Functional Configuration Audit (FCA) and Physical Configuration Audit (PCA) are performed on every part number in the specification. After the product passes these milestones, the design is fixed in the sense that any changes to its configuration documentation must be approved through the formal ECP process. Upon the delivery of the first article to the customer, strict rules on the form, fit, and function of each part apply, and the contractor is expected to keep tight configuration control. The majority of changes at this stage are discovered in manufacturing and testing. Poor connector fits or bad lots of material can cause manufacturing problems. Differing characteristics of vendor parts may result in unexpected test failures. Changes during production may impact previously manufactured units and require retrofitting. The mountain of documentation that has accumulated up to this point, including the specification, drawings, the BOM, the parts list, and technical and repair manuals, must be updated to reflect the new configuration. Development tests must be repeated to demonstrate continued compliance of specification requirements. All this can cause considerable expansion of both schedule and cost. If post-FCA/PCA changes are originated by the customer, the contract must be re-negotiated, often resulting in additional financial awards to the contractor.

5.1.2 The Change Process

MIL-STD-973 requires the contractor to follow eight steps when making any engineering change, as shown in table 5.1. The first step is the determination of the need for change, in which the problem is identified. The contractor then establishes the classification of the change as either major (Class I) or minor (Class II) (see section 5.1.3.1).

Table 5.1: Configuration Control Process
Source: MIL-STD-973, section 5.4.2.1, p. 34.

Step	Operator	Action
1.	Contractor or Government	Identification of the problem.
2.	Contractor	Classification of the change as Class I or Class II.
3.	Contractor	Review and evaluation.
4.	Contractor	Engineering management approval.
5.	Contractor	Preparation of an ECP for submittal to the government.
6.	Government	Review of ECP by the Configuration Control Board.
7.	Contractor and Government	Incorporation of approved changes into the configuration documentation or, if needed, negotiation into the contract.
8.	Contractor	Implementation of the change.

The most complex step from a technical perspective is the review and evaluation of the change. Engineers gather data to analyze the merits of potential approaches to solving the problem and eventually reach solution concurrence. If their management agrees to the selected solution method, the change is dispositioned and thereby enters formal configuration control review.

Engineers usually prepare the technical portion of the ECP, while configuration management personnel examine the overall impact of the change and spearhead efforts in other departments, such as integrated logistics support (ILS), that need to provide inputs. An internal configuration committee often reviews the final ECP, which can amount to several hundreds of pages, before it is submitted to the customer. Separate ECPs are required for each engineering change that has a "distinct objective," which keeps unrelated changes from being processed on the same form. Supporting data such as drawings, cost proposals, test data, and analyses are included to describe and justify the change and to determine its total impact on the system.[2] Revisions to previously approved ECPs may consist of only the revised pages as long as the change is minor.

After the ECP is submitted, it is reviewed by a government Configuration Control Board (CCB) comprised of technical and administrative representatives from the Contract Administration Office. The government CCB evaluates the ECP and recommends approval or disapproval of the proposed change.[3] If the ECP is not approved, the contractor is notified in writing within 30 calendar days from the decision.[4] If the change is accepted, it is incorporated into the configuration control documentation. If the change was customer-originated, the contract may need to be re-negotiated to encompass any work outside the scope of the original agreement. Finally, the change is implemented according to the plans laid out in the ECP. Implementation strategies for part replacement vary, but usually one of four approaches is followed.[5] If the change is needed to correct a problem with a product in the field, the change is often made all at once. Although this method is the easiest to schedule, it is expensive and can be disastrous if all the old material is not found and scrapped. Defining an "effectivity date" after which the old version can't be used is another fairly straightforward arrangement but may be hard to accomplish in a timely manner if material is located in remote storage places. If production is on-going, similar method consists of determining a cut-in unit number after which the change is incorporated into future lots. The use of an effectivity date or cut-in unit number assumes that the change is not critical for earlier versions already in use. The fourth strategy involves using up all available material and then phasing in the change. This method is the most difficult to accomplish, but a computer scheduling tool such as MRP II can help to keep schedules up to date (see section 5.2.2).

5.1.3 Government Requirements

The government requirements for ECP preparation laid out in MIL-STD-973 include four major identifiers: classification, justification code, type, and priority. The choices for each are defined below, accompanied by a description of the ECP document itself.

---

2 MIL-STD-973, §5.4.2.2.3.1-5.4.2.2.3.3, pp. 36-37.
3 MIL-STD-973, §3.20, p. 8.
4 MIL-STD-973, §5.4.2.3.1.4, p. 39.
5 Wight (1984), p. 290.

5.1.3.1 Classifications

As table 5.1 shows, Step 2 of the configuration control process is the classification of the change by the contractor as either Class I or Class II.[6] The majority of ECPs are labeled Class I, which requires government approval before the change can be implemented. These are major changes with mandatory re-identification of the part numbers involved. A change must be considered Class I if one of the following conditions is met:[7]

- Changes that cause technical requirements in the specification (performance, reliability, physical characteristics, interface, etc.) to fall outside specified limits or tolerances.
- Changes that impact government furnished equipment (GFE), delivered operation and maintenance manuals, preset adjustments affecting operating limits, or training.
- Changes that affect interchangeability, substitutability, or replaceability.
- Changes that affect compatibility to the extent that retrofit action is required.
- Changes that impact safety, biomedical factors, or human-engineering design.
- Changes that affect the cost to the government, contract guarantees or warranties, contractual deliveries, or scheduled contract milestones.

Although this list appears quite exhaustive, DOD stipulates that Class I changes "should be limited to those which are necessary or offer significant benefit to the government."[8] Examples of changes warranting Class I status include those that correct design or performance deficiencies, significantly improve logistics supportability, generate substantial life cycle cost savings, or prevent schedule slippage.

Class II ECPs cover minor alterations to the configuration, such as a change in vendor, and do not require customer approval. Since Class I changes involve government oversight, their reporting obligations are naturally more stringent. A Class I grade is assumed in the following discussions of ECP requirements.

---

6 In cases where the classification is in dispute, the government decides the outcome, as per MIL-STD-973, §5.4.2.2.1, p. 34.

7 MIL-STD-973, §5.4.2.2.1a, pp. 34-35.

8 MIL-STD-973, §5.4.2.3, pp. 37-38.

5.1.3.2 Justification Codes

Each ECP is given a justification code to indicate the nature of the change, as shown in table 5.2. The definitions of the eight codes (lettered nonsequentially) overlap somewhat. Code B covers changes that eliminate interface disconnects. Compatibility, Code C, acts to correct deficiencies discovered during testing or installation that must be rectified in order for the system to work. Code C changes should be within the scope of the existing contract and not involve any increase in contract price. When the elimination of a dangerous condition is used to justify an ECP, safety Code S is marked and must be accompanied by a system hazard analysis. Code D is used for correction of any general deficiency where Codes B, C, or S do not apply. Operational or logistics support alterations, Code O, entail significant effectiveness changes in these functions. Code P, production stoppage, prevents schedule slippage when production with the current configuration is impractical or will result in a delay. Changes that provide life cycle cost savings to the government are submitted under Code V if a value engineering contract clause is invoked, otherwise under Code R (cost reduction).

Table 5.2: ECP Justification Codes
Source: MIL-STD-973, § 5.4.2.3.2, pp. 39-40.

Code	Covers ECPs Involving...
B	Interface
C	Compatibility
D	Correction of Deficiency
O	Operational or Logistics Support
P	Production Stoppage
R	Cost Reduction
S	Safety
V	Value Engineering

5.1.3.3 ECP Types

Class I ECPs are divided into two types: preliminary (Type P) and formal (Type F).[9] As will be shown in section 5.1.3.5, formal ECPs provide detailed engineering information

[9] MIL-STD-973, §5.4.2.3.3, p. 41.

to support approval by the CCB and subsequent contractual implementation. Preliminary ECPs, on the other hand, are submitted to the government for review prior to the availability of information needed to support a Type F document. The Type P change notice includes a summary of the proposed change and its impact on related areas. This allows the customer to perform an initial evaluation of the change or to compare alternate proposals. In this way, the value of continuing the development of complete documentation is assessed before the investment is dedicated. Type P documents can also provide alternate proposals or supplement data submitted in an earlier emergency or urgent priority ECP.

If the definition of change topics is vague, an Advance Change Study Notice (ACSN) may be submitted. Similar to the preliminary ECP, this one-page form is sent to the government for approval before an official proposal is written.[10] ACSNs typically consider changes that might improve performance or reduce cost.

5.1.3.4 ECP Priority

The CCB's decision time is based on the criticality of the need for the change according to three priority categories.[11] If national security is at risk or there is an immediate danger to life, the ECP is given emergency status and evaluated within 48 hours. The same rating applies if the change is needed to prevent extensive equipment damage or to correct a system halt. Potentially hazardous situations or ones with significant cost or schedule impact are classified as urgent, with resolution taking place within 30 calendar days. Routine processing for all other changes takes 90 calendar days.

5.1.3.5 Documentation

All Class I changes must be submitted on DD Form 1692.[12] The first page of this form is a cover sheet that summarizes the ECP and provides information such as the following:

- Date
- Title and description of change
- Need for change

---

10 MIL-STD-973, §5.4.2.3.3.1.2, pp. 41-43.
11 MIL-STD-973, §5.4.2.3.1.1, p. 38; § 5.4.2.3.4, pp. 43-45.
12 MIL-STD-973, §5.4.2.2.3, p. 36; DD Form 1692, *Engineering Change Proposal*, is reproduced in Appendix D on pp. 163-169.

- Affected contract numbers and line items
- Classification, justification code, type, and priority
- ECP designation: identification #, ECP #, revision # (if applicable)
- Specifications, drawings, and lower level items affected
- Other systems or items affected (if yes, will require submittal of related ECPs)
- Effect on production delivery schedule
- Estimated costs or savings

The remaining six pages of the form provide back-up material to the cover sheet. Their inclusion depends on specific circumstances and the life cycle phases involved in the change, according to the criteria in table 5.3.

Table 5.3: Engineering Change Proposal Documentation
Source: MIL-STD-973, Appendix D, pp. 163-169.

ECP Page	Title	Criteria for Inclusion
1.	ECP Cover Sheet	Mandatory.
2.	Effects on Functional/Allocated Configuration Documentation	Change affects system specification or item development specification.
3.	Effects on Production Configuration Documentation, Logistics, and Operations	Change in performance, training, operation, support, etc.
4.	Estimated Net Total Cost Impact	Change to contract cost.
5.	Estimated Costs/Savings Summary, Related ECPs	Cost impact extends to related ECPs.
6.	Milestone Chart	Schedule change in more than delivery date for item.
7.	Milestone Chart	Schedule change involving software-intensive activities.

5.2 Using MRP II to Cope with Change

While commercial manufacturers have always faced variable orders that fluctuate with market reactions, the defense industry has dealt for most of its existence with a relatively consistent, albeit cyclical, market. Now that the demand has been substantially reduced by defense downsizing and does not appear likely to rejuvenate, many military suppliers are not prepared to compete under the same rules that the rest of the world has grown accustomed to facing. Constrained by the demands of government oversight and documentation, they end up with production systems that are not as flexible as their commercial counterparts. MRP II, with its built-in mechanism for the continuous updating of schedules based on real-time priorities, gives companies a decided advantage in dealing with a constantly changing environment. MRP II's most obvious aid to configuration control is its ability to track exactly which part numbers are found on every unit in development, in production, and in the field. Configuration changes can therefore be inserted into the proper items with a minimum of organizational effort. However, the system's contribution to managing engineering change goes much further than mere automation. Reliable information flow, rapid response to a variable schedule, and the ability to test options through simulation are the keys to effective planning and coordination of engineering change provided by MRP II.

5.2.1 Reliable Information Flow

A company that is processing a high number of engineering changes, only to modify them a short time later due to unexpected conflicts, is not in control of change; its efforts are being needlessly expended on redundant and unnecessary work. Likewise, a company that processes only essential changes will still be ineffectual if the changes take an exorbitant amount of time to be implemented. In order to insure that changes are both necessary and timely, all functional areas need to be working from the same set of data, and that data must be reliable. Equally important, all must consider the perspective of their fellow employees in other departments when making configuration decisions. Organized in the manner of an integrated product development (IPD) team, both the engineering and manufacturing functions need to be brought into the configuration team from the start. Likewise, the involvement of people from planning, purchasing, marketing, and finance will help make sure that the results obtained are the ones desired. Unpleasant surprises due to lack of coordination and foresight can be eliminated. In particular, engineering input is crucial to the creation of reliable schedules and to keeping the BOM a valid control document.[13] MRP II's computer database guarantees that the schedule information available to engineering when considering part lead times for a configuration change is identical to the delivery date towards which manufacturing is aiming. Easy access to the system from all areas of the company promotes interaction and consideration of potential conflicts before they occur.

---

13 Wight (1984), pp. 57, 292.

5.2.2 Improved Introduction of Changes

MRP II can aid the phase-in of ECPs by assigning an effectivity date after which the system shifts plans from the old configuration to the new. The MPS is therefore kept up to date without relying on individual revisions to each document affected by the change. Other methods for managing the introduction of changes include lot number control. Custom programming of the MRP II system can schedule an ECP to take effect with the production start of given lot number. Timing of the lot can then be adjusted to meet requirements as needed so that the optimal change-over date is mapped into the MPS and followed throughout the plant.

5.2.3 Simulation Capabilities

MRP II's simulation capability is invaluable in the analysis of engineering change. The impacts of the change relative to inventory balances, part lead times, obsolescence, cost, and other factors can be evaluated before the final solution is formulated.[14] Since the tests involve only virtual material stores, alternatives can be tested without the need for costly ECPs or ACSNs or the delay associated with government review. Compromises between manufacturing and engineering considerations can be measured ahead of time. Finally, the freedom of exploring in a riskless, real-time environment leads people to pursue creative alternatives ordinarily discarded when pressures mount. The very exercise of testing options is sure to generate further sources of interaction between functions not readily apparent with paper analysis alone.

---

14 Wight (1984), p. 292.

Chapter 6 Case Study: AIL Systems Inc.[1]

The history of MRP II at AIL Systems Incorporated provides a unique look at exactly what goes into getting such a system up and running. The problems the team encountered are representative of those that would arise for any small to mid-sized aerospace firm. The system helped the company meet the demands from its largest contract ever during the late 1980s and now acts to keep them competitive during the current market downsizing. This chapter contains a step-by-step timeline of the project and comments on the barriers that AIL faced along the path to full-scale MRP II insertion. The perspectives of top management, shop floor, and administration are considered, along with government impressions of the project.

6.1 Company Background

Founded in 1945 as the Airborne Instruments Laboratory and currently a subsidiary of the Eaton Corporation, AIL is a mid-size electronics manufacturer with an almost exclusively military product line. AIL's single plant, located in Deer Park, NY, serves as a self-contained operation providing full in-house capability for development, fabrication, assembly, and testing. Major products include electronic warfare systems for the B-1B bomber and tactical jamming systems for the Navy EA-6B. Future plans hinge on the aggressive pursuit of diversification growth in the civil and commercial markets.

AIL has not escaped unscathed by the decline of the U.S. defense base. As is typical in the industry, AIL's business volume has been steadily decreasing over the last few years. Sales totaled $191M in 1993, down from a high of about $800M in the mid-1980s. The work force has also shrunk by a comparable proportion during this time frame and now stands at about 1100 employees. To combat the adverse effects of downsizing, the company underwent a major reorganization and streamlining process to increase competitiveness. AIL heavily promotes its commitment to "continuously improve

1 Chapters 6 and 7 were prepared following in-depth interviews with AIL personnel over the course of two site visits conducted on March 23-24 and June 13-14, 1994. Pete Wilbur (MRP II project manager) and Rob Clark (Policy and Procedure Committee chairman) provided detailed information on the implementation process. Acknowledgment also is due to AIL staff from the Production Inventory Control, Integrated Management Systems, and Production Engineering departments who participated in interviews and demonstrations, especially Dave Campbell, Angela Contratti-May, Gary Gurick, Al Henneborn, Stu Kratky, Pat Muller, and Doug Winn. Finally, Gordon Corlew, Vice President of Engineering and Production, provided the initiative for this thesis project and contributed his perspective as the AIL "torchbearer."

everything," exemplified by a vigorous total quality management (TQM) program known as "AIL 2000." The success of the program was acknowledged in 1994 when AIL received the New York State Governor's Excelsior Award for organizational excellence and quality. While numerous activities to modernize business practices have been initiated as part of the project, the implementation of MRP II is one of the most visible and substantial manifestations of this vision.

6.2 History of the AIL Implementation

From the original software purchase to company-wide operation, the history of MRP II at AIL spans nearly a decade. Various forces were at work over the course of these years both to hasten and to hinder the process. Although MRP II software was purchased in 1983, it wasn't until late 1988 that a dedicated team was organized in order to fully implement the method. To a large degree, the ultimate success of the system implementation rested with Mr. Gordon Corlew, Vice President of Engineering and Production, who was brought in from the Eaton parent corporation in 1985 in part to introduce the business practice and cultural changes necessary for an MRP II system to succeed. This creation of a conducive environment was the key to AIL's achievements.

A wealth of detail on the history of MRP II at AIL can be found in company records, with progress during particularly intensive periods being measured almost on a daily basis. The timeline in figure 6.1 shows the course of the project in summary fashion. A step-by-step account is provided below.

6.2.1 Starting Point

Before the MRP II implementation, AIL's tradition of inventory management could be defined as a push system; if not enough output was being produced, the plan called for more input to be "pushed" into the flow at earlier and earlier intervals. Inventory levels were very high, but at the same time the production floor was always short of material. Adherence to schedule was also poor. The top priority for inventory support personnel was tracking work in process (WIP), an extremely difficult task given the lack of control over inventory accounting and management. For example, factory capacity for printed wiring boards (PWB) production was 150 units per day, but the WIP consisted of 13,000 boards. The process was almost totally manual, and a tremendous amount of time was spent finding and fixing problems.

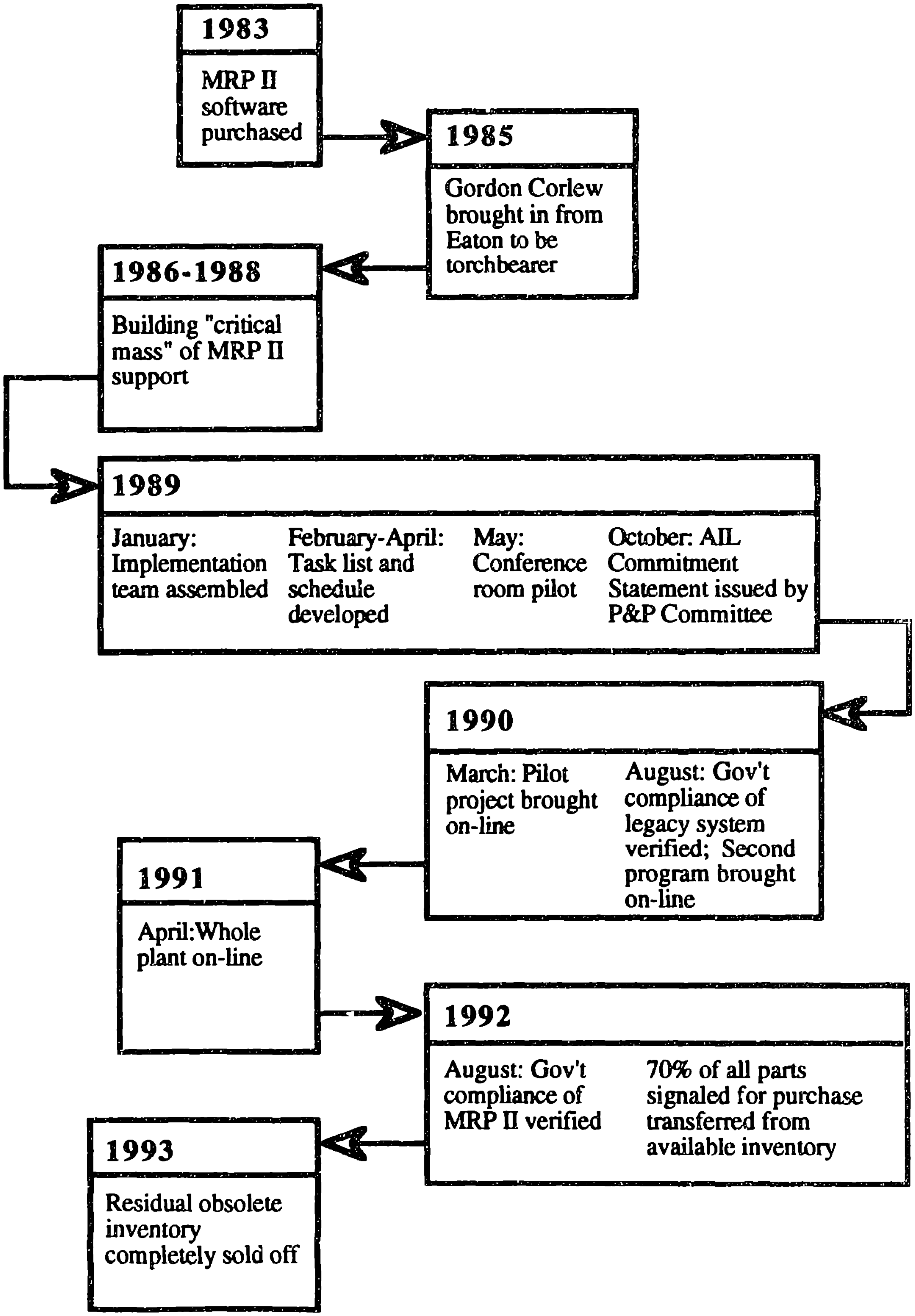

Figure 6.1: AIL MRP II Implementation Timeline

Poor material control was especially evident in the stockroom. The bill of materials submitted by the planner did not indicate if parts were in stock, so stockroom workers often searched for parts that were not there. Since processing a parts request list took at least 30 days, planners gradually began to drop off their orders up to eight weeks in advance, resulting in further backlog. Inventory in the stockroom was segregated by program, with no commingling of common parts. Material was stored in part number sequence by program, without a bin location system or bar-codes to track individual parts. All kits were rechecked by verification section personnel, and errors were frequent. Short kits could sit as long as six months before being completed. Formal physical inventory counting was conducted on an exception-only basis when mandated for cost plus contracts. Even when a full manual count was performed, its accuracy was only about 75 percent. Consequently, the computer system was often not synchronized with the physical count. Corrections, when performed, would fix the computer records without addressing the root cause of the problems. The attitude in the stockroom was in general to fend off criticism instead of looking for solutions to their myriad of inventory control difficulties.

6.2.2 First Efforts: 1983 to 1985

Although AIL purchased its MRP II software in 1983, installation was a low priority given the way business was booming at the time. Management focus lay in getting out the product and "fire fighting," or addressing problems only when they became a critical threat to maintaining production levels. There was no middle or top management support, let alone a torchbearer, to champion the introduction of new business tools. In 1985, Corlew was brought in from the Eaton parent company to fill this role when it became apparent that the current system was woefully inadequate to meet production demands. Despite corporate recognition of the need for change, at that time Corlew was the sole proponent of the use of MRP II as a solution.

6.2.3 Building Critical Mass: 1986 to 1988

Although Corlew was determined to update AIL's inventory control system, he soon realized that without a firm base of advocacy for MRP II among his fellow managers around the plant, a successful program would be unattainable. A brute force introduction of a new system would without a doubt fail, especially since that, while Corlew was in charge of manufacturing, he did not have managerial control of purchasing, receiving and storage, or the stockroom. The decision was then made to postpone a classic implementation until a "critical mass" of support was reached. In the meantime, the MRP II software modules for bill of materials and shop floor control were installed as a temporary measure. In 1987, the low level effort to scope out possibilities for the new inventory system ran into significant opposition due to negative publicity in industry journals. One aerospace company using a basic version of MRP software came into conflict with the government regarding proper allocation of costs to various contracts and was required to turn over large amounts of data to prove the integrity of its system. Fear of a similar episode at AIL further eroded management confidence in Corlew's approach.

The introduction of the government's Materials Management Accounting System (MMAS[2]) provided a key breakthrough in the mistrust of MRP II in the industry. Representatives from the American Production and Inventory Control Society (APICS), an industry working group, were members of the Blue Ribbon panel that developed the MMAS 10 Key Elements and designed the requirements with MRP II in mind. In fact, the nature of the requirement made it hard for companies to comply without using MRP II. AIL realized that progress payments would be withheld if the company didn't start working in the same direction as the new government approach. At the same time, management was gradually becoming aware of the many problems that the current lack of control created and realizing the inadequacy of reliance on stop-gap fixes. By late 1988, a project team, led by Corlew, was assembled to address the comprehensive implementation of an MRP II system that would integrate MMAS requirements into the fabric of the company's new material management system. Critical mass had been reached.

6.2.4 Team Endeavors: 1989 to 1990

The two-year implementation effort was extremely fast-paced, involving intricate planning at all levels. Wallace's *MRP II: Making It Happen* was used as a handbook for the project, so the plan adhered for the most part to the Proven Path described in chapter 4. The process can be described in three basic phases: educational preparation, software integration, and pilot program execution. This section describes each phase component of the plan in detail, along with details on the team organization, general approach, and policy decisions that meld the program together.

2 U.S. Department of Defense, *Defense Federal Acquisition Regulations Supplement (DFARS)*, "Materials Management Accounting System (MMAS) Standards," §242.72.

6.2.4.1 Team Composition

The MRP II implementation team, organized as in figure 6.2, was created in January 1989. The Executive Steering Committee, chaired by AIL's president and comprised of Corlew and other key senior staff, met monthly to discuss the impact of high-level issues and to recommend actions for their resolution. A parallel management committee focused on policy and procedures was made up of representatives from production control, accounting, and material control. This group met weekly to decide functional and business issues and to incorporate changes into the company policy and procedure bulletins (see section 6.2.4.3). The project manager (PM) was responsible for all day-to-day operations and oversight of team activities. Both the PM and the chairman of the Policy and Procedure Committee met with the Executive Steering Committee each month to coordinate team activities. The members of the project team itself were pulled out of their regular positions to act as full-time dedicated resources to the MRP effort. Team members were chosen for their abilities as key support people in manufacturing, materials, finance, industrial engineering, and information technology. The team was distributed into subgroups to focus on the five MRP II modules (see section 6.2.4.6). In addition, a government liaison was involved from the outset to coordinate joint efforts for training and to address specific issues relating to MMAS compliance.

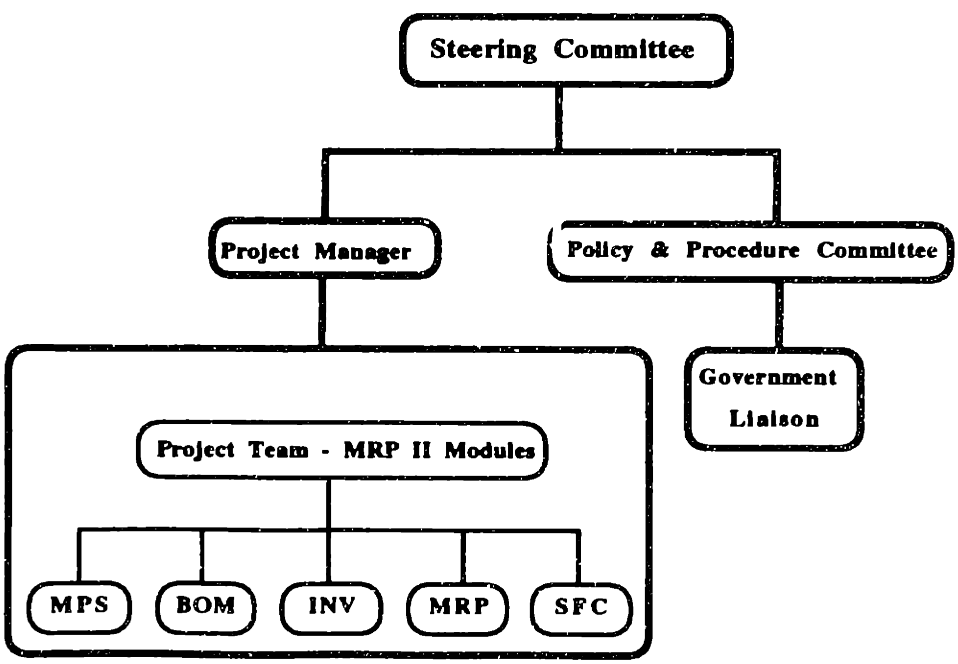

Figure 6.2: MRP II Implementation Team Organization Chart

6.2.4.2 General Approach

The team's first step upon convening in January 1989 was to develop a master schedule for the implementation project, along with a detailed breakdown of all tasks to be accomplished. The overall project plan is summarized in figure 6.3, and the details of each phase are explained in the subsections below. Since it wasn't feasible for the company to convert the entire plant to a new inventory control system at one time, AIL decided to bring one production program at a time on-line to enable them to maintain commitments to their customer. As suggested in the Proven Path, a fifteen-month deadline for completion of the first round of installation was determined as the optimal timeline to sustain momentum and interest. March 1990 was therefore designated the target date for implementation of the pilot program. A smaller scale "conference room pilot" was scheduled prior to the full pilot to insure that the software was fully operational. A "break-in" period of several months was added between the pilot program and subsequent implementation in other business segments to confirm that the results from the first installation met expectations. Considerable effort was placed on developing a tight correlation between company data and system requirements; information technology team members were given the tasks of correcting the errors pervasive in the previous, or legacy, system and developing the software environmental structure. Project publicity, education, and system training to generate user awareness, confidence, and competency were on-going.

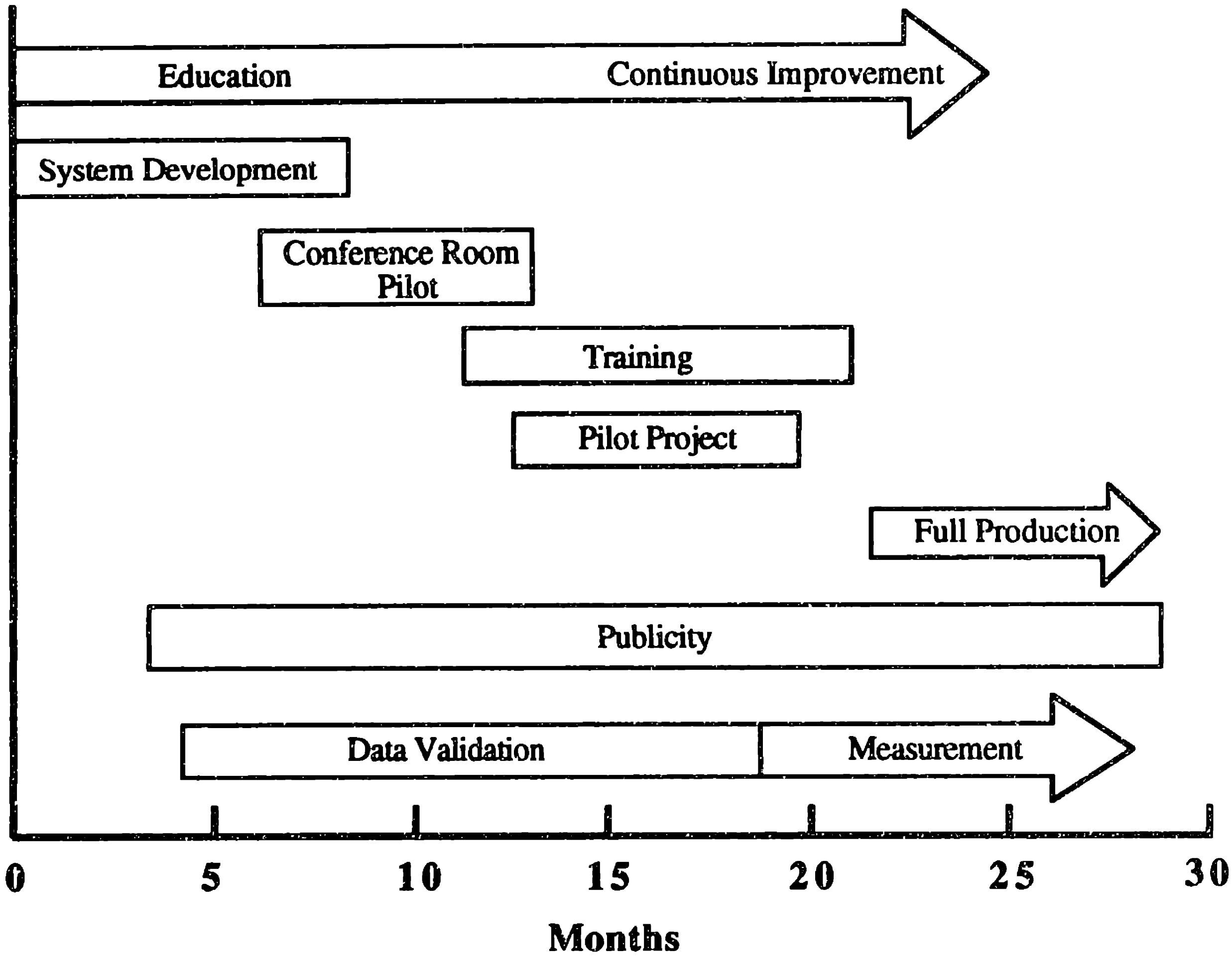

Figure 6.3: Implementation Plan

6.2.4.3 Policy Issues

The Policy and Procedure Committee formulated many policies critical to the cultural success of the project. A high degree of material and schedule accuracy alone would not have been sufficient to overcome the corporate inertia inherent in processes that had been stagnant for long periods of time, as was the case with AIL's legacy inventory management system. The Committee served as the driving force towards company acceptance of the need for change. Members, selected from all functions of the organization, had enough managerial clout to make decisions without constant corporate approval and yet were close enough to operations to maintain a balanced viewpoint.

The Committee's first formal policy statement was published in September 1989, asserting, "AIL will seek to fully utilize the advantages of our MRP II system." Consequences of this conviction included the introduction of electronic signature authorization, which obviated the requirement for signed requisitions on orders generated by the MRP II system. A company "commitment statement," excerpted below in table 6.1, was issued by the Office of the President a month later to convey management dedication to the MRP II approach. Senior managers were charged with familiarizing all employees not only with the use of the system but also the logic behind its philosophy. Company policy and procedure bulletins were updated to reflect MRP II use in September 1990 following full implementation, with copies of the revisions forwarded to the government.

Table 6.1: AIL Commitment to Manufacturing Resource Planning (excerpt)

It is the policy of AIL to effectively and efficiently utilize material, capital, personnel, and facilities in such a manner as to provide the greatest economy to AIL and its customers.

AIL is committed to an MRP II System which is based on:

- Efficient utilization of all AIL resources.
- Development of a basic logic for planning and prioritizing current and future work.
- Identifying and providing tools for managing.
- Meeting or exceeding the MMAS 10 Key Elements standards and guidelines.
- Providing world class manufacturing capability based on product integrity and honesty; a system in which an AIL customer can place its trust.

Among the group's many key policy decisions was the abolishment of part revision numbers in favor of interchangeability as the primary designation criterion (known as the "a part is a part" philosophy; see section 7.1.2). The Committee also worked to achieve seamless integration of the new system with existing automated functions and debated cases where replacement of previous in-house modules were warranted. Primary to this analysis was the affirmation that the MRP II software package would not be modified (see section 6.2.4.6). Cycle counting, a technique in which inventory is counted on a periodic basis with a frequency proportional to its value, was instituted to replace the costly but inaccurate annual full-scale physical count method, resulting in a procedure that AIL now considers to be "best in class" for the aerospace industry. Other crucial decisions include the determination of lead time components, the handling of safety stock, the extent of inventory commingling, and the selection of order policy rules. Policies were developed for these issues with the aim of addressing each item of the MMAS requirements to guarantee compliance of the new system. The Committee also developed a list of criteria to measure the success of the project (see section 6.2.4.7).

6.2.4.4 Education

Education and training requirements were given a great deal of up-front attention to insure a smooth transition from the existing system to MRP II for the users. Members of the implementation team, including the Policy and Procedure Committee, attended a week-long training class offered by the Oliver Wight Education Associates consulting group as part of their introductory preparation. A full time training director was hired in June 1989 to coordinate user education. The users associated with the pilot program attended consultant-run training camps to become fully versed in system operations. They in turn trained other employees company-wide, since in general workers were more receptive to training by their peers.

An advertising campaign was initiated to promote involvement and support for the project across the organization. Frequent newsletter articles, MRP II "Question of the Month" notices, pictures, and slogan buttons served to reinforce the project ideology that knowledge shouldn't be limited to the core group of team members. While not all employees were trained in the operating procedures of the system, nearly all received exposure to the basic concept. The main purpose of the publicity effort was to disabuse personnel outside the materials management departments, especially those in program management, finance, and engineering, of the notion that the project didn't have anything to do with them. A company-wide commitment to change and improvement was seen as a key attribute to the success of the MRP II initiative.

6.2.4.5 Government Interaction

The participation of government representatives was encouraged throughout the project, beginning with customer training that focused on evaluation of MMAS compliance. Since the requirement had to be met as soon as possible, team members worked simultaneously on demonstrating compliance of the current system while developing its replacement. The company planned to validate MRP II as soon as the system was fully operational, so government input concurrent with implementation served to expedite this goal. To this end, representatives from the resident Defense Contract Audit Agency (DCAA) and the Defense Plant Representative Office (DPRO[3]) received project updates initially on a monthly basis, increasing to weekly as the program developed. Government agents also had complete access to the system through their own computer terminals. MMAS compliance of the legacy system was officially verified in August 1990, with approval for the MRP II system coming in August 1992. Negotiations with the government were also undertaken to resolve various accounting issues that arose over the course of the implementation, such as how to value parts made under the legacy system. AIL also conducted "road shows" to demonstrate the efficiency of the new system directly to the customers of their products (government buyers), who in turn communicated their enthusiasm to the government oversight officials. Although most negotiations with the government ended positively for the company, issues occasionally became mired in delays. For example, a request for blanket authorization of material transfer took six months to be approved after the company had revised its original proposal to satisfy government concerns.

6.2.4.6 Software

As the backbone of any MRP II system, the computer software deserves attention in its own right. In 1983, AIL purchased the C/PIOS software (Contract/Production Inventory Optimization System) developed by Rath & Strong.[4, 5] The program is written in the COBOL programming language and runs on an IBM mainframe computer. The software consists of five stand-alone modules (see figure 6.2): master production schedule (MPS), bill of material (BOM), inventory (INV), material requirements planning (MRP), and

3 The DPRO has since been renamed the DCMAO (Defense Contract Management Area Operations).

4 The software company was subsequently bought out by a competitor, Andersen Consulting, who supported C/PIOS for a year before taking it off the market. AIL had completed system installation and testing by that time, although they are now without product support.

5 Although a number of years passed between the original purchase of the software and the decision to implement MRP II, AIL decided not to reinvest in a newer package due to the high cost and the fact that several modules were already in place within the company. AIL plans to replace C/PIOS with a new package, one able to run in real time on a minicomputer using relational database technology, within the next several years.

shop floor control (SFC). Each module is tested separately and then integrated to form the complete MRP II system.[6]

While other products may have had superior functionality in various modules, C/PIOS was selected for its explicit aerospace and defense focus. In particular, it was one of the few packages available which included the ability to segregate material by contract, a required feature for meeting government accounting standards. In 1989, a significant upgrade (version 4.1) was delivered to fit the system to the government's MMAS requirements. The AIL system was configured to set up "invisible walls" around material belonging to isolated sectors, or "plants." For instance, inventory belonging to Air Force contracts had to be accounted for separately from that for Navy jobs. The C/PIOS contract pegging function delivered in version 4.1 allowed inventory to be traded automatically to meet schedules among contracts within such walls. Government concern about proper accounting across military services was thereby assuaged. The pegging capability also proved fortuitous in dealing with the potentially obsolete material left in various locations around the factory from past contracts. In order to avoid contamination of the new MRP II system, this inventory was isolated in a separate plant and the residual eventually sold off over the next three years.

As emphasized in the Policy and Procedure Committee charter, the approach mandated changing business practices to fit the system software, not the reverse. The first action in support of this goal was to restore the software to its original state, removing the alterations to modules that had been conducted in the past for stand-alone fixes. The development of interfaces to tie in to existing systems outside the C/PIOS modules, such as purchasing and accounting, were also extremely important to guarantee continuity across company operations. Even if no changes were made to the stand-alone systems in function, updates had to be made as to how access of other common areas, such as the BOM, would be accomplished.

In addition to creating custom reports for government and company use, information technology team members spent many hours identifying and correcting errors in the existing database. All of the 1200 errors found in the system were fixed by October 1990.

---

6 Since shop floor workers wouldn't know which critical ratios to follow if more than one system were operating within the company, AIL decided to postpone integration of the SFC module until the very end of the conversion program and then transition the whole plant at one time.

6.2.4.7 Pilot Program

The Universal Exciter (UE) product line, an aircraft-based defense electronics suite, was selected for the pilot program. Due to the strong need to prove the viability of MRP II as a substitute for the current system, AIL carefully chose a program that would guarantee success. The UE, comprised of a single box with a stable design, provided high volume (15 units per month) and a steady schedule on a fixed price contract that was financially successful.

As suggested in the Proven Path, "conference room pilot," a reduced scale mock-up for software and database testing purposes, was performed in May 1989. The one-week simulation tested "what if" scenarios and provided transaction training for planners preparing for the full-scale pilot. The conference room pilot proceeded as planned with few surprises. The resulting output was subsequently used as documentation of MMAS compliance.

Specific criteria for the success of the pilot program were developed in advance to measure progress, as shown in table 6.2. This list also served to evaluate the success of the entire implementation project. Important metrics included MMAS compliance, cost reporting by part number and program for material and labor, traceability of material and cost, material availability, and reduced expediting effort.

The pilot implementation took place as scheduled in March 1990. The three-day round-the-clock effort occurred over a weekend, so as to minimize the impact on business operations. Contrary to the success of the conference room test, the full pilot did not go as well as expected. System problems necessitated last minute site visits from C/PIOS experts to discuss and answer questions that were not evident during previous software testing. The users also experienced problems dealing with "live" data instead of the conference room mock-up. More familiar with the intricacies of MRP II than the recently-trained planners, team leaders struggled for over a month supervising operators step-by-step as they learned the system. Nevertheless, the training project was in hindsight considered sufficient; the users had to learn from their own mistakes. Most of them had no previous exposure to MRP and limited computer experience, which required a formidable culture change along with the accumulation of technical skills. Those planners who caught on quicker were given more complicated product lines and later became peer trainers.

Table 6.2: Criteria for Pilot Program Success

AREA	METRICS
Inventory Control	• Provide inventory balances and locations for all items in stock • Report value of inventory by part number (purchased and manufactured items) and contract • Track shrinkage history • Consider bulk items • Control both stock and WIP inventory • Control shelf life material
Bill of Material	• Replace the current APR system • Show reference designation of hardware • Plan for shrinkage and yield
Cost	• Provide rolled up costs (material and labor) by project to the appropriate level for financial reporting
MRP	• Schedule Manufacturing Orders and Purchase Requisitions for correct quantity and date • Include all elements of lead time • Schedule "as required" items (quantities and dates)
Purchasing	• Include catalog to identify vendors • Generate automatic Purchase Requisitions
Capacity Requirements Planning	• Calculate people and equipment load and capacity by work center • Perform "What if exercises" (e.g. off line planning to see impact of proposed change in schedule or new production) • Provide a steady flow in production
Work Measurement	• Calculate productivity and efficiency measurements • Feed touch labor data to Work Measurement reporting systems
Quality	• Capture scrap/rework/repair/replacement material and labor
MMAS	• Provide data to measure required accuracy levels • Comply with the 10 key elements • Provide audit trails within the basic system

After the pilot, the second program was brought on-line during the following August. The balance of the programs followed in quick succession, with the entire facility converted to MRP II by April 1991. Records for all plant inventory, including that for inactive programs, are scheduled to be on-line by fall 1994.

6.2.5 Reaping the Rewards: 1991 to 1994

In the four years since the implementation project, AIL has accomplished significant improvements in its materials management practices. MRP II has quite possibly kept the company from falling victim to defense downsizing extinction by bringing production processes under control. Although significant changes to business practices were required, the company feels that the benefits of the new system far outweigh the disruption caused by the implementation procedures. This subsection describes the operation of AIL's MRP II arrangement and provides quantifiable evidence of business progress. Comments on the impact to engineering change issues can be found in chapter 7.

6.2.5.1 MRP II in Action

A complete transaction cycle of the AIL system, as controlled by operators in the planning department, the stockroom, and the shop floor, can be subdivided into seven steps, outlined in table 6.3. The MRP II computer program is executed during each weekend, creating reports available every Monday morning to the planning department computer terminals. The planning department is organized into four commodity planning areas -- PWB, cables and harnesses, sheet metal fabrication, and purchased parts -- plus one more for end item integration. The planners' desks, each with its own computer terminal link to the MRP II system, are located on the shop floor near the respective manufacturing hardware commodity site. The MRP II reports show what materials needs to be released to the shop floor each day to maintain the master production schedule. The planner approves each order manually to generate allocation reports done in batch processing at night. The MRP II system reserves material in the stockroom bins needed to assemble the order, or kit. These first steps, which used to require at least 13 weeks, now can be performed in one day.

Table 6.3: AIL's MRP II System

Step	Operator	Action
1.	Planner	Generate need date report showing what material needs to be released to the shop floor.
2.	Planner	Generate allocation report to reserve material in the stockroom.
3.	Planner	Generate kit pick list, manufacturing order, and drawings. System automatically sends copies to stockroom.
4.	Stockroom	Assemble kit. Update system to reflect material issued.
5.	Planner	Pick up kit at stockroom. Deliver material to shop floor.
6.	Planner	Perform on-line check of job progress/status.
7.	Shop Floor	Return finished jobs to stock room for later kitting as end items.

If enough material is available in the stockroom to allow the kit to be assembled, or pulled, the planner requests a pick list to be generated by the system. An electronic copy is automatically sent to a computer printer located in the stock room, along with, if desired, an assembly drawing and an electronically-generated manufacturing order (MO) that describes each step of the production process. Two days are needed for the stockroom to pull the kit (down from 30 days), a lead time taken into consideration by the system when the material need list is generated. If for some reason all of the material needed for the kit is not currently available, the planner consults with the manufacturing supervisor as to whether it would be practical to start work on the job without all of the parts. For instance, if some of the material is on back order but will be received within a few days and is not required for the first few assembly steps, then the decision might be made to release an incomplete, or short, kit to the shop floor.

The pick list sent to the stockroom enumerates only that material which is currently in stock and provides its bin address. The former system listed all material needed for the kit, with no regard as to its receiving status, and did not indicate its location. The MRP II system eliminates the time that used to be spent needlessly searching for material that had not yet arrived at the plant. After the stockroom worker assembles the kit, the system is updated through an MRP II terminal located in the stockroom to reflect that the material has been issued. The process is not completely paper free; the pick list printout request is signed by the stockroom worker, then automatically recorded on microfiche. The paper copy provides the short term backup documentation required by the government customer and is discarded after one month.

The planner performs an MRP II transaction to officially release the material to manufacturing and then physically transports the kit from the stockroom to the appropriate shop floor area. An on-line check of the status of the kit can be performed by the planner at any time during the production process. For example, if manufacturing had agreed to accept a short kit, the shortage would be listed on the MO and the job placed on hold when the stopping point was reached. The planner, notified by the system when the back order is filled, checks on the progress of the kit on-line and delivers the missing material directly to that manufacturing step. Finished jobs are returned to the stockroom for kitting as end items, such that the commodity planners act as vendors to the end item planners.

6.2.5.2 Changes to Business Practices

MRP II has resulted in a radically different operational environment from AIL's previous system, mainly due to the mechanization of the manufacturing process from requirements through shipping. Table 6.4 summarizes the improvements AIL generated in several key areas of inventory management.

Table 6.4: AIL Before and After MRP II

Metric	Before MRP II	After MRP II	Improvement
Inventory accuracy	83%	99.4%	+ 16%
Inventory floorspace	93,000 ft^2	53,000 ft^2	- 43%
Material transferred from existing inventory	< 1% /year	70% /year	+ 6900%
Kit request time	13 weeks	1 day	- 98%
Kit pull time	30 days	2 days	- 93%
"Unplanned Issue" pull time	4 hours	4 minutes	- 98%
Kit pull accuracy	87%	99.6%	+ 12%
Time to reverify kits	32 hours /week	4 hours/week	- 88%
Stockroom data entry staff	10	1	- 50%*
Planning staff	125	8	- 73%*
POs per planner (average)	190 /year	260 /year	+ 37%

* Corrected for decline in business volume of ≈75%.

The company attitude toward inventory has changed from one of ambivalence to constant attention. In stark contrast to the previous system of automatically increasing every material order by 15 percent to account for shrinkage and safety stock, the MRP II method keeps track of all parts in the plant to keep from re-buying unnecessary material, the goal being to have zero inventory left at the end of every program. Since the implementation, 60 to 70 percent of all items signaled for purchase by the system have been transferred from available inventory on existing or previously completed programs. This thrift reduces space and staffing requirements as well as overall inventory. The planning department staff has been reduced to 8 employees, down from 125 in 1986, in part because of a shift to a buyer/planner concept in which a single individual performs both functions. The number of stockroom data entry operators has dropped from 10 to 1, since the pickers now perform this function directly through the MRP II terminal. Although the volume of business has declined as well during this period, each employee can now do more work more efficiently, eliminating the need for clerical help and expediters.

Dramatic improvements have also been evidenced in inventory storage and handling. The stockroom strives for inventory and MPS accuracy of at least 95 percent and BOM accuracy of 98 percent, tremendous improvements over the previous physical count accuracy of 75 percent. Inventory accuracy currently exceeds 99 percent. Cycle counts, now no longer a time intensive task, are performed on a daily basis, totaling 17,000 counts per year of approximately 10,000 part numbers. Kitting time has decreased by over 90 percent. Statistical process control (SPC) is used to determine the root cause of errors, promoting a team attitude to look internally for problems first instead of assigning blame. Kit accuracy has increased to 99.6 percent, up from 87 percent, with verification now done by random audits. SPC records are used to look for trends in the type of kitting mistakes so that solutions can be implemented quickly and methodically. For example, when some of the inventory balance figures were found to be incorrect, each stockroom worker was given a calculator to reduce subtraction errors.

6.2.5.3 Government Response

The AIL management and users, now comfortable in the workings of MRP II, express great satisfaction with the performance of the system. Although the decision to implement MRP II was entirely contractor driven and not a mandate from the customer, government representatives associated with the site seem to appreciate the benefits of improved process control as well. Prior to the implementation, government audits were more difficult for the DCAA representatives, since the paper trail was not always complete, making residual material hard to find. Although the legacy system was compliant, it was not cost effective for either party. In addition, the government's relationship with AIL prior to the implementation could be described as contentious at best, since the contractor gave the agents only what they asked for specifically.

Over the course of the implementation, the company and the government consciously worked toward a cooperative approach for mutual survival. The company needed to comply with government standards to stay in operation, and the government wanted to realize cost and schedule benefits on their contracts. The DPRO leader, who had previous experience with MRP II at other sites, advised AIL as to potential problems and worked with the company to avoid them. As discussed above, AIL provided training and addressed government concerns up front as to proper accounting procedures by forming joint TQM teams. This cooperation was essential in building trust between the two parties and eliminating the need for costly adjustments to meet compliance standards after the fact.

The most obvious benefit of MRP II from the government perspective is the contract cost savings that can be passed on to the customer. Overhead costs are reduced due to the increased efficiency of inventory personnel; appropriation of existing parts and reduction in shrinkage and safety stock allow less material to be purchased; and schedules are more accurate and swift due to the ability to transfer material across contracts. AIL gives their government representatives full access to the MRP II system. As the DCAA became comfortable with the accuracy of inventory records, the agency was able to eliminate some manual audits and verification checks. The reduced number of accounting processes make it easier to track contract labor costs. The system is set up to generate the reports and audits the government needs automatically, saving hundreds of hours a year in government auditing cost. The contractor gains comparable savings, as they no longer have to generate paper records for the government which are of no use to the company.

6.3 Barriers to Implementation

Despite the overall success of the project, the implementation was not without its stumbling blocks. On the technical side, software bugs in the initial shipment of C/PIOS 4.1 caused some delays, and testing for the pilot program was actually performed with the previous version. A more substantial problem, however, was the initial lack of management commitment. At the start of the initiative around 1985, only two of the 17 AIL vice presidents (Gordon Corlew being one), had heard of MRP II system techniques. The long period of building critical mass speaks to this lack of awareness. Business practices are extremely difficult to change, especially during boom years, and it took a considerable amount of time for management to become receptive to the idea of revamping manufacturing processes. MRP II was not fully embraced across the company even after the program was commenced, as evidenced in the sluggishness of some departments to dedicate personnel to the implementation team. For example, management in the information technology group took a long time to allocate resources and continually lost people to retirement or relocation without providing quick replacements. The software debugging effort was severely hindered by consistently inadequate information technology resources, so consultants were eventually hired to take up the slack and end the schedule slip once the project manager realized that internal solutions were not satisfactory.

Similarly, some AIL departments, including finance, didn't want to be involved with the program at first, since they didn't think they would have input into what they considered a manufacturing system. As is the case in many established companies, the cultural climate was devoted to maintaining the status quo; as long as they could operate in the same manner that they always had, they saw no need to be concerned with what other parts of the company were doing. Some engineers continued to work alone, thinking that the IPD manufacturing team members weren't technically versed enough to understand design constraints. A "hero complex" was also observed, in that last minute expediting had made for exciting management, a situation which an efficient system would preclude. Resistance to putting in a new system manifested itself as excuses, such as a complaint that the MRP II package printed purchase orders in landscape mode instead of portrait. However, many issues relating to the finance arena came up during the course of the implementation, ones the recalcitrant departments weren't aware they had. Often the token representative provided to meet corporate demands turned into a valuable team asset who later promoted the system throughout the organization.

Chapter 7 Using MRP II to Control Engineering Change in Practice

AIL managers frankly admit that the company would not have survived the defense downsizing of the past few years without MRP II, since the information needed to bring manufacturing processes under control wasn't present in the previous system. MRP II permits the company to be run in the same manner as a low to medium volume commercial factory, which, as was discussed in chapter 5, is unusual for a defense contractor. The control of engineering change is one area that has shown significant improvement, mostly because MRP II has made the company more configuration sensitive. This chapter describes the revisions to AIL's handling of engineering change as a result of the implementation and provides additional information on the benefits of MRP II from the engineering perspective.

7.1 A New Approach to Change

Prior to the introduction of MRP II, AIL followed a method for dealing with engineering change that was essentially the same process described in chapter 5. If a problem was identified on the floor during manufacture or test, an "action request" would be sent to the engineering department. The engineering change notice (ECN[1]) written by engineering passed through an ECN Review Board that checked for technical correctness but did not address the impact of the change on manufacturing. No input on inventory, part lead times, or other manufacturing issues was solicited until the job returned to the shop floor, when it was too late to influence the content of the ECN. Often further changes were required to address aspects of the engineering fix that were incompatible with the manufacturing process and material management considerations (known as "ECNing the ECN"). These delays often impacted schedule and cost. AIL realized that simply using a computer network to automate the ECN tracking system would provide little improvement if numerous changes and repeat changes were still being processed inefficiently. In response, the engineering representatives on the implementation project team developed a new approach to ECN handling to incorporate the capabilities of the MRP II system.

---

1 AIL employs the term "ECN" instead of "ECP," but the meaning here is identical to the configuration documents described in chapter 5.

7.1.1 The New System Under MRP II

The engineering team members' main goal was to take advantage of the informational integration that a networked manufacturing system provided. Instead of operating in a vacuum, the revised engineering change system incorporates a manufacturing impact review into the formal ECN process (figure 7.1). Manufacturing feedback is actively sought during the formulation of a concurrent solution *before* the ECN is written. This additional step takes only about 8 extra hours but ends up reducing the total length of the ECN process from 15 manufacturing days to just 8 days on average, with cycle times on some programs as low as 4 days. Manufacturing planning representatives are consulted during the design of the change as to the status of parts under consideration. The potential impact on inventory, WIP, schedule, and cost is weighed side by side with technical constraints. IPD lets engineering and manufacturing personnel understand how their work affects the other function, while TQM helps them learn from mistakes by keeping track of the most common changes and the reasons behind them. Oversight is decreased, since the Review Board is able to concentrate on the solution process rather than trying to pull in important impact information at the last minute. This facilitates more rapid and efficient implementation of the change. As well, the new process reduces cost, since the company is able to make use of residual inventory, minimize scrap and rework, and eliminate the processing of ECNs that correct previous ECNs.

7.1.2 Other Revised Procedures

Several other key policies were revised to increase the effectiveness of the manufacturing impact review process. As mentioned in section 6.2.4.3, the Policy and Procedure Committee decided to eliminate the use of revision labels to inventory part numbers. Under the new philosophy of "a part is a part," inventory items bear identical numbers so long as the form, fit, and function are the same. Interchangeability became the determining criteria instead of issuing letter suffixes (as in parts 123456-1 revision A or 123456-1 revision B) to indicate changes in vendor or nonfunctional specifications. This policy served to clear up confusion over which revision was acceptable for each job and simplified the designation of part numbers on technical drawings and other documentation.

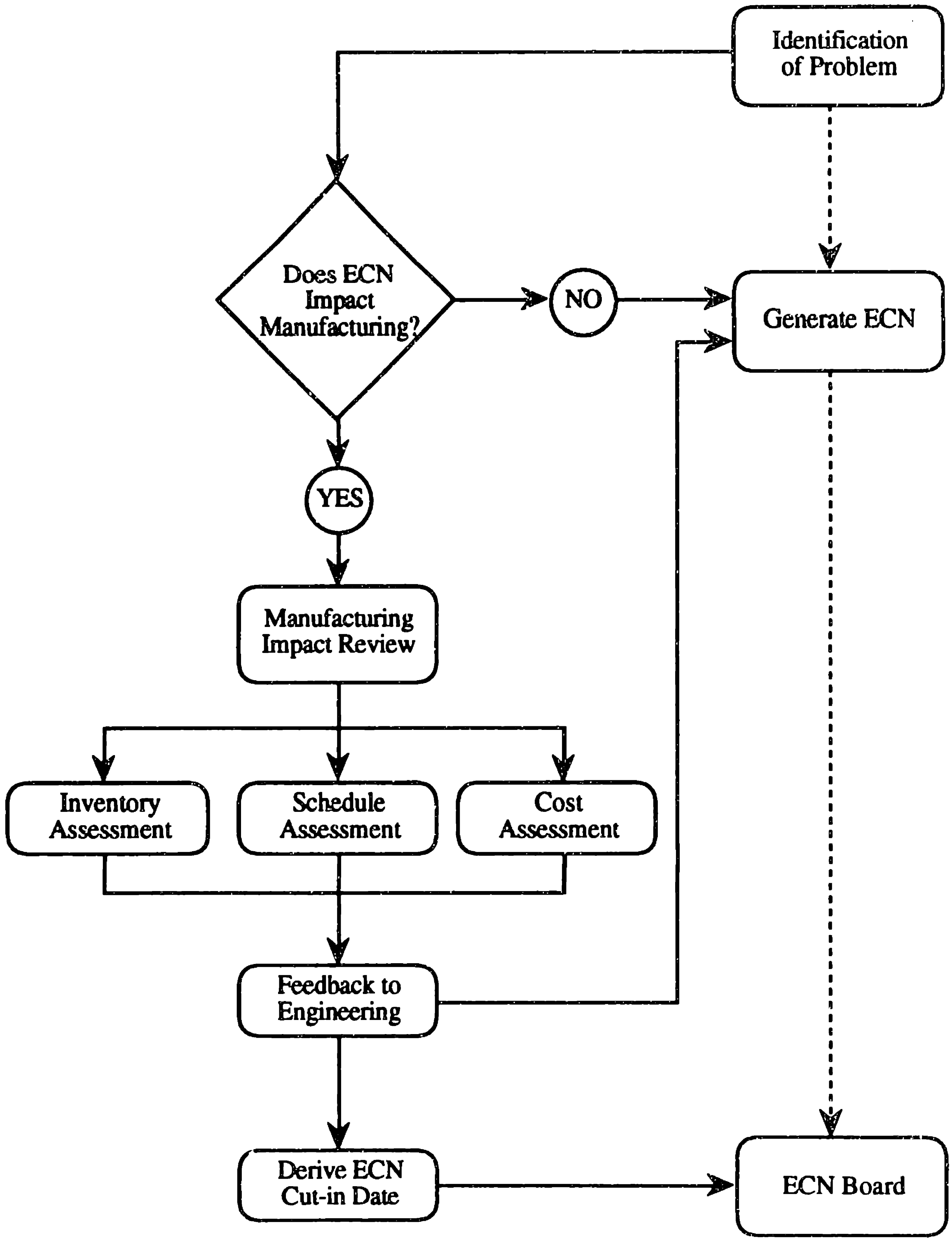

Figure 7.1: Summary of AIL Manufacturing Impact Review Process
Dashed lines indicate prior approach having no solicitation of manufacturing input (average time of 15 days). Solid lines indicate current approach using MRP II (8 days).

To coordinate the MRP II BOM effectivity date with ECN activity, the engineering team developed a new method of deriving the cut-in date for scheduled implementation of changes. Rather than arbitrarily assigning a date for the change to go into effect, the revised procedure takes into account the type of change. A phase-in/phase-out cut-in leaves residual inventory but provides the quickest repair for a performance problem. For an ECN that merely reflects a change in vendor, not function, a better strategy might be to use up all existing inventory and then replace the part. Regardless of the method selected, a delay between the derivation of the cut-in date and review by the ECN Board may require a recalculation to keep the date valid. Formal procedures were also enacted to incorporate BOM bookkeeping changes (part number, description, make/buy status, lead time, etc.) into the MRP II system after an ECN is issued.

7.1.3 New Organizational Tools

Two new organizational tools were adopted to reduce the total number of ECNs being generated. The "open ECN" concept allows multiple changes during prototype assembly to be listed on the same ECN. Changes are recorded, signed off, and implemented as they arise, but the actual ECN is not released until a number of associated changes have collected. A new type of change document, the temporary equipment modification (TEM), was introduced for use during the development testing phase. Less formal than the ECN, the TEM does not require government approval before the change can be made. Redesign is fully documented on the TEM, but a formal ECN is not issued until the product operates according to specifications. The TEMs are then combined into one ECN. This reduces multiple ECN revisions during the exploratory phase of development and permits engineers to try changes that may not work. In addition, the considerable cost and time burdens of adhering to the formal ECP process outlined in chapter 5 is lessened.

7.1.4 Vendor Interaction

One final aspect of the new engineering process that helped to cut back on ECN activity is early vendor interaction. Suppliers are brought in to discuss the design while specifications are still being derived. The company is thereby able to assess performance and schedule capabilities of competing vendors with far greater accuracy relative to the specific job at hand. Working together, engineers at AIL and the subcontractor can get the design together faster and with fewer changes needed after the fact. A qualified vendor list constructed by the quality assurance and purchasing departments rates suppliers on schedule delivery and performance on a per commodity basis to aid in evaluating the true cost of doing business with them.

7.2 Benefits from the Engineering Perspective

From the engineering standpoint, the main advantage of the MRP II implementation is increased visibility. Decisions can be based on as much factual information as possible up-front, so that the impact of changes can be assessed before they are made. The MRP II networked database also serves to facilitate IPD in the engineering department. Aside from the success that improved cooperation and teamwork can bring, IPD needs a systematic flow of accurate information to create an environment in which everyone has access to correct data. Engineers are then able to see the impact of design delays and part selection on the manufacturing schedule, improving accountability across the company. Finally, MRP II allows the engineering function to work more efficiently with fewer people, as required in a downsized environment.

Overall, despite minor problems with cultural barriers, the implementation was so successful in the engineering arena that an introduction of engineering resource planning (ERP) is under consideration as the next step. This tool employs the basic MRP II structure to control product development by making analogies between manufacturing and engineering processes. For example, the engineering design steps, such as brainstorming, technical analysis, and review meetings, are inputs to the finished design in the same manner that the part numbers in the BOM are inputs to the finished product. Similarly, the development schedule, moving from initial concepts to the final specification, maps to the MPS from initial fabrication to final assembly. Just as MRP II is used to understand the manufacturing process flow and to guide the scheduling of complex interdependent elements, ERP can be used to bring the engineering side of operations under the same tight control.

Chapter 8 Industry Implementation Issues[1]

One of the inherent dangers of the case study method is the tendency to focus so tightly on a single organization that problems facing others are neglected. While AIL has experienced great success with its MRP II system, this result should not be blindly extrapolated to the aerospace industry as a whole. The intent of this chapter is to broaden the viewpoint of the analysis to judge the applicability of MRP II for industry-wide use. As explained in chapter 4, one of the first steps in the Proven Path is to perform a cost/benefit analysis to determine whether or not there will be sufficient return on the investment to fund the implementation. There is no generic solution; each company must perform its own evaluation to determine the appropriateness of MRP II principles to the individual business environment. The major areas of implementation cost and an idea of the benefits that companies have obtained in the past are outlined below. Some of the key issues facing any company considering MRP II as a means to gain control over inventory and engineering change are also presented.

8.1 Costs

The most significant costs of the implementation lie in three areas: computers, data, and project team staffing.[2] Hardware and software are the most obvious computer expenditures, but systems engineers and programmers will also need to be paid to install the system, code any necessary enhancements, interface the off-the-shelf product with existing systems, train the company users, document the operating procedures, and maintain the system. The high level of inventory and BOM record accuracy required to use MRP II leads to large costs associated with data. These may include manpower for cycle counting and capital equipment, such as shelves and bins, for reworking the plant layout. The cost of human resources can be most considerable. The full-time PM and other project members temporarily removed from direct billing positions must be paid through overhead for 15 months or more. Education for the team will incur travel expenses and consultant fees, and training for the rest of the company is also expensive. However, to reiterate, the most integral factor for a successful implementation is the

---

1 Valuable feedback was provided by the following LAI representatives who generously donated their time to review this chapter during the MRP II industry implementation conference held on July 7, 1994 at M.I.T.: Bill Bullock (Lockheed), Gordon Corlew (AIL), John Fialko (Hughes), Vern Lovejoy (Textron), Bob Morris (GE Aircraft Engines), and Jim Struss (Rockwell).

2 Wallace, pp. 48-49.

people, not the computers. If budget cuts must be made, it is wiser to scale back on the complexity of the computer system instead of scrimping on people-related charges. Careful planning and evaluation up-front is essential to keep costs low; companies that don't understand what their priorities should be often spend too much on software instead of on their people. In general, the average size business will need to allocate at least $1M to the implementation project.

8.2 Rewards

The company that undergoes a successful MRP II implementation can expect increased inventory turns, reduced overtime, increased output, better adherence to schedule, and fewer engineering changes. The goal shouldn't be predetermined numerical improvement of one function of the business but better management of supply and demand for the whole.[3] Based on a survey of MRP II implementations,[4] some quantitative estimates can be made as to the scale of progress to be expected in the three most significant areas: direct labor productivity, purchase cost, and inventory. Organizations meeting Class A standards often enjoyed results 50 to 100 percent greater than that of the average implementing company. In performing the cost/benefit analysis, the company should consider these appraisals as a basis for judgment, not an absolute indication of what the company will achieve. Improvement may be gradual during the first few years following the implementation as the company adjusts to a new way of doing business.

The average company in the survey was able to increase their direct labor productivity by 11 percent following MRP II implementation, while Class A organizations averaged a 20 percent increase. This improvement was due to reduced expediting, fewer shortages, and less unplanned overtime. MRP II's valid schedules permitted buyers and planners to accomplish more productive work instead of expediting and shuffling paper, leading to reduced indirect costs for their function. Their newfound time was also used towards value analysis, vendor selection, and negotiation, which translated to better bargains.

---

3 Goddard, Walter and James Correll, "MRP II In The Year 2000," *APICS - The Performance Advantage*, American Production and Inventory Control Society, Falls Church, VA, Vol. 4, No. 3, March 1994, p. 38.

4 *Survey Results: MRP II/Just-in-Time*, Wallace, p. 50. Conducted by the Oliver Wight group in 1988, the survey compiled results from over 1200 manufacturing companies that had implemented MRP and MRP II. Most of the respondents were from commercial firms, but some had government business as well. Since MRP II operates in essentially the same manner in either sector, the survey results are comparable to those that can be achieved in the defense aerospace industry.

This resulted in an average seven percent reduction in purchase cost (13 percent for Class A). In the area of materials management, the reliability of the MPS caused a 16 percent reduction in inventory, with Class A users able to cut inventory by nearly one-third on average. As a side effect, the companies experience less obsolescence of their parts lists due to lower inventory levels and better management of engineering change. Floor space previously dedicated to inventory storage was also freed. The accuracy of MRP II eliminated the need for an expensive annual physical inventory that disrupted production. Work in process (WIP) could be cut back by 30 to 40 percent on average.[5]

Overall, the company with a successful MRP II implementation will welcome the improved teamwork and "quality of life" that comes from being able to work to a reliable schedule instead of constantly dealing with rush orders. MRP II's common database allows closer communication between departments and more effective supervision, both of which will promote quality control.

8.3 Challenges

An MRP II implementation is not without its pitfalls. The project team should be aware of particular areas where trouble is likely to occur so that they can work to avoid them up-front. This section outlines prominent trouble spots and identifies some of the special concerns facing companies in the aerospace and defense industry.

8.3.1 Cultural Hurdles

By far the biggest challenge to any company attempting to instill a new business tool comes from the internal cultural environment. Changes in well-established business environments come slowly, and often the first response the torchbearer will encounter from peers falls under the "we're-unique" syndrome.[6] The inertia present in large organizations acts towards preservation of the status quo at all costs, often in the form of argument that the company is different (for a variety of reasons) so that "fad" techniques such as MRP II won't work there. These resistant individuals, or even departments or divisions, tend to focus on differences instead of similarities and will blame the system if dramatic improvement is not immediately apparent. On the chance that a new tool is adopted, it is often modified to the point that it ends up looking very similar to the old

5 Chamberlain, p. 26.
6 Wallace, p. 34.

system. This can lead to systems that are extremely over budget,[7] behind schedule, unpredictable, and do not result in any measurable improvements to company processes. To deal with such opposition, the project team must demonstrate the proven success of MRP II elsewhere and concentrate on education as their primary weapon against the fear of the unknown. Once again, the emphasis should not be on the introduction of a new computer system but on the empowerment of the employees. The team must not become frustrated when MRP II doesn't seem to be catching on and instead should try to win converts one step at a time until a critical mass of support is attained throughout the company. AIL overcame the "fraternity environment" that made the company reluctant to adopt a system few of its peers were using by bringing people from the commercial sector with MRP II experience who could testify to its effectiveness. Strong support from upper management, especially via the torchbearer, is essential to instill an environment at all levels that is accepting of change.

In a similar vein, the mystique that surrounds the computer world should be debunked to the greatest extent possible. Employees who have little or no computer experience may tend to be frightened at the thought of being responsible for expensive hardware or may be anxious about losing their jobs to automation. These concerns should be addressed, focusing on providing users with hands-on experience to increase their comfort level. Training should be treated as manufacturing training, not computer training, and computer jargon should be avoided. At the same time, the technical aspects of the implementation should not be assigned solely to the company's information services department. Representatives from all areas are needed to ensure complete integration of the system with the company's internal processes. In brief, the computer should support manufacturing, not be expected to control the workforce.[8]

8.3.2 Special Considerations with a Government Customer

The strict contract accountability required by the government customer places an added burden on the aerospace and defense MRP II user. All material must be tracked by contract, not just by part number, and records must also be kept on WIP, inventory movement, and all associated costs. The system must be able to perform borrow/payback

---

7 Some companies surveyed reported unsuccessful implementations costing on the order to tens of millions of dollars.

8 Kapp, Karl M., "MRP II: It's Not a Computer System," *APICS - The Performance Advantage*, American Production and Inventory Control Society, Falls Church, VA, Vol. 4, No. 3, March 1994, pp. 57-58.

transactions such that material transferred to another contract due to scheduling demands is accounted for properly.[9] If the item has a different cost in each contract, for instance, if the receiving project was able to obtain a quantity discount, a cost transfer must take place so that the loaning project isn't penalized for sharing its material to improve the company manufacturing flow. These special requirements are often unsatisfied by software designed for commercial manufacturers, but several defense-oriented systems that extend MRP II's reach into the non-commercial sector have become available in recent years. Increases in computing power, speed, and memory size now make MRP II practical for use in the defense industry with its high-volume data requirements. Even companies with an extremely high part number count and a variable product mix, such as airframes, should be able to operate with a modified BOM that aggregates the MPS at the highest level of commonality between products. The defense company implementation team must take care to select a package that meets its special environment without customization. In the commercial world, a poor implementation risks lost profit. For military contractors, who have an extremely high degree of visibility in the public sector, it risks bad publicity, loss of contracts, and possible loss of their sole customer.[10]

Reluctance to deal with government oversight is another reason often cited for not implementing MRP II, but this may not be the major hurdle it first appears. Of course, any company that changes its material or cost accounting system will have to re-demonstrate MMAS compliance. However, the rewards of having a more satisfied customer can outweigh this temporary inconvenience. In the AIL case, the on-site government representatives did not want to interfere in the company's plans as long as MMAS compliance could be demonstrated. In fact, the government would have continued to pay for excess inventory, mostly in the form of redundant shrinkage and minimum buys across contracts, without complaint. However, they appreciated the benefits the new system passed on to them, such as cost and schedule savings and a reduced supervisory burden. The teamwork approach that AIL took in introducing the system to its customers greatly improved communication and working relationships

---

9 Haupt, B. Michael, "MRP II in A&D: Are We Ready for the Challenges of the 1990s?" *Improving the Process: The Smart Challenge*, APICS Aerospace and Defense Symposium Proceedings, Los Angeles, CA, May 2-6, 1992, p. 116.

10 Thomae, Dave and Kevin Campbell, "What to Do When the Salesman Leaves? Implementing MRP in Aerospace and Defense," *The Vision: Critical Thinking for Critical Times*, Proceedings of the 1989 Los Angeles - Aerospace and Defense Special Interest Group Conference, Los Angeles, CA, May 15-17, 1989, p. 323.

between the two. Overall, the implementation process formed the basis for new cooperation and understanding that will ease negotiations for future contracts.

8.3.3 Trend Consciousness

While many people adhere to the latest new management "fad" and discard any previous system as outdated, the core principles behind MRP II, developed almost thirty years ago, still hold true in today's competitive manufacturing environment. Many newer techniques have popped up over the years trying to unseat MRP II, but most met with little success since they didn't replace the essential concept of material and capacity requirements planning. The philosophy of MRP II is so fundamental that all future systems, no matter what they are called, will encompass the universal manufacturing equation.[11] Often viewed as a competitor, the just-in-time (JIT) technique need not preempt the use of MRP II, since the two systems are best used to complement each other.[12] Since MRP II assumes fixed production buffers, the system is unable to react as quickly to changes in the shop floor environment as JIT's finite scheduling. At the same time, the JIT approach can't recognize future events that may cause large demand fluctuations since it doesn't have MRP II's built-in forecast capability. The best solution is therefore a hybrid approach, such that MRP II determines material and factory resources and long term requirements, while JIT is used to pull material through the shop. The teamwork and reliability aspects of the JIT philosophy mesh well with the informational network that MRP II creates so that, together, the two systems do even more to augment the company's quality management.

8.3.4 Unrealistic Demands

MRP II can dramatically improve business metrics, but it is not a panacea to heal all of the company's problems in one easy step. When MRP II is applied to inefficient or poorly designed manufacturing processes without modification, its chances of success are poor. Serious deficiencies in the existing design approach, manufacturing processes, and management structure present an obstacle that even the most sophisticated system can't overcome.[13] The development of the list of 500 tasks related to sales, logistics, and

---

11 Wight (1982), p. 17.

12 Karmarkar, Uday, "Getting Control of Just-in-Time," *Harvard Business Review*, Harvard University Press, Cambridge, MA, September-October 1989, p. 123.

13 Chamberlain, pp. 25-26.

manufacturing processes is not a trivial one. Only after carefully evaluating and restructuring the existing system can the project team develop the understanding required to create an environment in which MRP II can succeed.

8.4 Conclusions

The inventory practices survey demonstrated the lack of control over production processes that currently pervades the aerospace industry. Immediate action should be taken to improve adherence to schedule, cut back expensive inventories, and eliminate expediting. The defense sector needs to take steps towards modern manufacturing methods before it can attempt to embrace the more complex management systems found in the commercial world. Table 8.1 outlines the crucial factors that should be present to insure a successful MRP II implementation and take the company one step closer to manufacturing process control. Unless circumstances are extremely divergent from the typical manufacturing organization, chances are extremely good that the introduction of MRP II will have a net positive effect at most defense companies. Table 8.2 provides a summary of the primary benefits to be won, the extent of which depends on the dedication and perseverance of the implementation team and the company's top management. At AIL, reduced material costs paid for their system in one year. The benefits of improved control over the manufacturing process will continue to make the company competitive in the years to come. The more efficient interface between manufacturing and engineering that MRP II provides also acts to reduce costs and schedule, both of which are competitive deciding factors in the determination of future government awards. Although justifying large indirect capital outlays during periods when the volume of business is low may seem counter-intuitive at first, an operating environment with efficient processes under tight control is absolutely crucial if a company ever expects to raise its production volume in the future. In fact, implementing a large system is easiest when volume and inventories are low and production demands aren't as all-consuming. Companies that stagnate during the downsizing years will find themselves far outpaced when it comes time to compete for new contracts. More than ever, companies need to learn to utilize their resources to the fullest, and approaches such as IPD are mandatory for maximizing productivity while keeping costs low. These factors all point to MRP II as a system that can bring the aerospace industry up to modern manufacturing standards while facilitating interaction within and between functions. The control that MRP II brings will lead to cost reductions and the ability to do more with less, both important characteristics of lean manufacturing.

Table 8.1: Keys to MRP II Success

- Commitment to change and improvement
- Serious evaluation of current situation and future goals
- Active support from top-management (via the torchbearer)
- Full-time dedicated PM (excellent "people" manager)
- Cross-functional implementation team
- Methodical implementation plan (such as the Proven Path)
- Implementation schedule that is long enough to be thorough but short enough to sustain momentum (about 15 months from start to pilot program)
- Unmodified off-the-shelf software package (with available support and upgrades)
- Database integrity before implementation begins
- Pilot program before gradual cutover
- Company-wide training and education (focus on people, not computers)
- Up-front customer interaction (focus on MMAS compliance)
- Minimal reliance on consultants once system is operational
- Perseverance to overcome the cultural barrier

Table 8.2: Primary Benefits of MRP II

- Increased direct labor productivity (fewer people can do more)
- Reduction of inventory (less WIP and stock, less floor space, less overhead for upkeep)
- High inventory accuracy
- Reduced volume, quicker review time, and improved introduction of engineering changes
- Facilitated interaction within and among function due to common reliable database and improved information flow
- Simulation capability to test "what-if" scenarios in a risk-free environment
- Simplified accounting for transfer of inventory between contracts
- Easier MMAS compliance
- Improved "quality of life" (company focus shifts from crisis management to process control)

Appendix A Results of the Inventory Practices Survey[1]

The Inventory Practices Survey was grouped into eight major sections:

- General
- Organization and Management Policy
- Metrics
- Inventory Handling and Facility Management
- Accounting Practices
- Government Relations
- Planning, Inspection, and Simulation
- Final Comments

This appendix highlights some of the more notable results of the analysis for each survey section. Where applicable, results are accompanied by an explanation of how they do or do not reflect lean principles. Charts and graphs have been culled from the numerous presentations given over the past year to a variety of interested groups.[2] The material presented here represents only a portion of the data and analysis available from the lengthy survey analysis process. Complete analysis of the survey is still ongoing at this time.

A.1 Organization and Management Policy

This section of the survey asked a number of questions related to the organizational structure of the responding company. Questions were also asked to gauge attitudinal characteristics of the workforce, both management and labor. Perhaps most fundamental to the subject of inventory management is an understanding of the sheer number of people required to support inventory related functions within the company. Respondents were given a list of labor categories and asked to indicate how many employees were involved in each function. The categories were:

- Master Schedulers
- Production Schedulers
- Order Writers
- Pickers and Kitters
- Planners
- Dispatchers

---

1 This appendix was co-authored by Christina Houlahan, LAI Research Assistant.

2 Please refer to the following M.I.T. presentations: "Initial Results of the Inventory Pilot Program," October 1993; "Results of the Inventory Pilot Program for the Electronics Sector," December 1993; and "Results of the Inventory Pilot Program for the Airframe Sector," January 1994. All presentations were prepared by Dr. James Ling, Christina Houlahan, Renata Pomponi, and Todd Stout.

- Purchasing Agents
- Material Expediters
- Receiving Inspectors
- Receiving/Payment Clerks
- Internal Transportation
- Production Control Expediters
- Buyers
- Procurement Quality Assurance
- Stock Keepers
- Crib Attendants

Respondents were also free to add additional categories as needed to represent their particular organization. Industry-wide, the most abundantly populated categories were buyers and planners. Figure A.1 shows a graphical representation of the number of personnel supporting inventory as a percentage of total employees, both for the industry as a whole and also for the individual sectors. It is apparent that there is a large discrepancy between respondents' answers. Some companies identified as much as 27 to 32 percent of their total employees as being affiliated with inventory handling and related support functions, while some companies reported figures as low as 4 percent. Some industry sectors such as the Systems, Engines, and "Others" did not have an enormous range in responses, while other sectors such as Airframe and Electronics had wide ranges. This information demonstrates the presence of best and worst practices within the industry when it comes to the lean management of inventory. Leanness in this case is assumed to be inversely proportional to the number of people required in support of any activity.

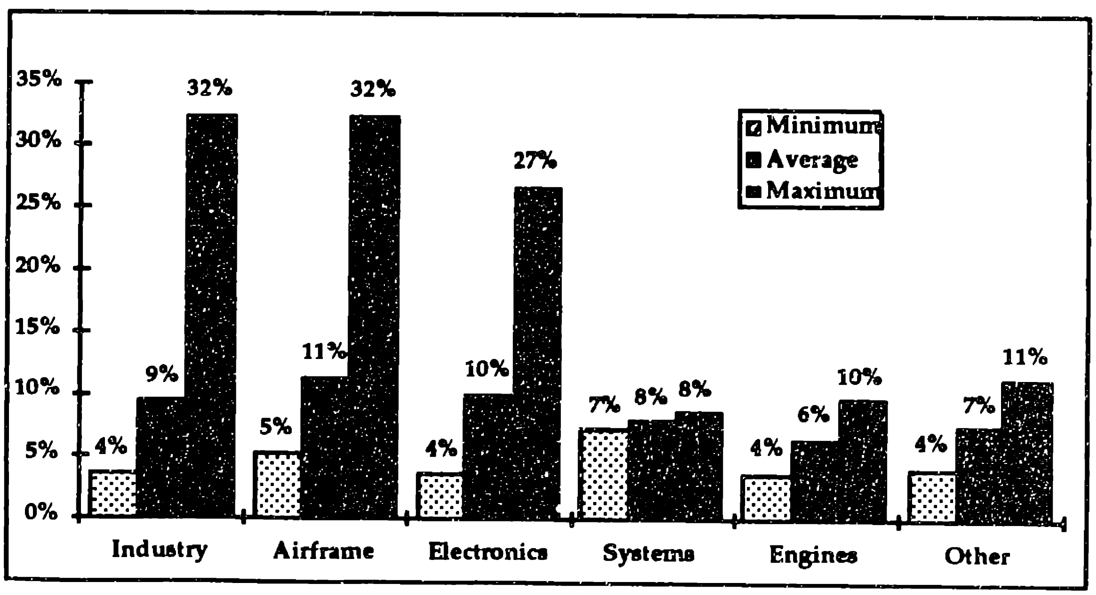

Figure A.1: Average Number of Personnel Supporting Inventory
(As a Percentage of Total Employees)

Another series of questions within "Organization and Management Policy" studied the inventory goals held by corporate management and government overseers. One such question asked, "Does your organization have a stated inventory goal?" Here, the intent was to verify the presence of a goal towards which the company was working, such as the reduction of inventory. The results were surprising, for not all companies responded affirmatively (table A.1):

Table A.1: Percentage of Companies Having a Stated Inventory Goal

Airframe	90%
Electronics	77
Systems	100
Engines	100
"Others"	100

Following this question, respondents were asked if their corporate management played any role in determining inventory levels (table A.2):

Table A.2: Percentage of Responses Where Corporate Management Plays a Role in Determining Inventory

Airframe	70%
Electronics	54
Systems	100
Engines	100
"Others"	67

Companies cited "setting performance goals" as the most common role played by the corporate management. Finally, a similar question was asked as to the government role in determining inventory levels (table A.3):

Table A.3: Percentage of Responses Where Government Plays a Role in Determining Inventory

Airframe	50%
Electronics	69
Systems	50
Engines	0
"Others"	83

Respondents cited "setting performance goals" and "MMAS guidelines" most frequently when asked to name the specific government role. A lean series of responses in this broad line of questioning would be: 1) to have a stated inventory goal, and 2) to have the corporate level playing some role in determining this goal or in determining the overall manner in which inventory levels are determined. It is not certain that it is necessary for the government, the customer in this case, to have a *direct* hand in setting goals or in determining inventory in order for a particular company to be moving towards lean practices. However, given the unique relationship of the government and industry in the aerospace business, it would be wise for a corporation to be aware of government expectations in this area.

One last relevant question from this section attempted to gauge the various attitudes throughout a company's organization structure concerning the excess or shortage of inventory. The responses to this question were enlightening. While upper management tended to have a moderate inclination to avoid shortfalls and a slight inclination to avoid excess, middle management seemed to have a moderate inclination to avoid shortfalls but a neutral attitude regarding excess. When asked about shop floor workers' attitudes the picture changed somewhat. Here, workers had a moderate inclination to avoid shortfalls, and a slight inclination to encourage excess. In short, although it was reported that the dominant attitude within most companies lay with either upper or middle management, it is clear that shop floor workers have a different approach. It is important to note that in most cases representatives from middle management filled out the survey. It is possible that this fact influenced the results somewhat. Regardless, a rift in attitudes is perceived between layers of the organization. Shop floor employees are often driven by schedule, avoiding shortfalls at all costs in order to stick to that schedule. Management at the upper levels has the somewhat more progressive view that a balance between shortfalls and excess should be struck, while middle management plays apparent lip service to the need to avoid excess while still keeping their eye on the schedule and the excess inventory they perceive is required to maintain it. A lean practice or attitude would be to avoid both excess and shortfalls. Also, a consistent attitude towards inventory should be shared across all of the company's levels so that all employees are working towards the same goal. The industry as a whole has not yet made this attitudinal transition.

A.2 Metrics

Metrics measure the "pulse" of the organization and tell a great deal about what the company believes to be important. This extensive section was designed to accomplish two major goals: 1) to determine what metrics were currently being used, and (2) to provide quantitative indicators of progress towards lean manufacturing. This brief review of the results is not intended to be an exhaustive treatment of the "Metrics" section but instead will highlight a few interesting findings.

Companies typically listed a number of metrics which they tracked. Among these were accuracy of inventory as measured by counts or against records, supplies on hand in terms of number of days, cycle time (both overall and within the various production stages), inventory turns, and "effectiveness" measured by actual performance in comparison to corporate goals. Less common, but also conducive to progress towards a leaner operation, were metrics such as the percent of kits released short to the floor, the ratio of actual cycle time to touch labor time, and the ratio of active inventory to inactive inventory.

The "Metrics" section of the survey also asked companies to identify where their inventory was located by dollar value on their government contracts. The results were surprising. Figure A.2 shows the breakdown within each production stage, expressed in terms of percent of the whole, both by sector and industry. One-third of overall inventory for government contracts is located in receiving and storage, a surprisingly high number.[3] A lean inventory profile in this case would have a relatively low percentage of total inventory in receiving and storage as opposed to the fabrication or assembly stages.

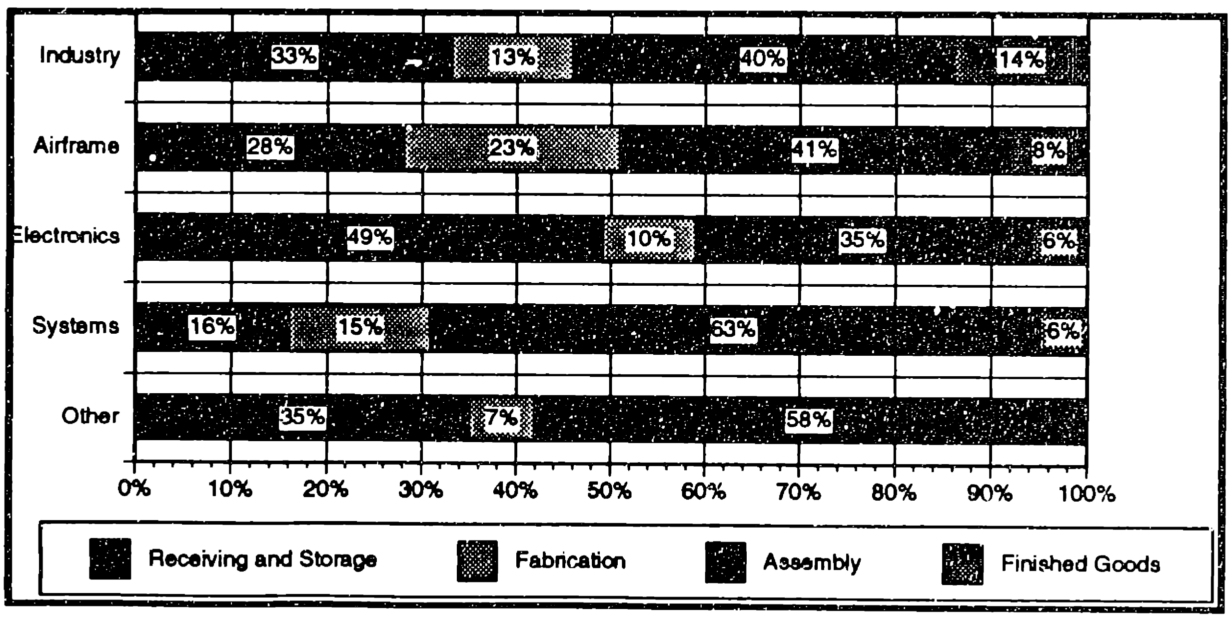

Figure A.2: Inventory Location by Stage for Government Contracts

3 This observation, the apparent "front-end loading" of inventory in receiving and storage, is elaborated upon in the Houlahan thesis.

Finally, results from the "Metrics" section also gave interesting insights into the extent of scrap, rework, and repair (SRR) in the aerospace industry. These data can be seen in graphical form in figure A.3, tailored to show SRR as a percent of total sales within each stage. Note the variation in response between sectors, some having large amounts of SRR in some stages while others do in different phases of production. As well, some sectors seem to have more SRR in total than others. In a related area, companies were also asked to quantify their obsolete and excess inventories within each production stage. These results, again expressed in terms of percent of total sales, are shown in figure A.4. The overall conclusions are similar to those related to SRR -- certain sectors have more of a problem than others. Interestingly, to some extent the data look as if those sectors which are "upstream" in the acquisition process have a problem with obsolete and excess inventory late in their own production process (see finished goods for Systems and Engines in particular), while those which are "downstream," customers of the upstream contributors, seem to have the problem early on in their individual production flows (see receiving and storage for Airframe sector). This indicates a disconnect in the material flow from vendor to purchaser, which is counter to the lean practice of tight integration of all phases of production with the supplier.

A.3 Accounting Practices

The third section in the Inventory Practices survey addressed accounting issues. Although not all of the questions were of an accounting nature in the purest sense of the word, at the time the survey was generated it was believed that the majority of questions within this section would be answered by people charged with accounting responsibilities within their respective companies. A fundamental question was asked at the start of the section: "Are figures readily available for the value of total inventory?" The answer was expected to be a resounding "yes." Instead the answers were surprising, the industry average answer reported at only 91 percent (see table A.4).

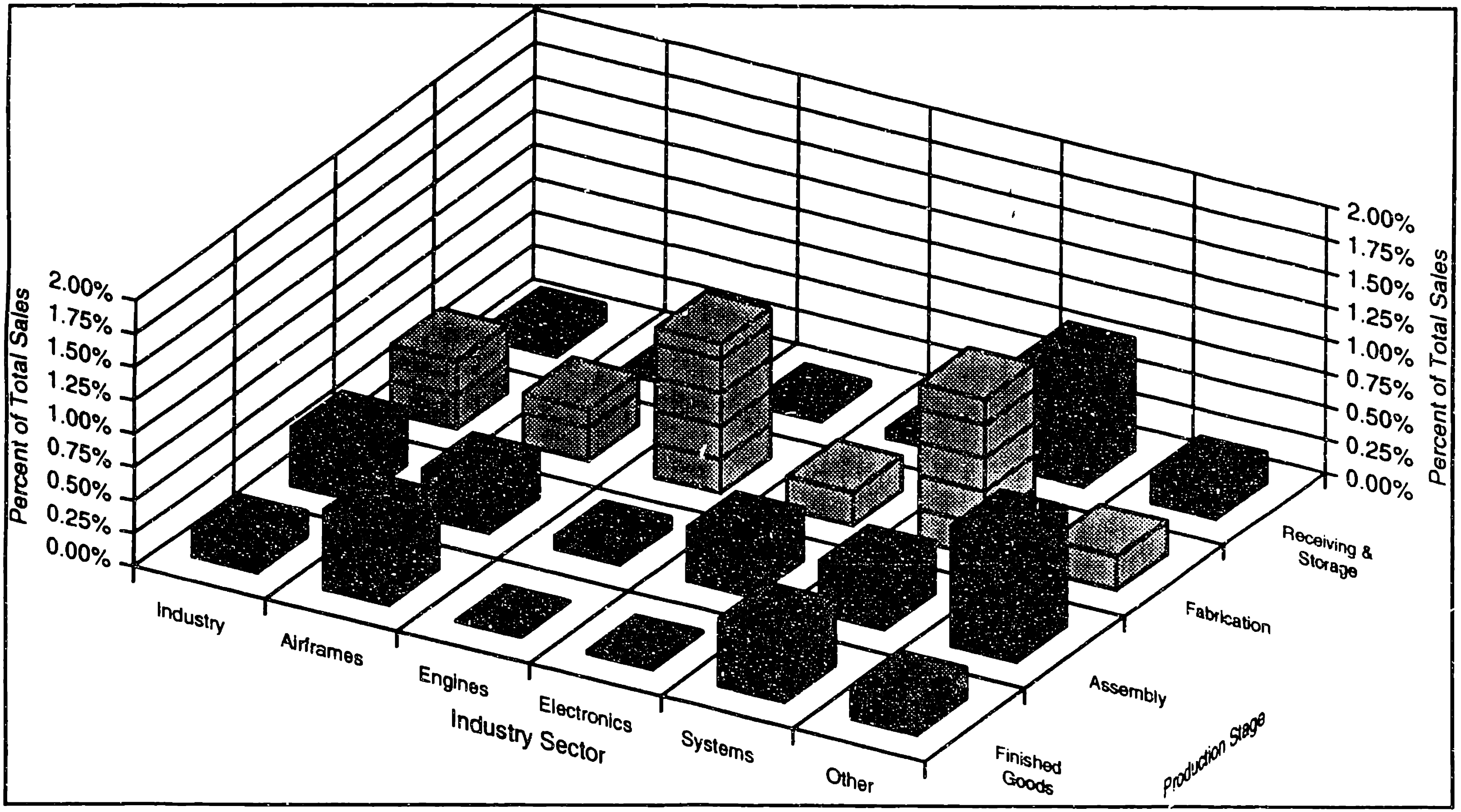

Figure A.3: Scrap, Rework, and Repair Cost As A Percent of Total Sales

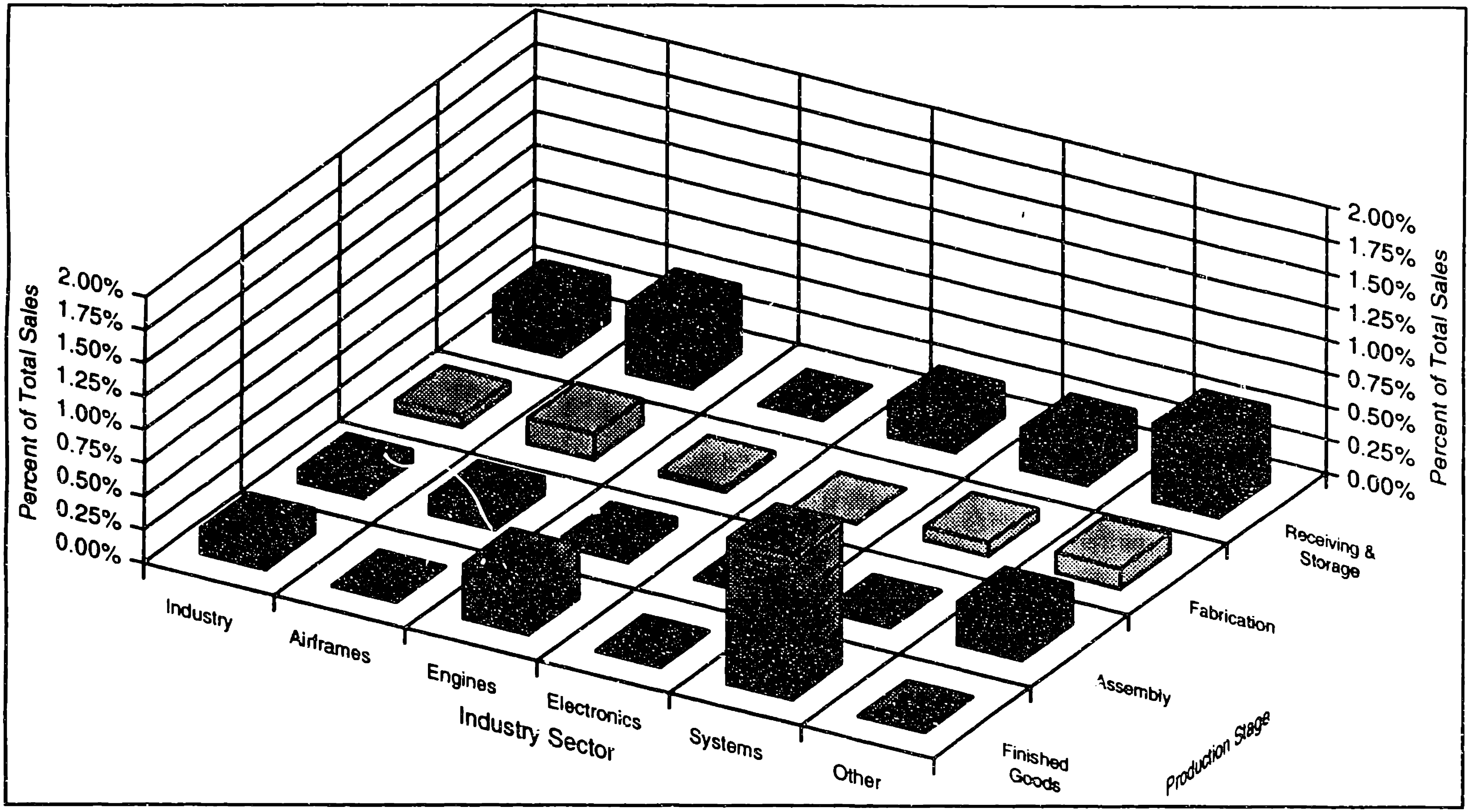

Figure A.4: Obsolete and Excess Inventory As a Percent of Total Sales

Table A.4: Percentage of Responses Where Figures Are Readily Available for Value of Total Inventory

Airframe	90%
Electronics	92
Systems	100
Engines	100
"Others"	83
Industry	**91%**

Alsc within the Accounting Practices section, respondents were asked to provide a profile of the age of inventory within each stage (receiving and storage, fabrication, assembly, and finished goods). This information was then combined with data from the Metrics question which asked companies to provide the *relative* percentage of inventory contained in each stage by dollar value. Figures A.5 to A.8 show the resulting inventory profiles (by age and by stage) of the various sectors. Perhaps most informative about these questions is the fact that so few companies were able to respond. In the Airframe sector, only one company out of the ten surveyed had this information available and, in the "Other" sector, only one of six. Even the Electronics and Systems sectors' response rates of 46 percent and 75 percent respectively were still surprisingly low. A lean profile would show inventory which is relatively young in age and which is clearly progressing through the various stages (i.e. no inventory over a year old in receiving and storage when all other stages show younger inventory). It is not clear that any of the sectors surveyed possess these lean inventory qualities.

A third area of interest in the accounting section of the survey was the use of Activity Based Costing (ABC). This relatively new accounting method is a departure from the traditional manner in which manufacturing costs have been tracked. Typically, specific individual activities during the manufacturing process cannot or have not been tracked. Costs instead are pooled into overhead and assigned to various products or processes in a number of (sometimes seemingly random) ways. ABC attempts to address this problem by monitoring individual activities and attributing costs directly to that activity. The result is a much clearer picture of which items or products are profitable or not and to what extent -- a leaner way of looking at accounting. Simply knowing where your true costs lie is certainly a step toward leanness. ABC is increasingly being adopted in the commercial world, but its use for a number of reasons is still limited in the aerospace industry, as shown in table A.5.

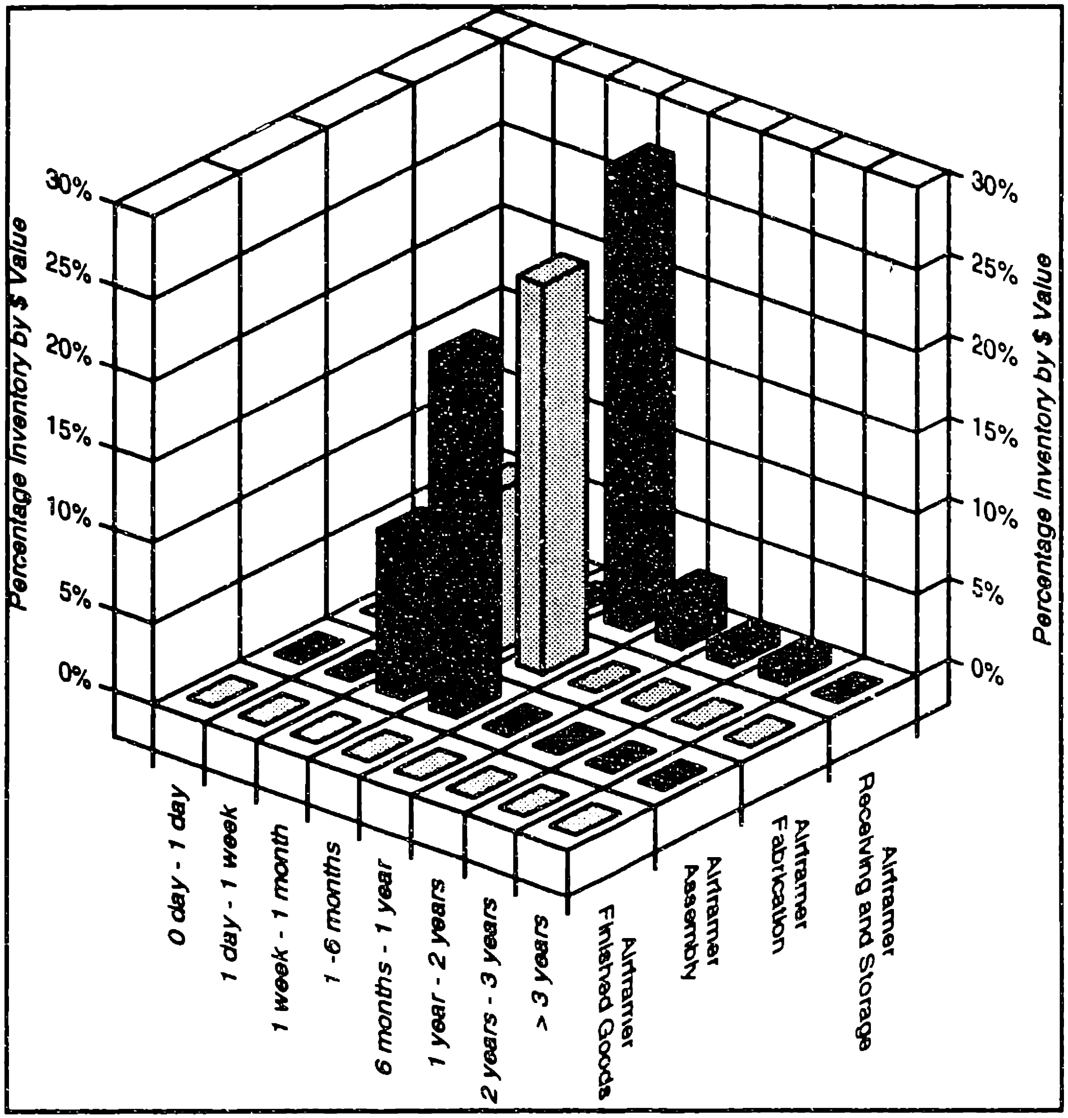

Figure A.5: Age by Stage for the Airframe Sector (Percent Airframe Responding: 10%)

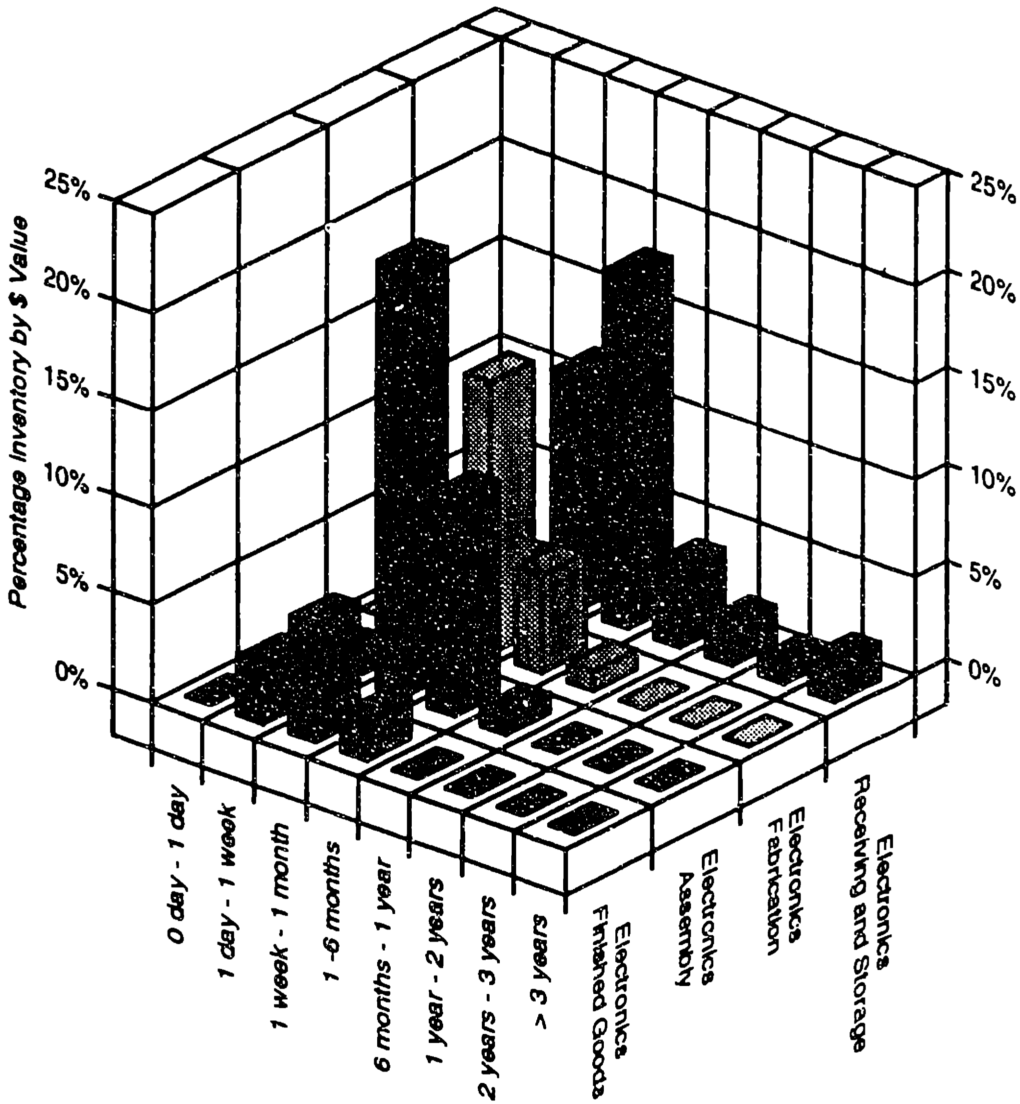

Figure A.6: Age by Stage for the Electronics Sector (Percent Electronics Responding: 46%)

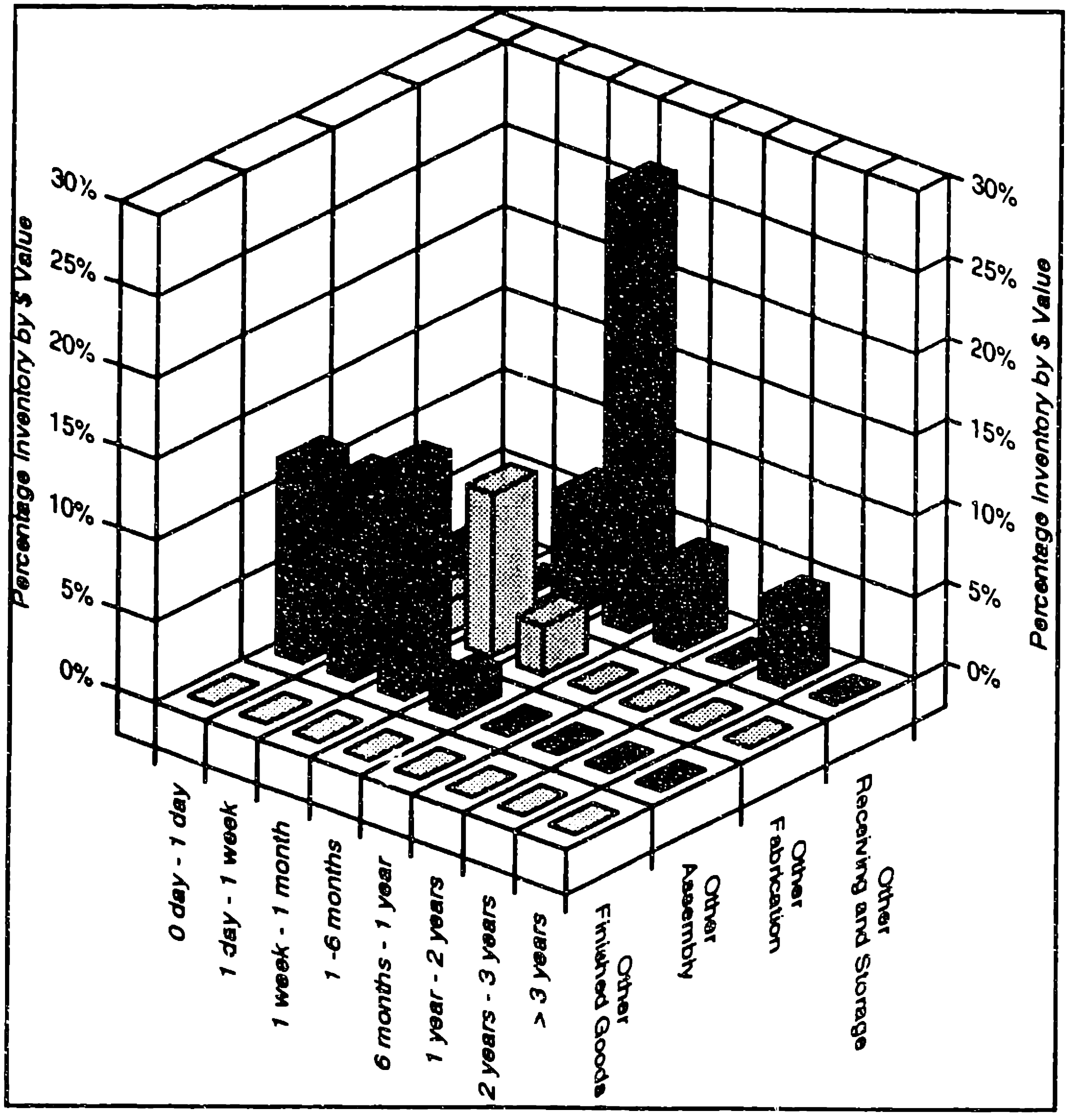

Figure A.7: Age by Stage for the "Other" Sector (Percent "Others" Responding: 17%)

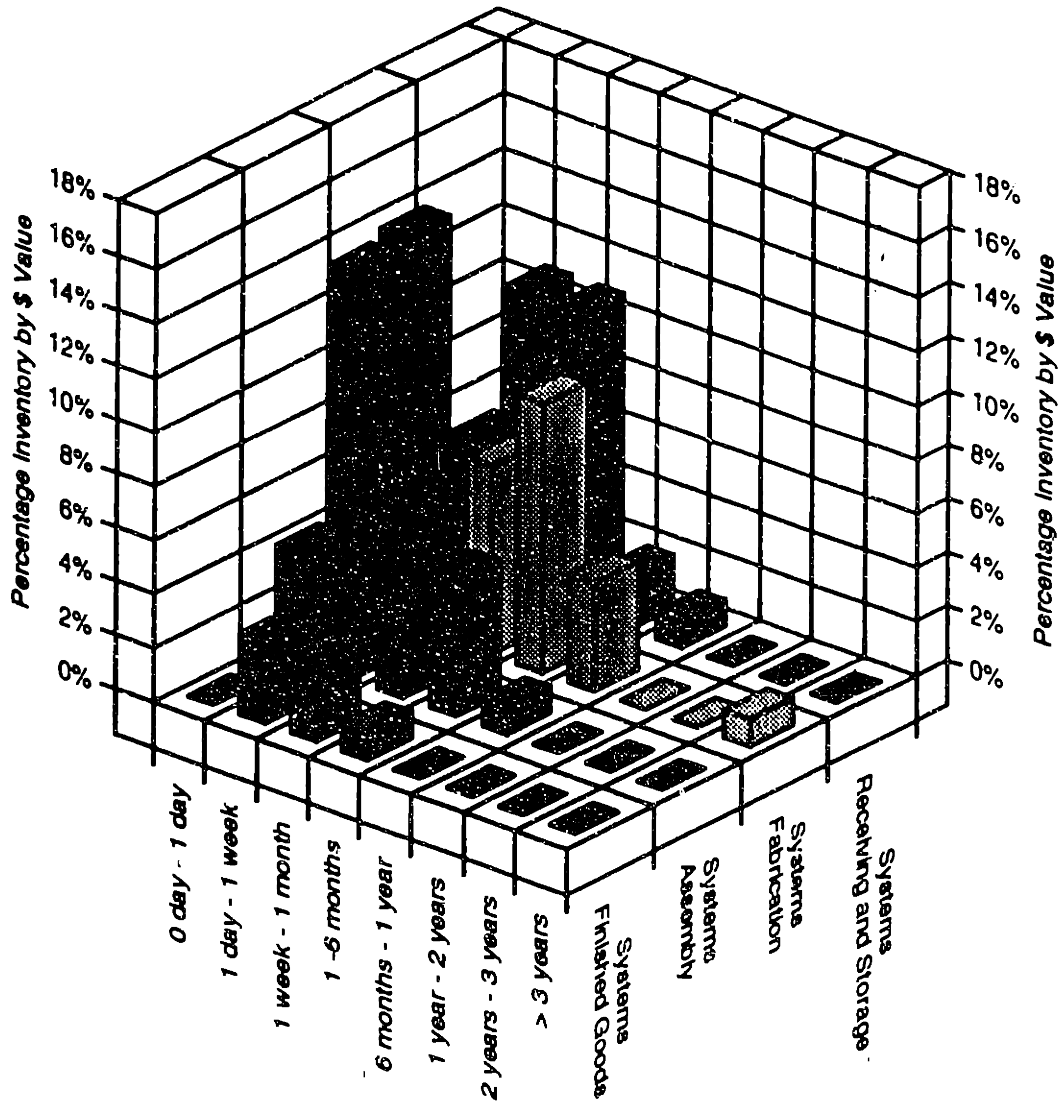

Figure A.8: Age by Stage for Systems Sector (Percent Systems Responding: 75%)

Table A.5: Percentage of Companies Using Activity Based Costing

Airframe	30%
Electronics	23
Systems	0
Engines	0
"Others"	33
Industry	**22%**

There is not a great deal of incentive for companies to transition from traditional cost accounting to the arguably more accurate ABC method. Government representatives have access to much of the data which companies generate on their operations. Industry representatives worry that, should the government discover an area where profits are high in a particular operation, there would be an attempt to limit profits in this area. On the other hand, the industry is concerned that, should the government discover an area where profits are low or even non-existent, there would be no similar attempt to adjust for this loss. Clearly, the incentive system is not conducive to change. This entire topic is too broad and its impact has too great a consequence to industry and government to be adequately covered here. Activity Based Costing in the aerospace industry should be an area for further research under the Lean Aircraft Initiative.

The final questions in the "Accounting Practices" section compared accounting methods for tracking inventory with the actual method of picking inventory (last-in first-out (LIFO), first-in first-out (FIFO), random, moving average, etc.). Figure A.9 displays these results and indicates that picking and accounting methods do not match up well. The way in which an activity is being accounted for does not align with the way in which that activity is actually being done.

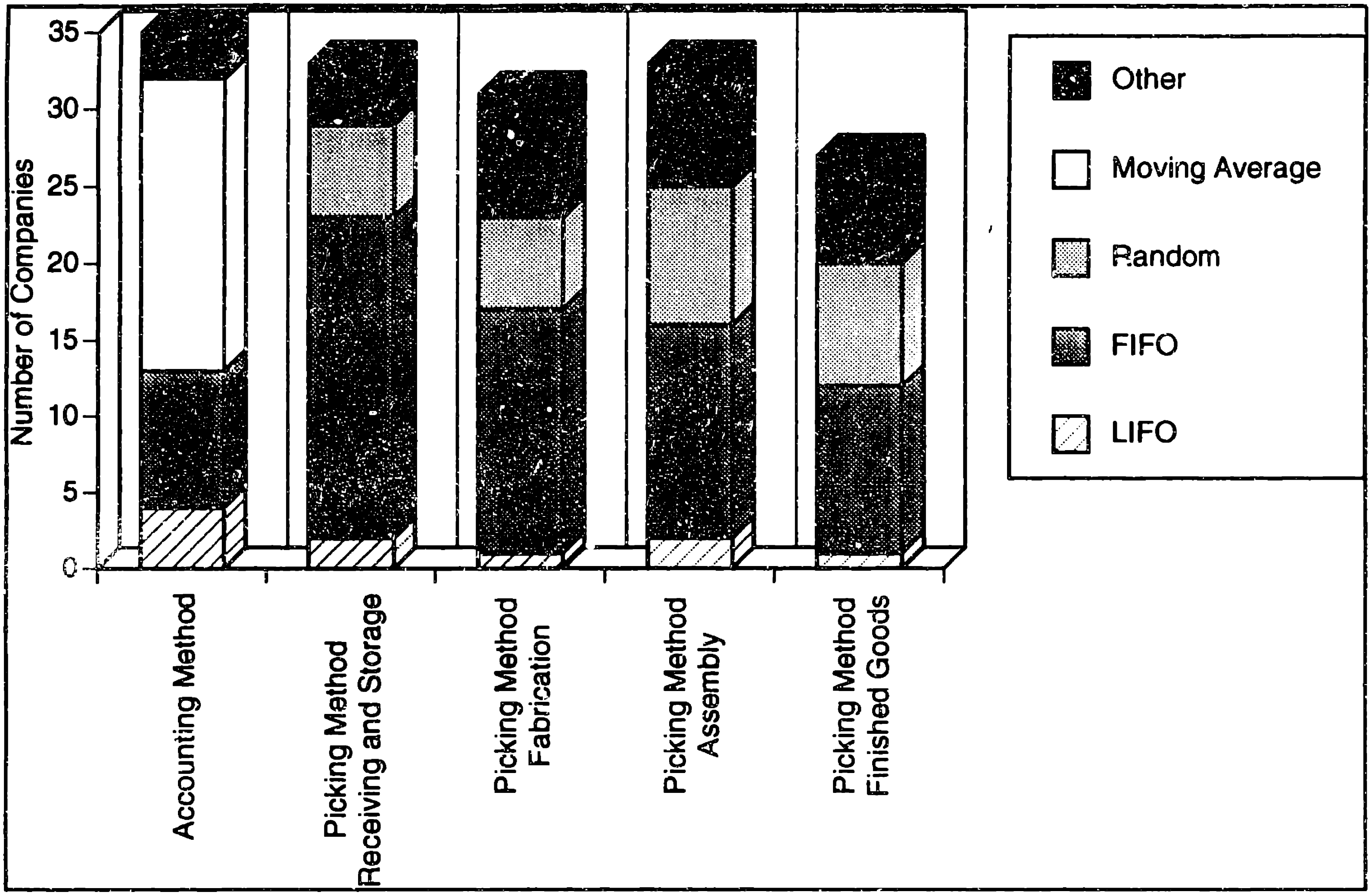

Figure A.9: Inventory Tracking Practices, Actual vs. Accounting

A.4 Inventory Handling and Facility Management

The "Inventory Handling and Facility Management" section covered questions which related to the physical handling and storage of inventory as well as to details on the actual management of the plant. For example, the section asked responding companies to identify their preferred storage locations. Figure A.10 shows a graphical representation of responses. Again, the answers were sector dependent; Electronics and Systems companies tended to prefer on-site central storage sites, while Airframes tended to distribute inventory in a variety of locations. For the most part these preferences seem to correspond with the nature of the project -- a large product with a number of manufacturing steps (such as an airplane or engine) is going to be being stored at the workstation itself. As evidenced by the Toyota Production System, a manufacturing system with little inventory as a whole, stored primarily at the stations themselves (in view of the production line), is an optimal lean arrangement. It would seem with this tenet in mind that the airframe and aerospace industry could do more to reduce inventory in certain phases such as receiving and storage and could also work to move the existing inventory to locations which are more conducive to ultimately eliminating that inventory to the greatest extent possible.

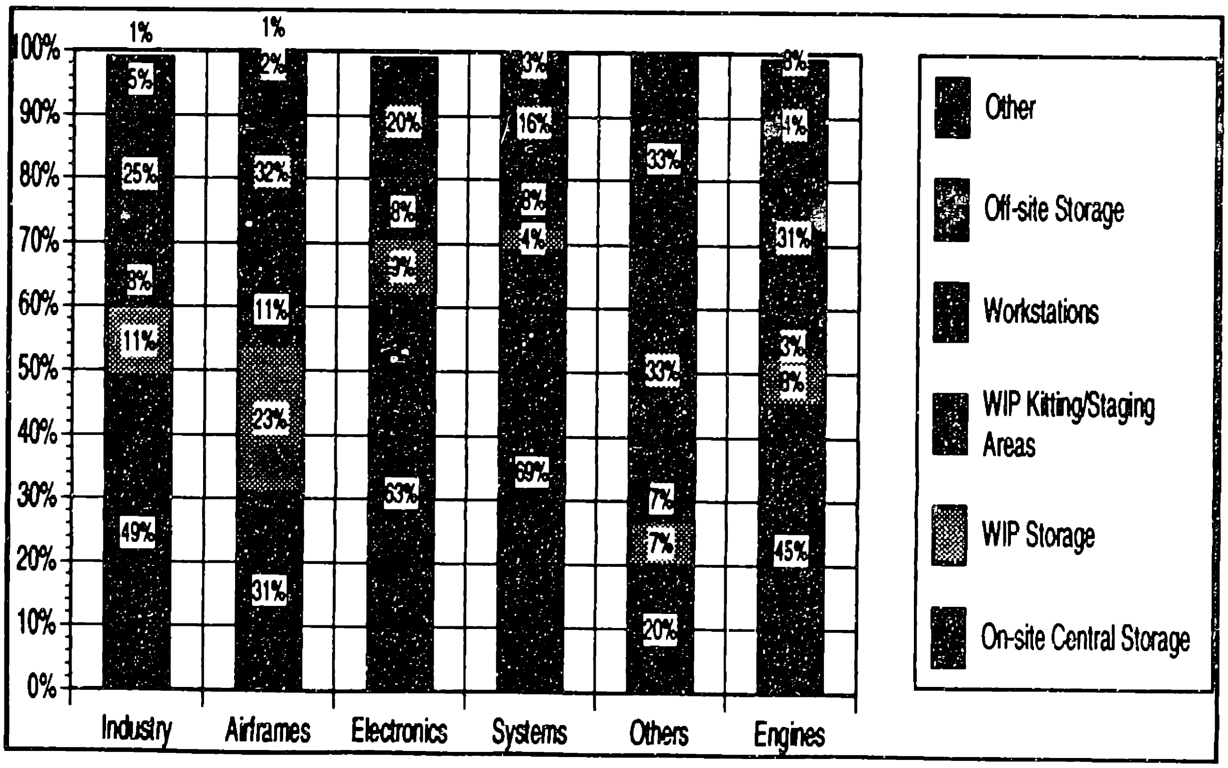

Figure A.10: Preferred Inventory Storage Locations

A.5 Planning and Simulation

The "Planning and Simulation" section was designed to gauge the extent to which companies had utilized and implemented common production techniques and accepted simulation tools into their everyday operations. Companies were asked whether or not they employed job-scheduling to minimize or reduce inventory build-up or shortages. Although use of job-scheduling is the norm, fully 18 percent of the industry does not utilize this planning practice at all (see table A.6).

Table A.6: Percentage of Companies Using Job-Scheduling to Minimize Inventory Build-Up or Shortages

Airframe	80%
Electronics	92
Systems	100
Engines	100
"Others"	50
Industry	**82%**

Respondents were also asked whether they have a master production control schedule, and, if so, if that schedule is automated. Most companies (nearly 95 percent) do have production control schedules, and nearly three-quarters of them are fully automated.

Companies were also asked to identify the simulation tools used in their operations, such as Manufacturing Resource Planning (MRP II), Program Evaluation and Review Technique (PERT), and Critical Path Method (CPM). The results, displayed in figure A.11, appear to be sector dependent Some sectors show more advanced usage than others for tools such as MRP II (see "Others" specifically). This conclusion comes with the caveat that the sample size for the "Others" sector is smaller than that for sectors such as Electronics and Airframes. Industry-wide, use of any of the simulation tools runs at about 60 percent, with MRP II being the most commonly employed. Use of an automated process flow scheduling and planning system along with simulation modeling is considered to be an essential element in a company's progress towards lean manufacturing.

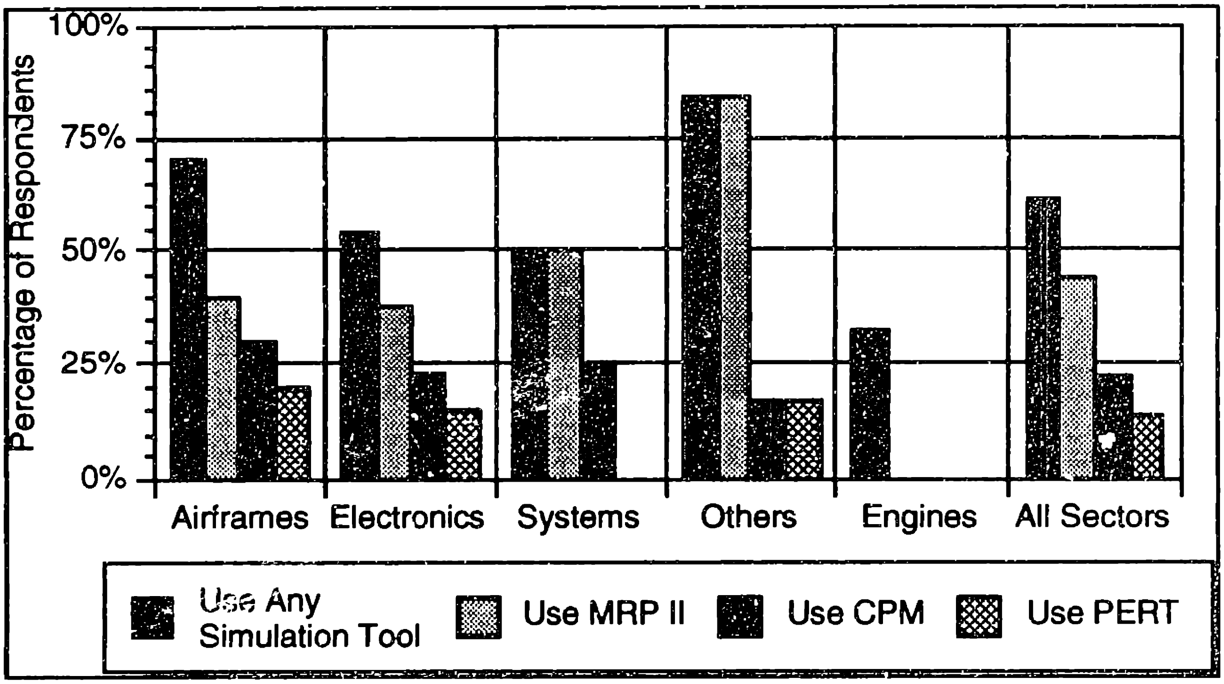

Figure A.11: Use of Simulation Tools

A.6 Inspection and Defects

A great many questions concerning inspection, process control, and overall procedures for the handling of defective work were contained in the "Inspection and Defects" section. Respondents identified inspection sites in the four stages of production, typically performed by corporate quality control representatives, line workers ("touch labor"), or government inspectors. As figure A.12 shows, the bulk of inspection seems to be done by the quality control organization of a company. The Systems sector seems to be the exception to this rule, for with these four companies there appears to be little in the way of inspection by quality control personnel in the stages of fabrication and assembly in particular. Other sectors report an extremely high percentage of inspection being done by quality control; numbers as high as 80-90 percent within a stage were not uncommon.

Companies were also asked to identify the percentage of inspection conducted by touch labor (see figure A.13). While the Engines and Systems sectors show a high percentage (up to 66 percent) of touch labor involvement in inspection, other sectors such as the Airframe group show nominal inspection (only 14 percent at the most) being done by those who execute value-added, hands-on work on the product. Lean principles hold that manufacturing touch labor should do their own inspection, in place of formal inspections

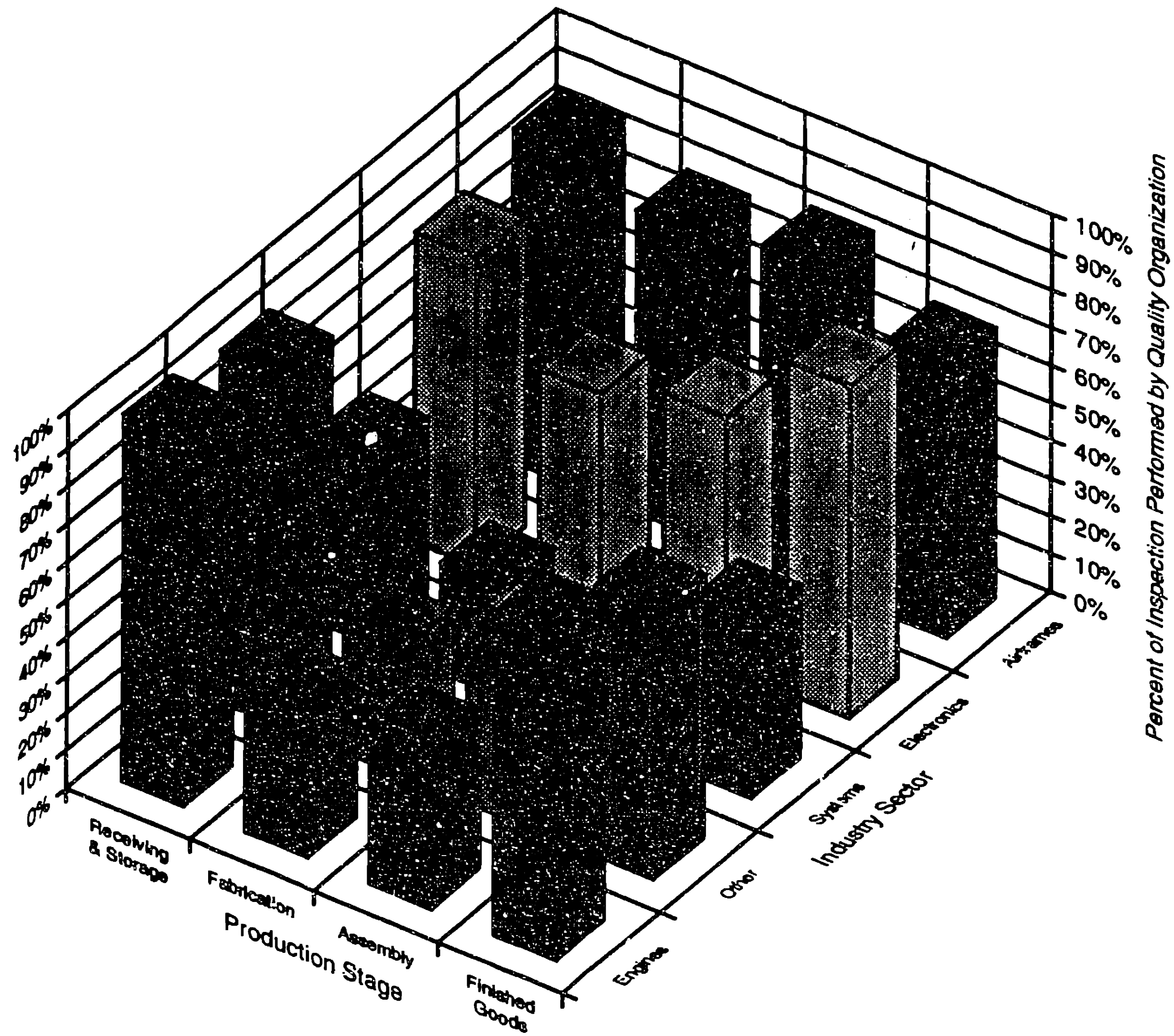

Figure A.12: Inspection by Quality Control Organization

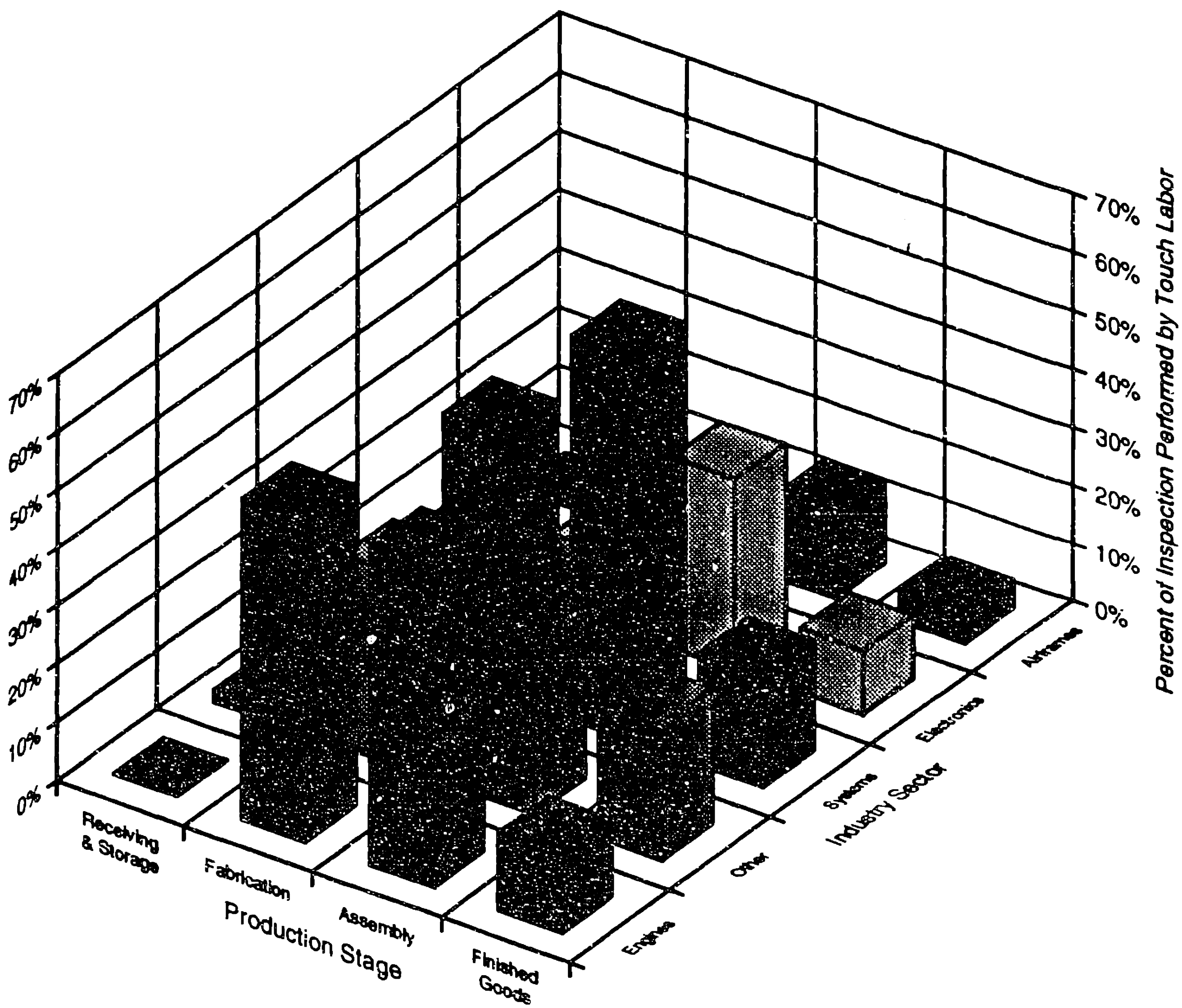

Figure A.13: Inspection by Touch Labor

by "quality control" affiliated personnel. Sponsoring companies were also asked to describe the distribution of government inspection over the four production stages (figure A.14). With the exception of the Airframe sector, the largest share of government inspections by far are in the finished goods area. The Airframe sector reports that the majority of the government inspection effort is in the assembly phase of production. The government is currently acting to remove the redundancy inherent in its system of inspection and is working towards the inspection of processes rather than products. Results from the survey show that industry is making the move towards process verification as well, and the source of this initiative is predominantly top management (see figure A.15). This trend is perhaps a sign that government and industry are in fact cooperating to improve the quality assurance process.

The "Inspection and Defects" section of the survey also queried participants on repair/scrap/use disposition cycles, the length of time it takes a company to deal with the disposition of defective parts or products. Results were consolidated over all stages of production for each of the industry sectors, and these results (figure A.16) show that the Airframe, Systems, and Engines sectors take approximately five days to determine the disposition of a repair/scrap/use issue. On the other hand, the Electronics sector takes an average of 9 days, and the "Others" sector an average of 16 days to make a similar judgment or determination. According to lean principles, there should be a rapid decision cycle in place to determine the disposition of faulty parts.

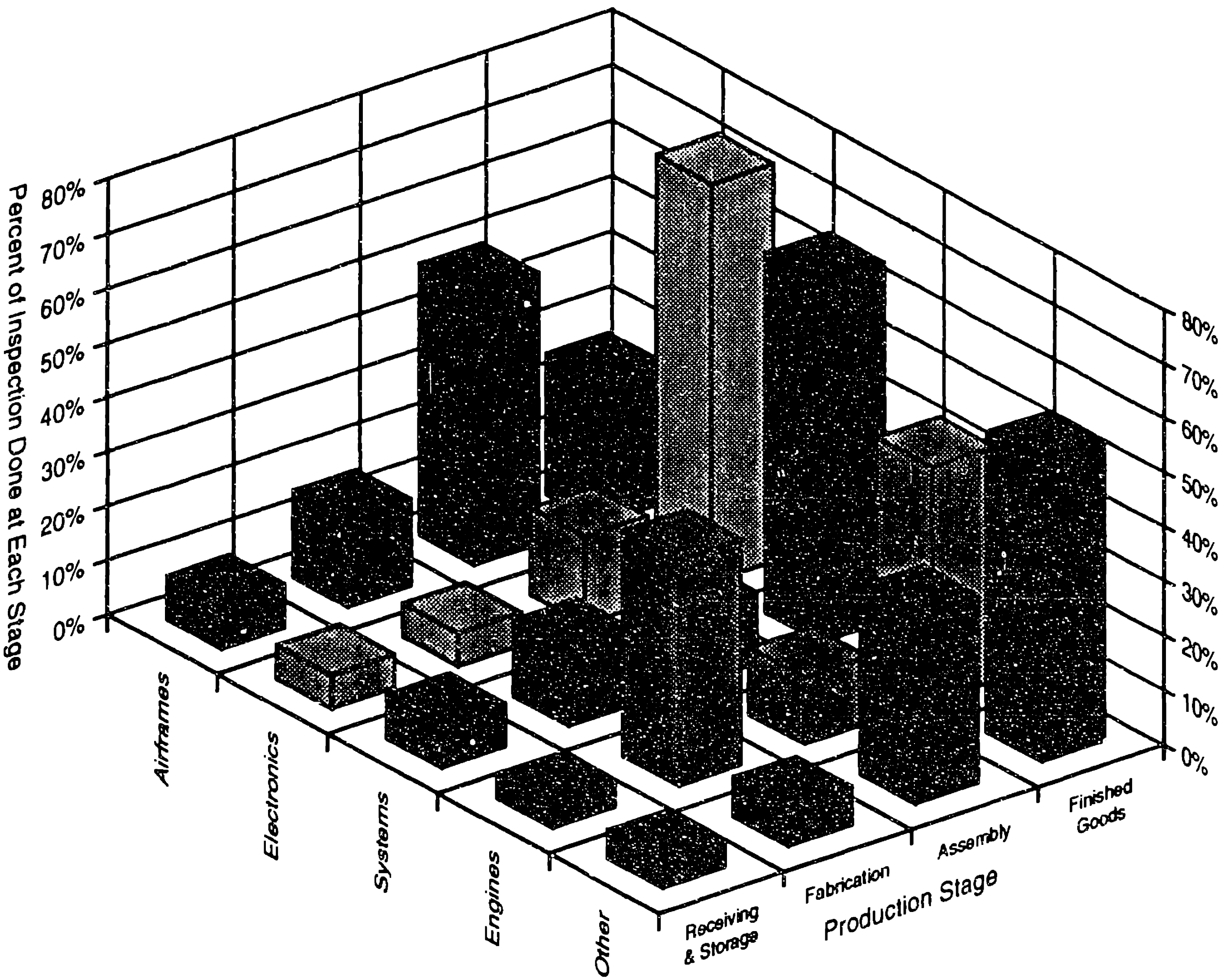

Figure A.14: Emphasis on Government Inspection

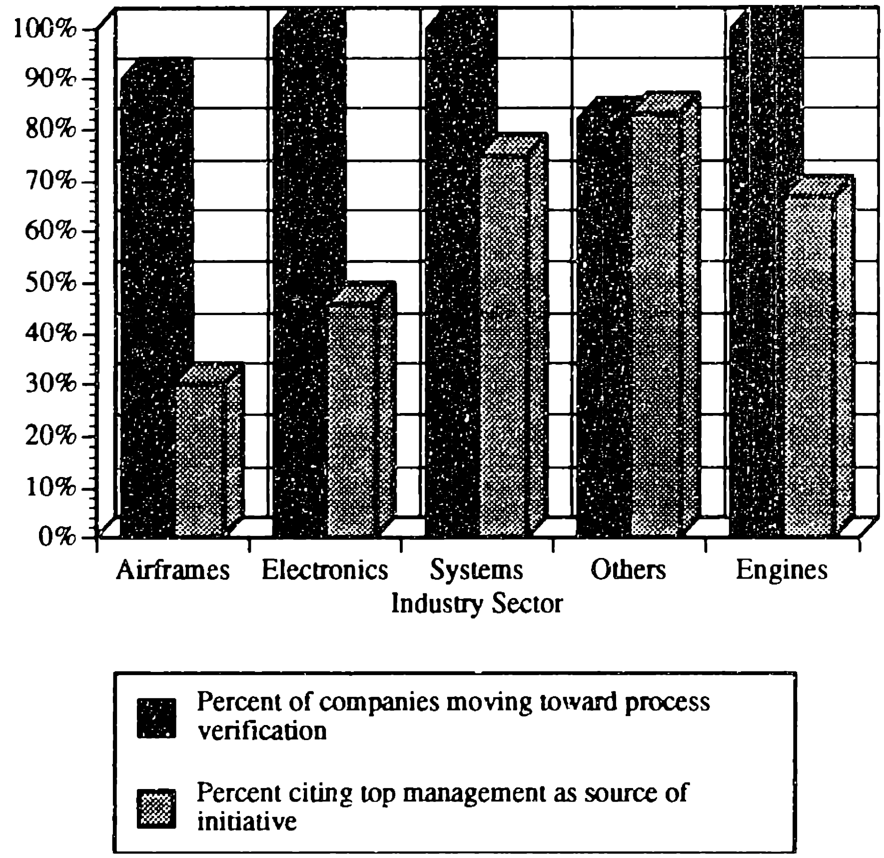

Figure A.15: Move Towards Process Verification

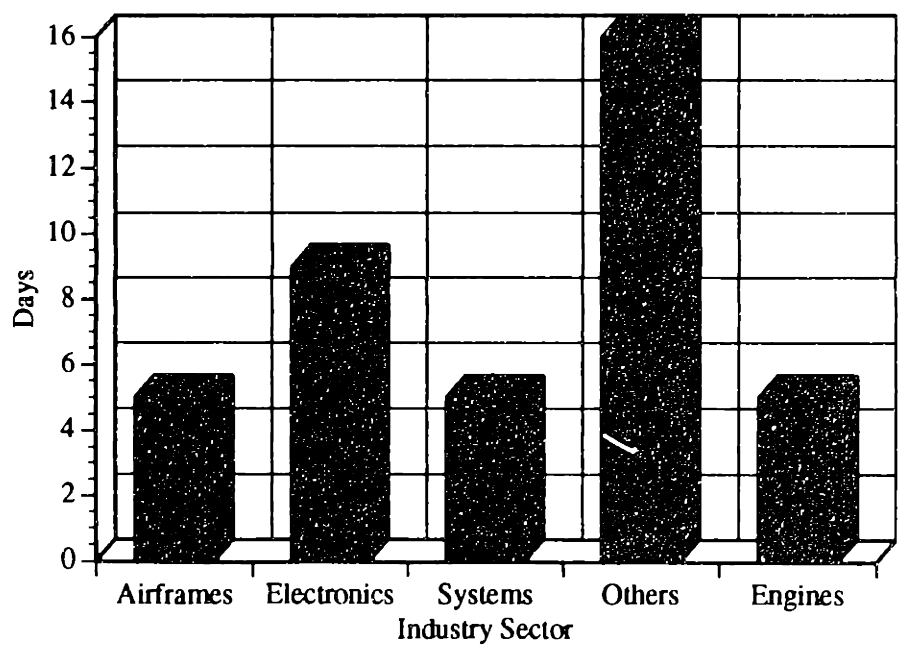

Figure A.16: Repair/Scrap/Use Disposition Cycles

This section of the survey also included questions about the use of Statistical Process Control (SPC) in production, a practice which is increasingly becoming the norm in commercial manufacturing. As is shown in figure A.17, the use of SPC in the aerospace industry is quite limited, with the Electronics and Systems sectors showing the greatest use of this process control method. When asked why the use of SPC is not more extensive, respondents most frequently alluded to corporate resistance to change. Problems implementing the technique with low production volumes and government resistance to change were also cited.

In a similar vein, respondents were asked about their production defect rates. Knowledge of Defects Per Million (DPM) for *any* stage is extremely limited in most sectors (figure A.18). Even fewer companies (approximately 10 percent of those surveyed) have this information for *all* stages of production. All responding companies in the Systems sector knew DPM for all stages, evidence of their advancement towards leaner production techniques.

Finally, companies were asked about inspection tests performed by suppliers. The repetition of these tests at the receiving company is most prevalent in the Electronics sector, occurring more than 45 percent of the time, and least prevalent with the Engines at only slightly less than 5 percent of the time (figure A.19).

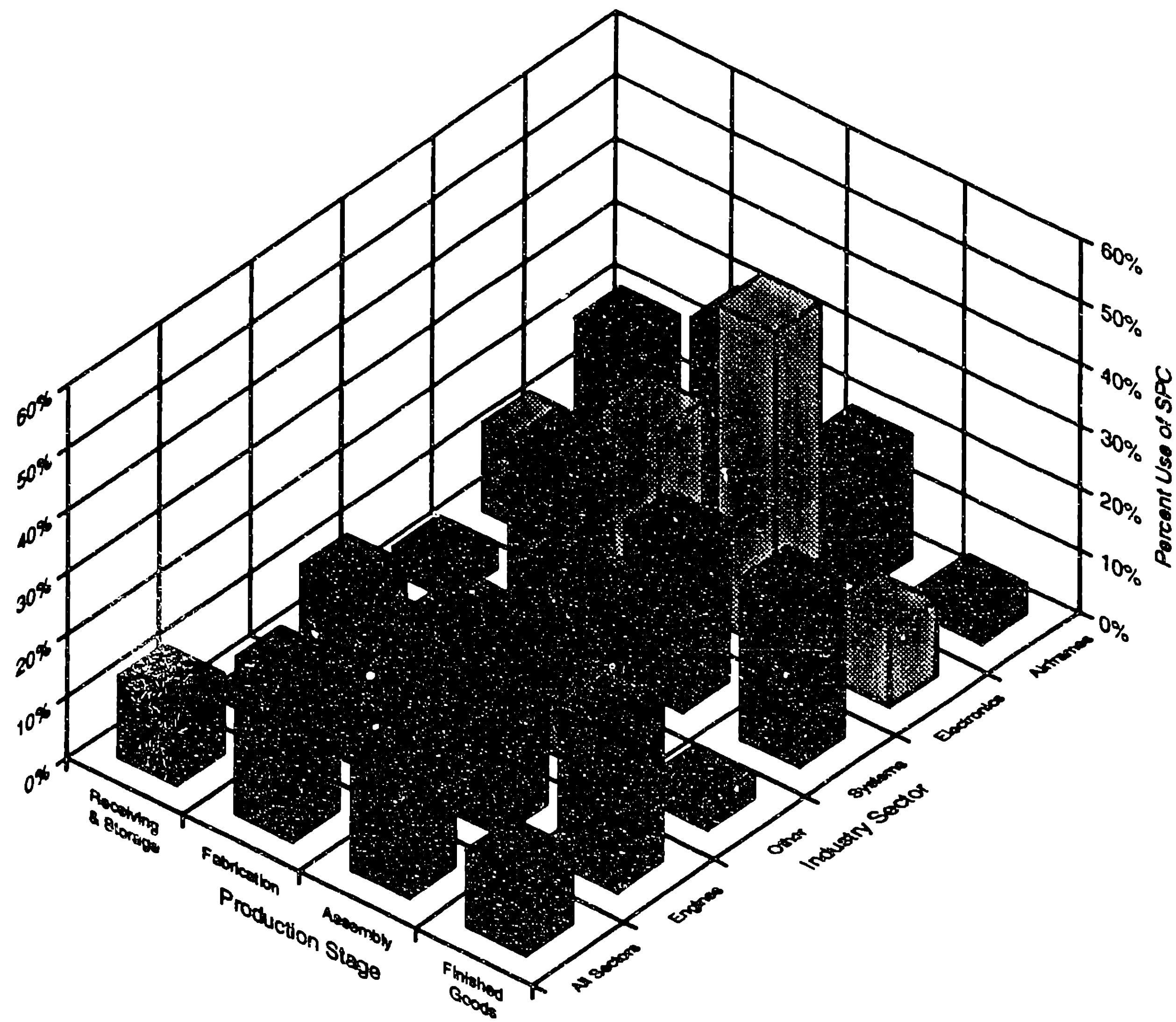

Figure A.17: Use of Statistical Process Control (SPC)

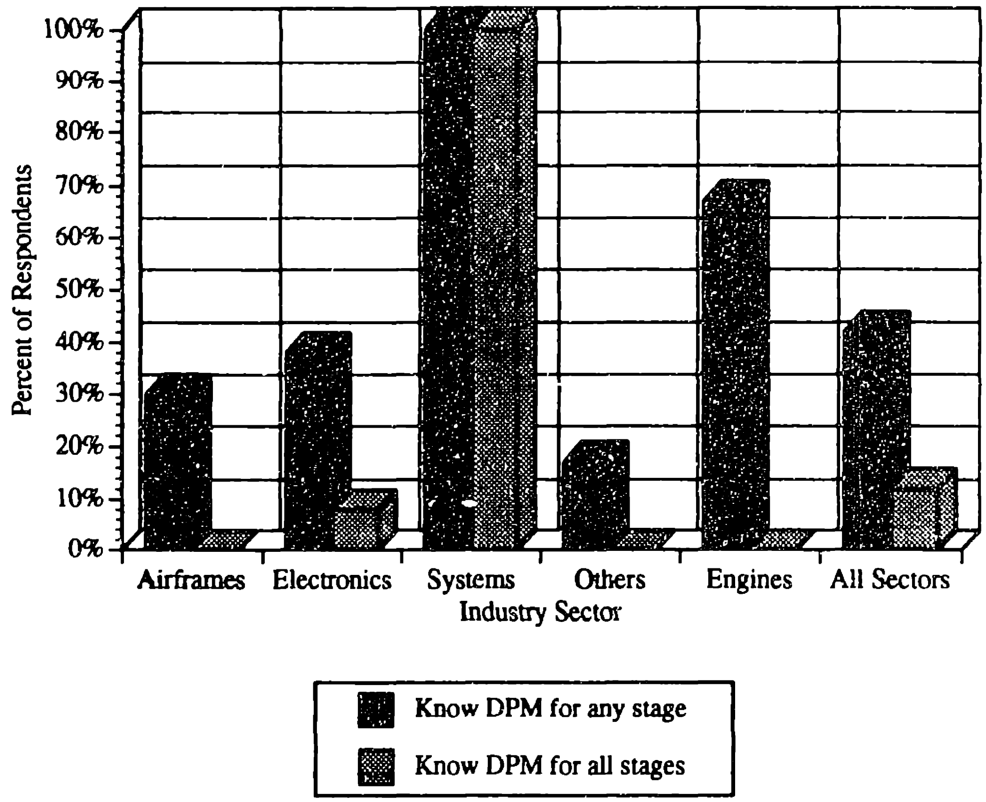

Figure A.18: Knowledge of Defect Rate

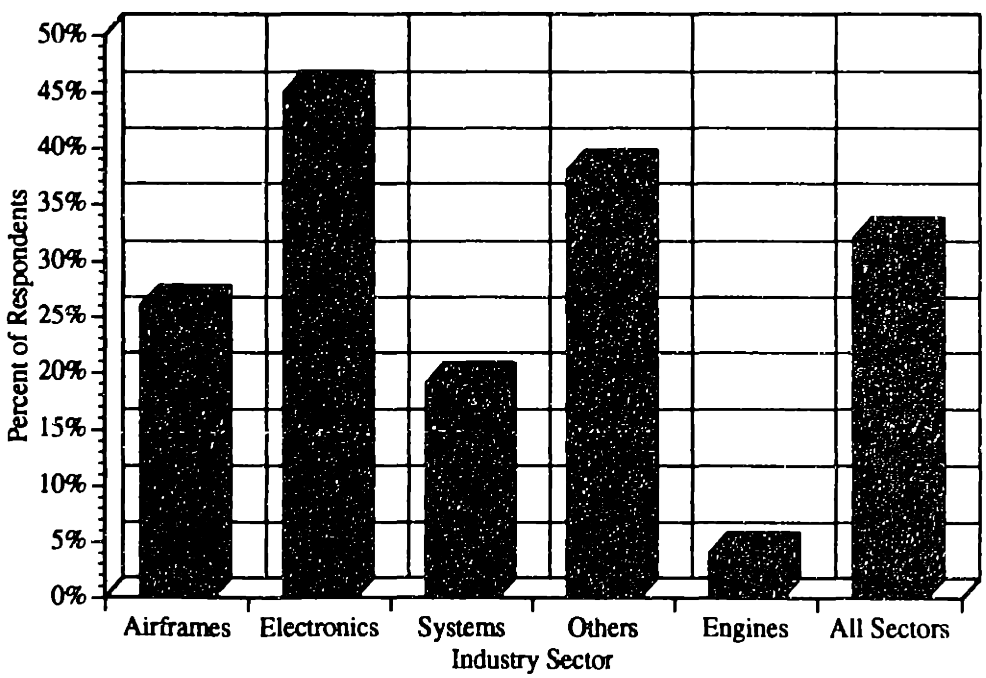

Figure A.19: Repeat Inspections or Tests

This information matches somewhat with data concerning the use of certified suppliers. As shown in figure A.20, an average of 50 percent of the suppliers to Engine manufacturers are certified for "dock-to-stock" shipments, with 70 percent or more of the value of total receipts for this sector being accounted for by these suppliers. Lean manufacturing depends on a close, lasting, and symbiotic relationship between suppliers and manufacturers, a relationship which would be exemplified and encouraged by such a "certified" supplier arrangement so that minimum re-inspection is performed by the receiving party.

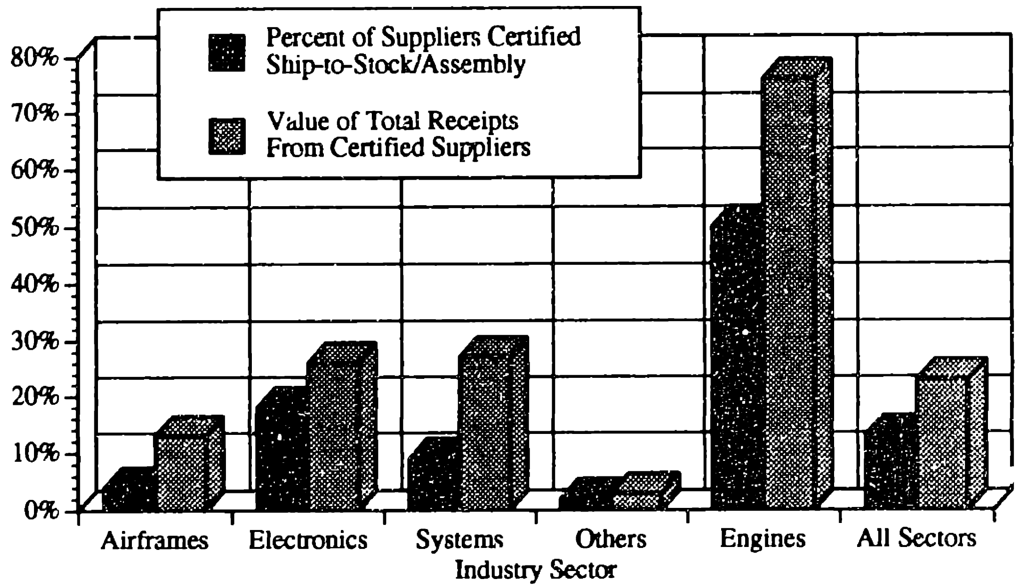

Figure A.20: Use of Certified Suppliers

A.7 Government Relations

There were five questions in the Government Relations section of the survey, some of which measured reactions to various government or company standards and practices, including:[4]

- Multi-year contracts with funding
- Fixed-type contracts with progress payments
- Fiscal-year buy quantities
- MIL-STD-1567A
- C/SCSC
- Government interpretation of contract
- Cost-type contract with public vouchers
- Contractor interpretation of contract
- MIL-Q-9858A
- MMAS

4 All of the standards and practices referred to here with acronyms are defined in the List of Acronyms found at the beginning of this thesis.

- DCAA audits
- Variability Reduction Guidance
- Government approval of suppliers
- Government socio-economic procurement practices
- MIL-STD-1520
- Government cost accounting standards
- MIL-STD-1535
- Government Property Clause
- Government initiated Engineering Change Orders

They were then asked to indicate how much these government standards and practices influenced inventory levels on government contracts according to a seven-point scale ranging from "tends to drive inventory levels up a lot" to "tends to drive inventory levels down a lot." The industry results can be found in figure A.21. Survey respondents evaluated how useful the standard was to their company's operations (figure A.22). Finally, companies were asked to rate the degree of financial and human resource burden required in support of the activity (figure A.23). This series of questions was designed to identify which standards were barriers to the reduction of inventory, required extreme financial resources, and were of low utility.[5] Multi-year contracts with funding are industry-wide considered to be "positive" (reducing inventory, low burden, and high utility). Items such as MIL-STD-1535, MIL-STD-1520, MIL-Q-9858A, MIL-STD-1567A, and government socio-economic procurement practices are considered to be less favorable to optimal operations flow and inventory reduction. In follow-on questioning, the Electronics and Airframe sectors were asked specifically why standards such as 1520, 1535, and 1567A drove up inventory. Some explained that the impact was really in terms of additional overhead incurred and direct labor cost increases. Others, however, responded that non-compliant deliveries from suppliers could require expedited deliveries to compensate for lack of quality and to maintain schedules. Further research is needed as to why certain standards or practices received favorable or unfavorable responses and as to the true magnitude of problem.

---

[5] Data from each of these three questions were normalized to account for the respondents' tendencies to answer all questions towards one end of the scale or the other. The graphs presented as figures 3.24 to 3.26 show average normalized responses to each standard or practice *with relation to* the other standards or practices within that same question.

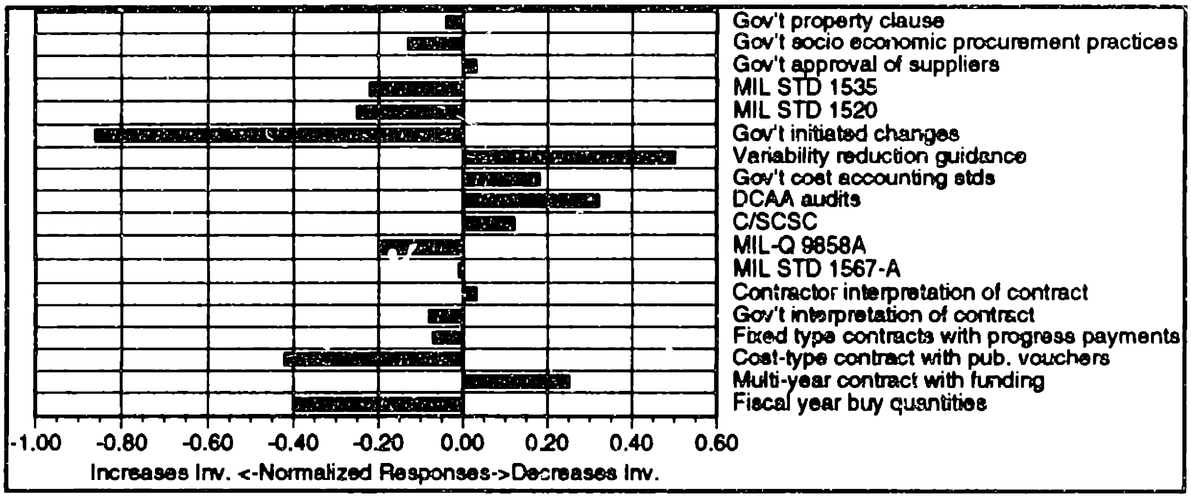

Figure A.21: Government Influence on Inventory Levels

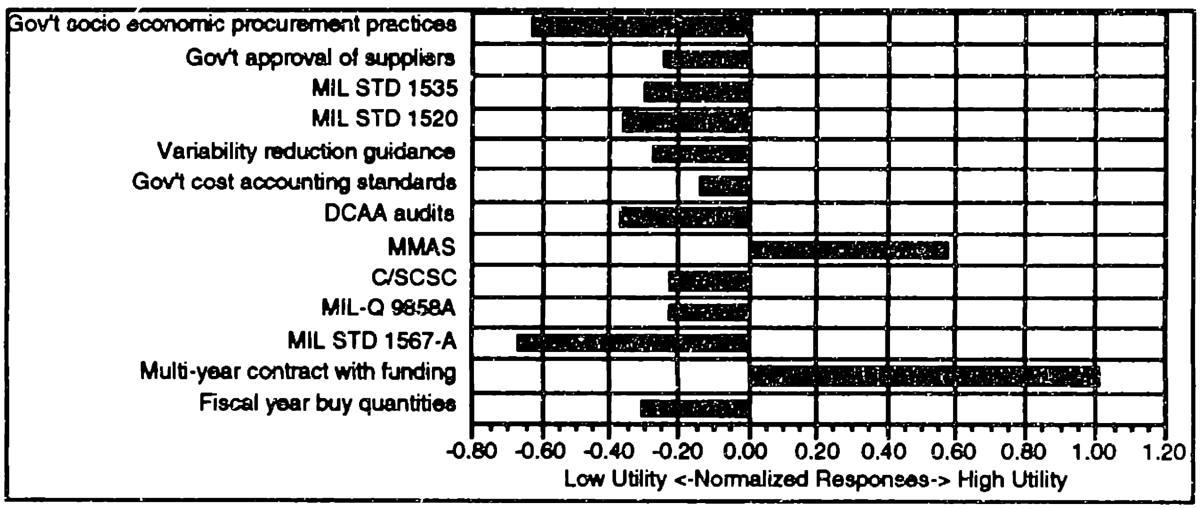

Figure A.22: Utility of Government Standards and Practices

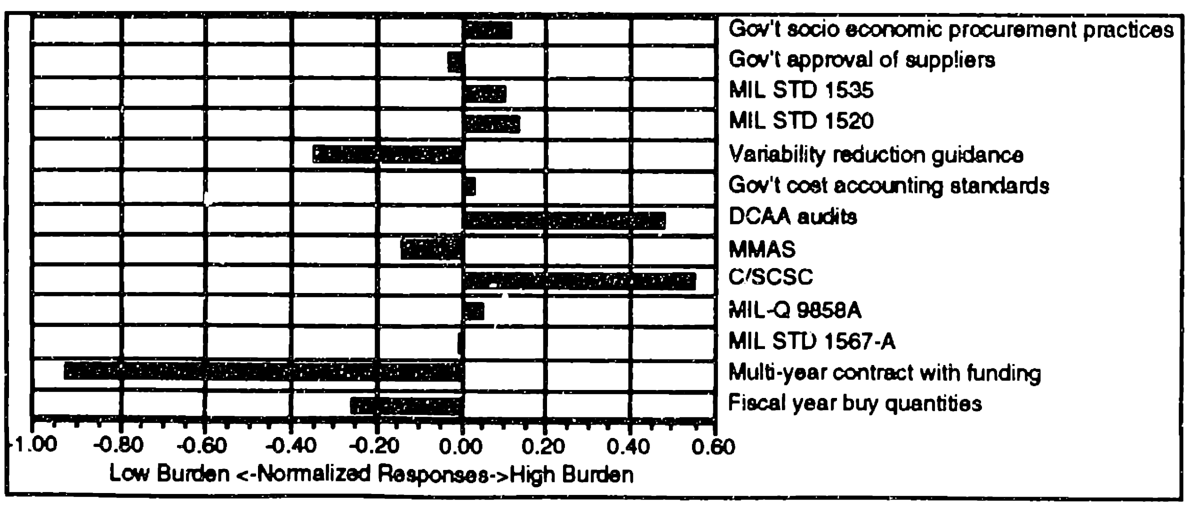

Figure A.23: Resource Requirements for Government Standards and Practices

Two final questions in the Government Relations section asked about differences in purchasing or acquisition between government and civilian contracts for various categories of inventory. Figures A.24a-b show the results just for the Airframe sector, but the results for the other sectors and for the industry as a whole were similar. In general, it would appear that ordering practices for commercial and government contracts are not radically different. Within sectors there are best practices, those companies who are ordering with much less buffer time. Some sectors such as Electronics seem to build in longer buffers (ordering more in advance of actual requirements) than others such as Systems and Electronics do. In this case, lean practice would be to purchase as close to need date as possible. Lead times for the industry are fairly short, but there is room for improvement as shown by the best practice participants.[6]

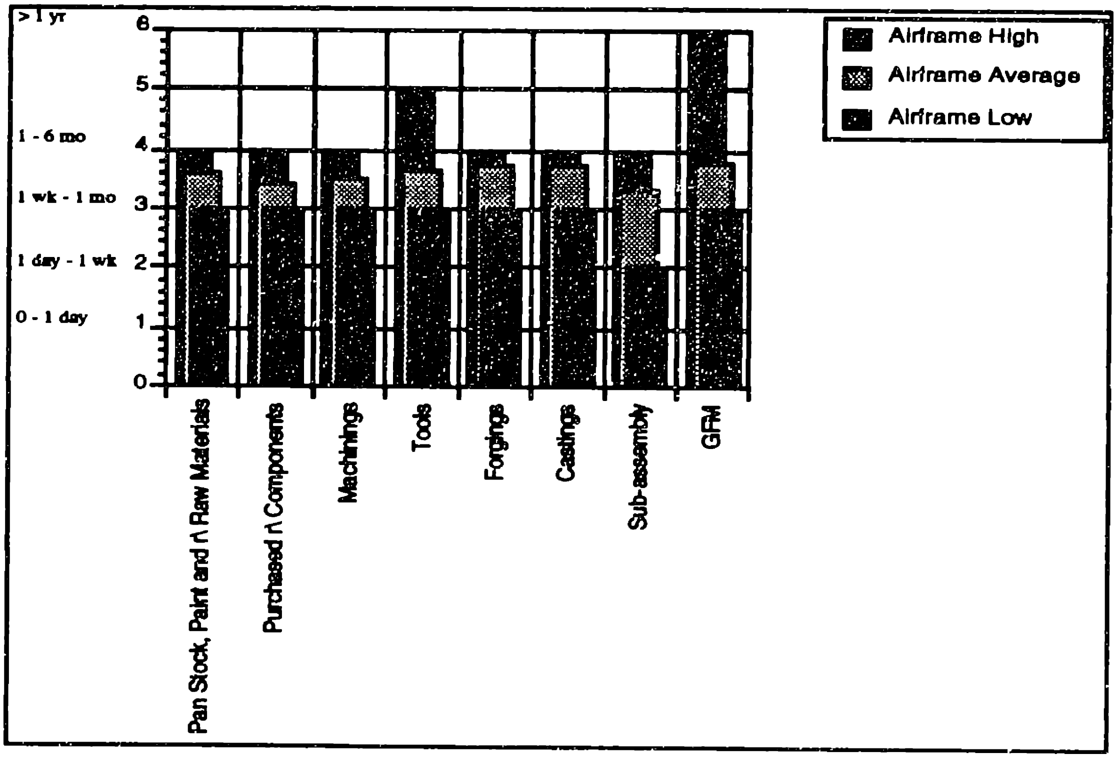

Figure A.24a: Receipt of Inventory for Government Contracts (Airframe)

6 Airframe sector participants suggested that they would have preferred even more gradation within the 1-6 month category for finer distinction between best and worst practices. These data are being collected and will be analyzed at a later date.

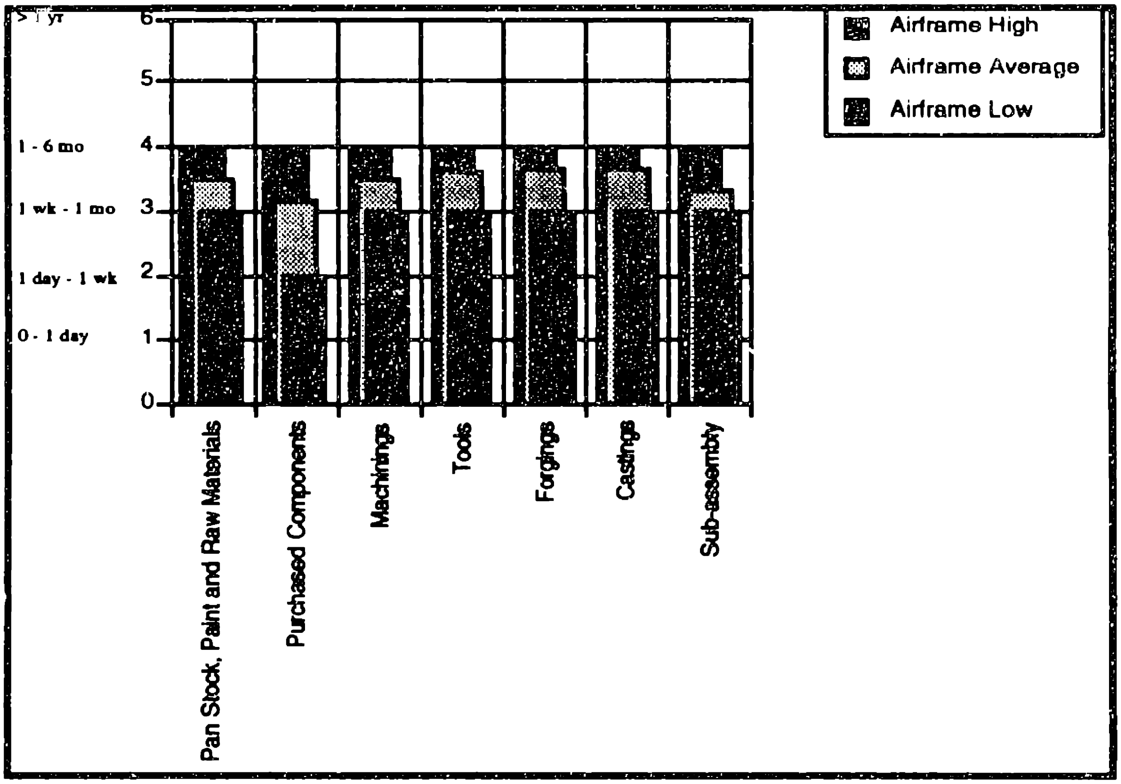

Figure A.24b: Receipt of Inventory for Non-Government Contracts (Airframe)

A.8 Final Comments/Conclusions

The final section of the survey gave respondents the opportunity to provide more extensive comments in the form of "essay answers" to general questions about company inventory practices. Industry-wide, 94 percent of respondents indicated that low inventory levels were a moderate or strong indicator of the company's good health (see figure A.25). Companies were also asked about the existence of programs within their corporations to reduce inventory. Only two companies surveyed did *not* have any such program in place, an indication that companies do find that reduced levels of inventory are in fact important to company survival and competitiveness.

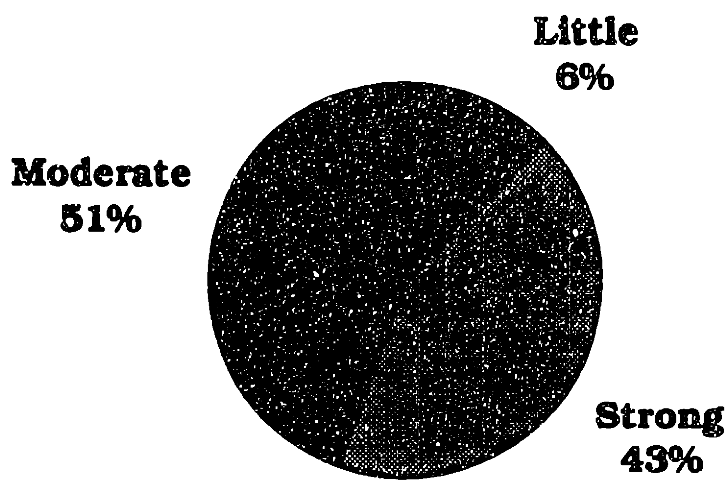

Figure A.25: Low Levels of Inventory as an Indicator of Overall Company Health

Respondents were also asked to name any company-originated disincentives which act to drive inventory levels away from the goal. Corporate emphasis on schedule, problems with the supplier base, desire for quantity discounts, and a focus on bringing in materials early were listed as the top company disincentives. In a related area, respondents were asked if there were government disincentives which would also tend to keep the company's inventory levels away from the desired goal. Here, the most common responses included progress payments, fiscal year buy quantities, and configuration and engineering changes made by the government after material procurement. Finally, the sponsoring companies were asked to name any accounting-related practices which kept inventory levels away from desired levels. Top responses were the separation of material by contract and the traditional practice of accounting for inventory as an asset. Each of the above issues comes up frequently in interviews with sponsoring companies and is itself a worthy topic for further investigation.

As the survey demonstrates, excess inventory can cover problems in other aspects of the production process. Companies are looking at the topic of inventory reduction, but progress is slow, as is consensus on where to begin. The Inventory Practices survey has been useful in revealing the weaknesses and strengths of companies, sectors, and the industry as a whole. It has also been helpful in showing where lean practices can be applied. As an output of the survey, a list of lean principles related to inventory management has been developed (appendix B). The survey accomplished its purpose of giving researchers and sponsors a snapshot of the current state of affairs. From here, best practices and areas for further research can be identified.

Appendix B Evidence of Lean Production[1]

1.	Have a stated inventory goal.
2.	Have a formal program to reduce inventory or streamline inventory handling processes.
3.	Same attitude at all levels of the organization with regards to shortfalls and excess inventory.
4.	Know age distribution of inventory.
5.	Know quantity and value of inventory, and communicate that information to all levels of the organization.
6.	Know location of inventory.
7.	High use of just-in-time (JIT) or near JIT.
8.	Low number of suppliers (high $/supplier ratio).
9.	Low and declining number of job classifications.
10.	Inventory age distribution that shows young inventory at all stages and a definite progression out the door.
11.	Use of manufacturing touch labor to do inspection.
12.	Small number of inspectors.
13.	Use of process verification to replace after-the-fact inspection.
14.	Total top management commitment to process verification.
15.	Rapid decision cycle for disposition of faulty parts.
16.	Have effective system of tracking problems to root causes.
17.	Use of systematic variability reduction .
18.	Use of Statistical Process Control (SPC).
19.	Use of SPC charts as evidence of quality.
20.	High use of SPC in all production stages.
21.	Have data on defects for all stages of production.
22.	Low rate of re-inspection for items already inspected by supplier.
23.	Large percentage of suppliers certified for ship-to-stock/assembly.
24.	Small number of people supporting inventory.
25.	Minimal (ideally zero) scrap, rework, and repair.
26.	No obsolete or excess inventory.
27.	Low cycle time.
28.	Use of automated process flow scheduling and planning system.
29.	Use of simulation to model and plan process flow.

[1] This list was synthesized from the results of the Inventory Practices Survey by Dr. James G. Ling (December 1993). Jim also provided immeasurable support, both intellectual and political, in the preparation of this thesis and deserves much credit for its successful completion.

Bibliography

Bozdogan, Kirkor, "Lean Aircraft Initiative Mission," LAI Internal Memorandum, March 26, 1993.

Chamberlain, Woodrow, "MRP II: Don't Write It Off Yet! Myths and Near Myths," *APICS - The Performance Advantage*, American Production and Inventory Control Society, Falls Church, VA, Vol. 4, No. 3, March 1994.

Goddard, Walter and James Correll, "MRP II In The Year 2000," *APICS - The Performance Advantage,* American Production and Inventory Control Society, Falls Church, VA, Vol. 4, No. 3, March 1994.

Goldratt, Eliyahu M. and Robert E. Fox, *The Race*, North River Press, Inc., Croton-on-Hudson, NY, 1986.

Haupt, B. Michael, "MRP II in A&D: Are We Ready for the Challenges of the 1990s?" *Improving the Process: The Smart Challenge*, APICS Aerospace and Defense Symposium Proceedings, Los Angeles, CA, May 2-6, 1992.

Houlahan, Christina J., *Reduction of Front-End Loading of Inventory: Making the Airframe Industry Lean Through Better Inventory Management,* M.I.T. Master's Thesis, May 1994.

Kapp, Karl M., "MRP II: It's Not a Computer System," *APICS - The Performance Advantage,* American Production and Inventory Control Society, Falls Church, VA, Vol. 4, No. 3, March 1994.

Karmarkar, Uday, "Getting Control of Just-in-Time," *Harvard Business Review*, Harvard Business School Publications, Cambridge, MA, September-October 1989.

Lengyel, Alexander and B.J. Bastow, "Key Issues Needing Resolution During MRP II Implementing in Aerospace and Defense Companies," *Thriving on Change*, Proceedings of the APICS Los Angeles - Aerospace and Defense Special Interest Group 1991 Annual Conference, Los Angeles, CA, May 13-15, 1991.

Ling, James G., "Lean Production," LAI Internal Memorandum, October 1993.

Ling, James G., Christina Houlahan, Renata Pomponi, and Todd Stout, "Initial Results of the Inventory Pilot Program," LAI Workshop presentation, Cambridge, MA, October 19, 1993.

Ling, James G., Christina Houlahan, Renata Pomponi, and Todd Stout, "Results of the Inventory Pilot Program for the Airframe Sector," M.I.T. presentation to the Airframe Sector, Marietta, GA, January 21, 1994.

Ling, James G., Christina Houlahan, Renata Pomponi, and Todd Stout, "Results of the Inventory Pilot Program for the Electronics Sector," M.I.T. presentation to the Electronics Sector, Cambridge, MA, December 8, 1993.

Military Standard: Configuration Management (MIL-STD-973), U.S. Department of Defense, April 17, 1992.

Thomae, Dave and Kevin Campbell, "What to Do When the Salesman Leaves? Implementing MRP in Aerospace and Defense," *The Vision: Critical Thinking for Critical Times*, Proceedings of the 1989 Los Angeles - Aerospace and Defense Special Interest Group Conference, Los Angeles, CA, May 15-17, 1989.

Turbide, David A., "This Is Not Your Father's MRP!" *APICS - The Performance Advantage,* American Production and Inventory Control Society, Falls Church, VA, Vol. 4, No. 3, March 1994.

U.S. Department of Defense, *Military Standard: Configuration Management (MIL-STD-973)*, Section 5.4.2: "Requirements for Engineering Changes," April 17, 1992, pp. 34-51.

Vollman, Thomas E., William Lee Berry, and D. Clay Whybark, *Manufacturing Planning and Control Systems*, 2nd edition, Dow Jones-Irwin, Homewood, IL, 1988.

Wallace, Thomas F., *MRP II: Making It Happen*, Oliver Wight Limited Publications, Inc., Essex Junction, VT, 1990.

Weiss, Stanley I., "Lean Aircraft Initiative," National Technological University (NTU) presentation, Washington, D.C., July 26, 1993.

Wight, Oliver, *MRP II: Unlocking America's Productivity Potential*, Oliver Wight Limited Publications, Inc., Williston, VT, 1981.

Wight, Oliver, *The Executive's Guide to Successful MRP II*, Oliver Wight Limited Publications, Inc., Essex Junction, VT, 1982.

Womack, James P., Daniel T. Jones, and Daniel Roos, *The Machine That Changed the World*, Rawson Associates, 1990.