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Summary of Inventory Pilot Project
March 1993 – December 1994

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Abstract

The Lean Aircraft Initiative began in the summer of 1992 as a "quick look" into the feasibility of applying manufacturing principles that had been pioneered in the automobile industry, most notably the Toyota Production System, to the U.S. defense aircraft industry. Once it was established that "lean principles" (the term coined to describe the new paradigm in automobile manufacturing) were indeed applicable to aircraft manufacturing as well, the Initiative was broadened to include other segments of the defense aerospace industry. These consisted of electronics/avionics, engines, electro-mechanical systems, missiles, and space systems manufacturers. In early 1993, a formal framework was established in which 21 defense firms and the Air Force formed a consortium to support and participate in the Initiative at M.I.T.

In March 1993, the M.I.T. research team undertook a pilot project to look at inventory and related production flow control practices in the sponsoring companies. Survey questionnaires were sent to all the sponsors in June 1993, and 36 responses were received - some companies sending responses for more than one plant or division. Survey data were analyzed for individual industry sectors (e.g. airframe manufacturers) and for all sectors combined.

The survey showed that:

- **On average, 9 percent of all employees were engaged in supporting inventory, ranging from a low of 4 percent to a high of 32 percent. The airframe and electronics sectors had the largest fraction of employees involved in supporting inventory.**
- **The most commonly used company metrics were:**
  - accuracy of inventory
  - supplies on hand (in days)
  - cycle time (overall and within each production stage)
  - inventory turns
  - effectiveness (actual performance relative to company goals)
- **At the time of the survey, about one-third of overall inventory for government contracts was located in receiving and storage. Much of that inventory appeared to be one to six months old.**
- **Relatively few (22 percent) of all companies surveyed use activity based accounting, many companies citing internal resistance and government cost accounting standards as barriers.**
- **Industry-wide use of simulation tools was about 60 percent, with Manufacturing Resource Planning (MRP II) being the most widely used.**
- **Except for the engines and systems sectors, there was relatively little inspection done by touch labor. Most inspection is still done by inspectors from the quality control organization.**
- **Use of statistical process control (SPC) in all stages of production was quite limited (less than 30 percent), with the electronics and systems sectors being**

the predominant users.

- **Very few (less than 10 percent) of the companies surveyed could provide data on defect rates for each stage of production.**
- **Companies viewed government variability reduction guidance, DCAA audits, and multi-year contracts with funding as having a positive effect on improving accuracy and reducing inventory levels. Government-initiated changes, cost-type contracts, and fiscal year buys were seen as having a negative effect.**

Data from the survey were also used to perform an internal benchmarking analysis. Twenty-two metrics derived from the survey questions were used to compare respondents with respect to: (1) best practices among the entire survey population; and (2) best practices within their industry sector. A composite score was calculated for each respondent and the distribution of these scores plotted as histograms. Using all the respondents to calculate a composite index, the highest composite index was 20 out of a possible 30 points scored by one of the airframe sector companies. The range of composite index scores for each of the sectors was: airframes (9.5 to 20), electronics (3 to 16), engines (11.5 to 12.5), other (5.5 to 14), and systems (12.5 to 16.5). A correlation analysis was done to show which metrics correlated best to high composite index scores and the results are listed below:

(1) Master production schedule accuracy (%) [high is best]
(2) Bill of material accuracy (%) [high is best]
(3) Average disposition cycle for repair/scrap/use-as-is (days) [low is best]
(4) Value of items received on ship-to-stock/assembly basis as percent of total shipments received [high is best]
(5) Inventory accuracy (%) [high is best]
(6) Use of fully automated production scheduling [yes to in use]

The survey results also formed the basis for performing two case studies. One electronics plant was examined to determine the cause of high (and often old) inventory in the receiving and storage stage on government contracts. It was discovered that the plant was in the process of making major changes in their manufacturing system, particularly through implementation of a new Manufacturing Resource Planning (MRP II) system. The excessively high inventory was in the process of being used up or otherwise disposed of. The other case study, also involving an electronics plant, was chosen because it was an example of successful implementation of MRP II. Both studies illustrated the requisites for successful implementation and also the benefits that were realized from MRP II.

The automobile industry has started a lean transition. With this as a basis, U. S. Department of Commerce data was used to assess inventory levels of the automobile industry compared to the aircraft industry over an eleven year period (1980-1991). After removing the effects of inflation and normalizing to shipping value, it was found that the automobile industry experienced roughly a 40 percent

reduction in inventory levels (with a variance of +/- 5 percent) as compared to a steady inventory level for the aircraft industry. Therefore, if the aircraft industry is able to adopt lean manufacturing practices, then a similar inventory reduction may be possible in the aircraft industry.

List of Acronyms and Abbreviations

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
CAS	Cost Accounting Standards (U.S. government)
C/PIOS	Contract/Production Inventory Optimization System
C/SCSC	Cost/Schedule Control Systems Criteria
CCB	Configuration Control Board
CDR	Critical Design Review
CPI	Continuous Process Improvement
CPM	Critical Path Method
CRP	Capacity Requirements Planning
DCAA	Defense Contract Audit Agency
DFARS	Defense Federal Acquisition Regulations Supplement
DOD	Department of Defense
DPM	Defects per Million
DPRO	Defense Plant Representative Office
ECN	Engineering Change Notice
ECO	Engineering Change Order
ECP	Engineering Change Proposal
EOQ	Economic Order Quantity
ERP	Engineering Resource Planning
FAR	Federal Acquisition Regulations
FCA	Functional Configuration Audit
FIFO	First In First Out
GFE	Government Furnished Equipment
GM	General Motors

GUI	**Graphical User Interface**
ILS	**Integrated Logistics Support**
IMS	**Inventory Management System**
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	**Material Management and Accounting System**
MRP II	**Manufacturing Resource Planning**
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**
ROI	**Return on Investment**
SFC	**Shop Floor Control**
SPC	**Statistical Process Control**
SPO	**System Program Office**
SRR	**Scrap, Rework, and Repair**
WIP	**Work in Process**

1. Introduction

The Lean Aircraft Initiative began in the summer of 1992 as a "quick look" into the feasibility of applying manufacturing principles that had been pioneered in the automobile industry, most notably the Toyota Production System, to the U.S. defense aircraft industry. These principles had been described in the book, *The Machine That Changed the World*[1], which was the result of research done in the International Motor Vehicle Program at M.I.T.'s Center for Technology, Policy, and Industrial Development. The Lean Aircraft Initiative began at M.I.T. under sponsorship of the Air Force's Aeronautical Systems Center (ASC) at Wright Patterson AFB, Ohio. The "quick look" phase focused only on the major airframe assemblers. Once it was established that "lean principles" (the term coined to describe the new paradigm in automobile manufacturing) were indeed applicable to aircraft manufacturing as well, the Initiative was broadened to include other segments of the defense aerospace industry. These consisted of electronics/avionics, engines, electro-mechanical systems, missiles, and space systems manufacturers

In early 1993, a formal framework was established in which 21 defense firms and the ASC formed a consortium to support and participate in the Initiative at M.I.T. The mission of the Lean Aircraft Initiative is to spearhead an organized process of research and action leading to a fundamental transition of the defense industry over the next decade by instituting substantial improvements in both industry and government practices. Major goals are to identify "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 work of the International Motor Vehicle Program but takes into account the unique features of the aerospace industry, particularly the relationship between defense manufacturers and the government.

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[1] Womack, James P., Daniel T. Jones, and Daniel Roos, *The Machine that Changed the World*; Rawson Associates, 1990.

1.1 The Inventory Pilot Project

During the "quick look" phase, a workshop was held at M.I.T. to discuss, among other topics, potential research directions and priorities. Workshop attendees represented M.I.T. and the airframe manufacturers. The industry representatives were asked to rank order their recommendations for research topics, and the top five topics that emerged from this process were:

1. Inventory
2. Suppliers
3. Product cycle time
4. Quality assurance
5. Human resources and organization

Since the industry representatives were primarily involved in factory operations, their major concerns were in fabrication and assembly. Based on this list of topics, the M.I.T. fabrication and assembly (later renamed "factory operations") team undertook a pilot project to look at inventory and related production flow control practices in the sponsoring companies. It was a pilot project in the sense that it was to test a research methodology that could be followed by other groups. The topic was also limited enough to provide opportunities for near-term findings and recommendations.

1.2 Methodology

The research team decided at the outset that the pilot project would be centered on a survey of the companies involved. The survey would provide a snapshot of individual companies as well as the industry as a whole, thus giving an indication of how "lean" they were and also serving as a baseline against which future progress could be measured. Survey questions were focused broadly on inventory practices as indicators of production management and control rather than on detailed features of inventory management. Figure 1.1 shows the pervasiveness of inventory in its impact on a manufacturing firm's activities.

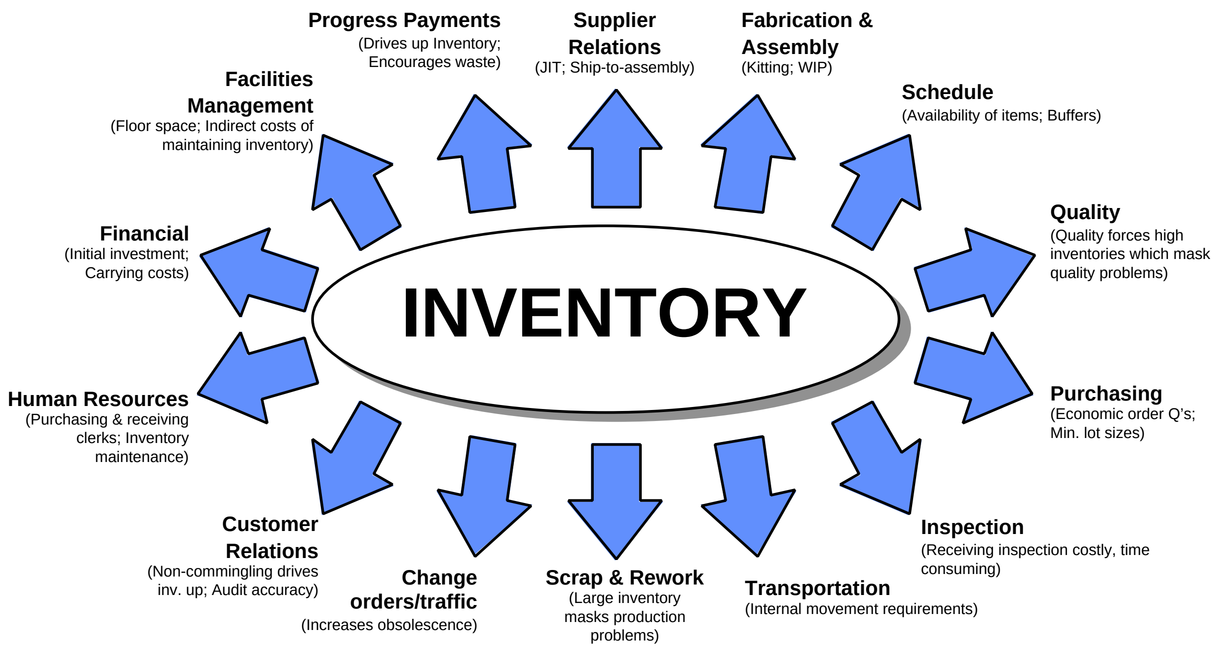

Figure 1.1: Pervasiveness of Inventory

The research team drafted a survey questionnaire which was sent to a selected group of reviewers who were specialists in production and inventory control from a cross section of the sponsoring companies. Also included in the reviewers were a representative from an Air Force System Program Office (SPO), a Defense Plant Representative Office (DPRO), and the Defense Contract Auditing Agency (DCAA). These reviewers were invited to M.I.T. where they spent an intensive day and a half covering all the questions in the survey. An important finding of the inventory survey mini-workshop was that no standard nomenclature exists for the manufacturing cycle within the aerospace industry. It was apparent that standard models had to be defined in order to ensure comparability of survey responses among companies. It also turned out that graphic descriptions were the best way to define these models. The standard industry model and standard planning model that were adopted are shown in Figure 1.2 and 1.3 respectively. These descriptions were included in the survey questionnaire, with space provided for respondents to graphically describe their own models if theirs could not be readily correlated with the standard ones.

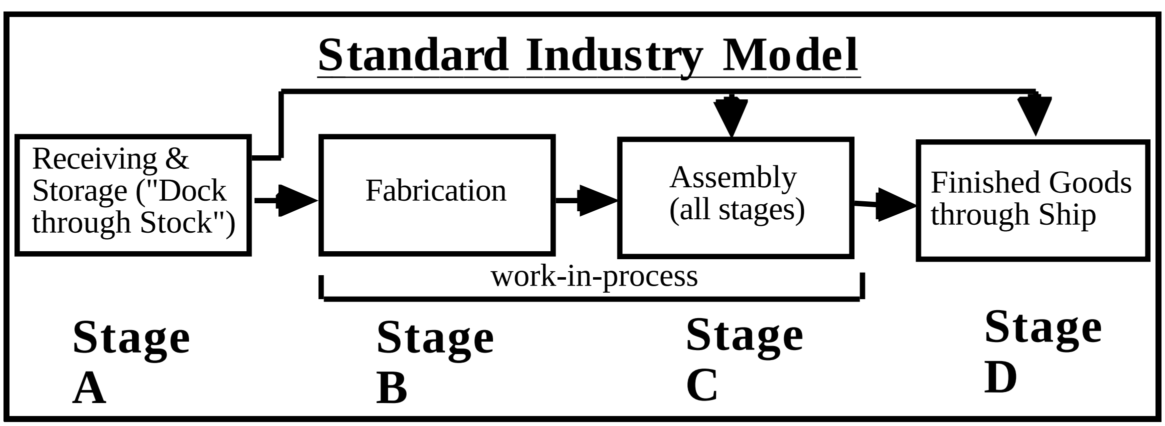

Figure 1.2: Standard Industry Model

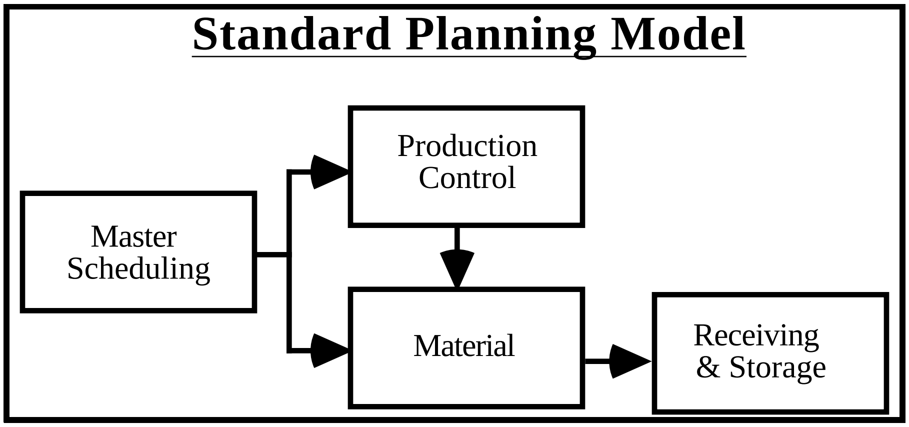

Figure 1.3: Standard Planning Model

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

- **Company Overview and General Statistics**
- **Organization and Management Policy**
- **Metrics**
- **Accounting Practices**
- **Inventory Handling and Facility Management**
- **Planning and Simulation**
- **Inspection and Defects**
- **Government Relations**
- **Final Comments**

The survey was distributed to the member companies in late June 1993. Each company was asked to complete surveys for those internal organizations that, in total, comprised 80 percent or more of its annual Department of Defense (DoD) business. Additional criteria for the responding organizations were:

- **Must be an independent business unit**
- **Must have at least 200 employees**

Thirty-six valid surveys were returned, representing 20 companies (six companies provided surveys for multiple plants/divisions). For purposes of analysis, the respondents were grouped into five industry sectors as shown in Table

1.1. Data were analyzed for all sectors as a whole, as well as for individual sectors.

Table 1.1: Survey Returns by Industry Sectors

Number of Respondents	Industry Sector
10	Airframe and Major Assemblies (fuselage sections, major structures, or skins)
13	Electronics and Avionics (flight computers, guidance equipment, etc.)
4	Aircraft Subsystems (electro-mechanical systems and components)
3	Aircraft Engines (primary power plants)
6	Others (missiles, satellites, communications systems, etc.)

2. Survey Results

This section presents highlights of the survey results. It does not cover all the questions asked in the survey but concentrates on those which relate to key lean practices. Also, some survey questions had to be omitted because they were ambiguous or had been misinterpreted by a significant number of respondents. More details on the survey results are given in the M.I.T. Masters' theses by Christina Houlahan[2] and Renata Pomponi.[3]

2.1 Company Overview and General Statistics

Taking all industry sectors together, the 36 respondents had a median size of 2932 salaried and 2636 hourly employees. Their median gross sales in Fiscal Year (FY) 1992 were $836 million government and $450 million commercial. Tables 2.1 and 2.2 show general data by industry sector.

The engine sector in Table 2.1 reflects a few firms whose commercial sales were almost double the amount of sales to the government. Similarly, the systems sector had more commercial than government business. The electronics firms surveyed had very little commercial business. Table 2.2 shows that airframe assembly involved the largest number of unique parts and a correspondingly large number of suppliers. Interestingly, the "Other" sector had essentially the same number of suppliers for about one-fourth as many unique parts.

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[2]Houlahan, Christina J., *Reduction of Front-End Loading of Inventory: Making the Airframe Industry Lean Through Better Inventory Management*, S.M. Thesis, Technology and Policy Program, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1994.

[3]Pomponi, Renata A., *Control of Engineering Change with Manufacturing Resource Planning (MRP II): Benefits and Barriers in the Defense Aerospace Industry*; S. M. Thesis, Technology and Policy Program and Dept. of Aerospace and Astronautics, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1994.

Table 2.1: Median Sales for FY 1992

Sector	Gross Government Sales	Percent Cost Reimbursable*	Gross Commercial Sales
Airframe	$1270 million	19	$228 million
Electronics	235	20	9
Systems	133	6	187
Engines	2200	36	4200
Other	325	14	51

* The percentage of gross government sales that were performed under cost reimbursable contracts.

Table 2.2: Median Production Data

Sector	Number of Unique Parts in Top Product	Number of Active Suppliers
Airframe	24300	1354
Electronics	3190	600
Systems	664	405
Engines	4000	782
Other	5838	1355

2.2 Organization and Management Policy

In this section the survey looked at the allocation of personnel resources to support inventory and also the degree to which there was a shared vision within the company regarding inventory. As background, employment and labor data determined in the Company Overview section are shown in Table 2.3.

Table 2.3: Median Employment and Labor Data

Sector	Salaried Employees	Hourly Employees	Percent Employees Unionized	Labor Classifications 5 years ago	Labor Classifications Now
Airframe	2310	3460	45	350	340
Electronics	781	380	30	30	23
Systems	1130	740	not available	20	16
Engines	4000	11000	47	1200	290
Other	2810	1024	15	194	31

Table 2.3 shows that the engine manufacturers had the largest concentrations of workers per facility and the largest percentage of unionized employees. However, the engine manufacturers also experienced a decrease of more than 75 percent in the number of labor classifications compared to five years ago. Even more dramatically, plants in the "Other" industry sector showed a drop in labor classifications by more than 80 percent. This move toward a multi-skilled labor force is one indication of lean manufacturing practices. The airframe manufacturers now have the largest median number of labor classifications within the respondent population.

An important metric in determining the "leanness" of a manufacturing organization is the percentage of the work force that is engaged in some way to support inventory. The labor classifications defined in the survey as supporting inventory were:

- Master schedulers
- Production schedulers
- Order writers
- Purchasing agents
- Material expediters
- Receiving inspectors
- Receiving/payment clerks
- Internal transportation
- Pickers and kitters
- Planners
- Dispatchers
- Production control expediters
- Buyers
- Procurement quality assurance
- Stock keepers
- Crib attendants

Industry-wide, the classifications with the largest populations were buyers and planners. Responses for the total number of inventory-related employees ranged from a low of 4 percent to a high of 32 percent as shown in Figure 2.1. The range of responses was particularly large in the airframe and electronics sectors - which drove the industry data.

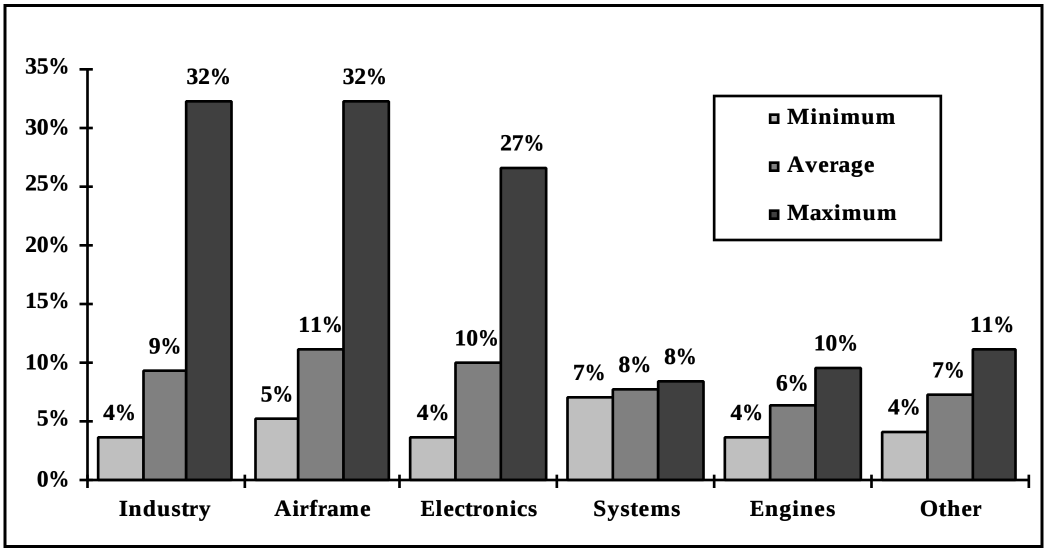


Figure 2.1: Average Number of Personnel Supporting Inventory (as a percentage of total employees)

Survey respondents were asked if their companies had stated inventory goals. Almost all said they did, with the exception of the electronics firms, where only 77 percent answered in the affirmative. Respondents were also asked if the government played any role in determining inventory levels. The answers are shown in Table 2.4. Respondents cited "setting performance goals" and "MMAS[4] guidelines" most frequently when asked to name the specific government role.

[4] Material Management and Accounting System

Table 2.4: Percent of Responses Citing Government Role in Inventory

Airframe	50%
Electronics	69
Systems	50
Engines	0
Others	83

2.3 Metrics

The Metrics section of the survey was designed to: 1) determine what metrics were currently being used by the responding companies; and 2) obtain quantifiable data for those and other metrics that could be used in assessing how "lean" each company was. The most commonly reported company metrics were:

- Accuracy of inventory
- Supplies on hand (in days)
- Cycle time (overall and within each production stage)
- Inventory turns
- Effectiveness (actual performance relative to company goals)

Less common but conducive to progress toward a leaner operation were:

- Percent of kits released short to the floor
- Ratio of actual cycle time to touch labor time
- Ratio of active to inactive inventory

The Metrics section also asked companies to identify where their inventory was located by dollar value on their government contracts. Figure 2.2 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.[5] A lean

[5] This observation, the apparent "front-end loading" of inventory in receiving and storage, is elaborated upon in the Houlahan thesis (see section 4.1).

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.

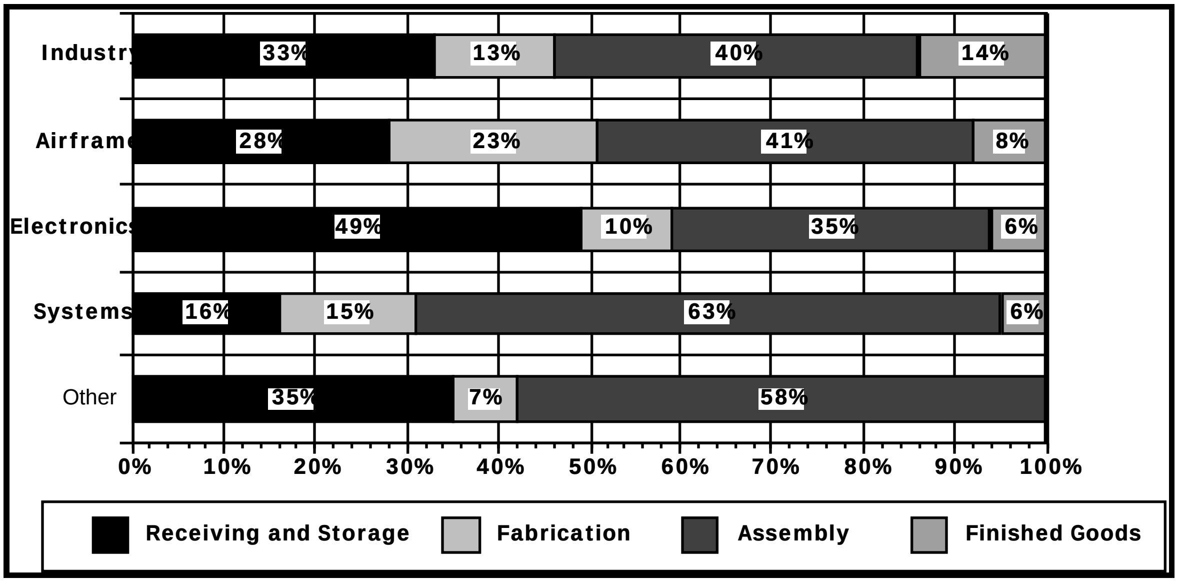


Figure 2.2: Inventory by Stage for Government Contracts

Finally, results from the Metrics section gave interesting insights into the extent of scrap, rework, and repair (SRR) in the aerospace industry. These data can be seen in Figure 2.3 which shows SRR as a percent of total sales within each stage. 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 2.4.

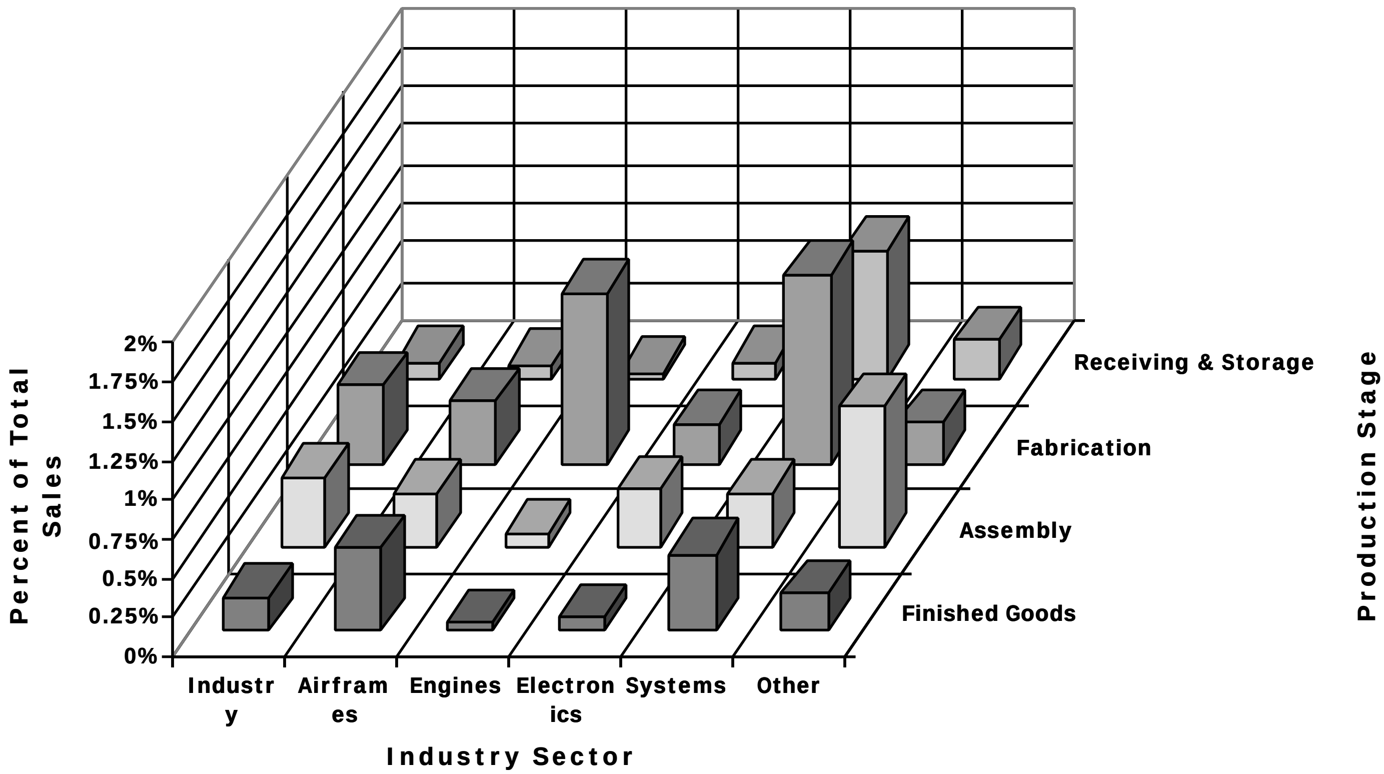


Figure 2.3: Scrap, Rework, and Repair Cost as a Percent of Total Sales

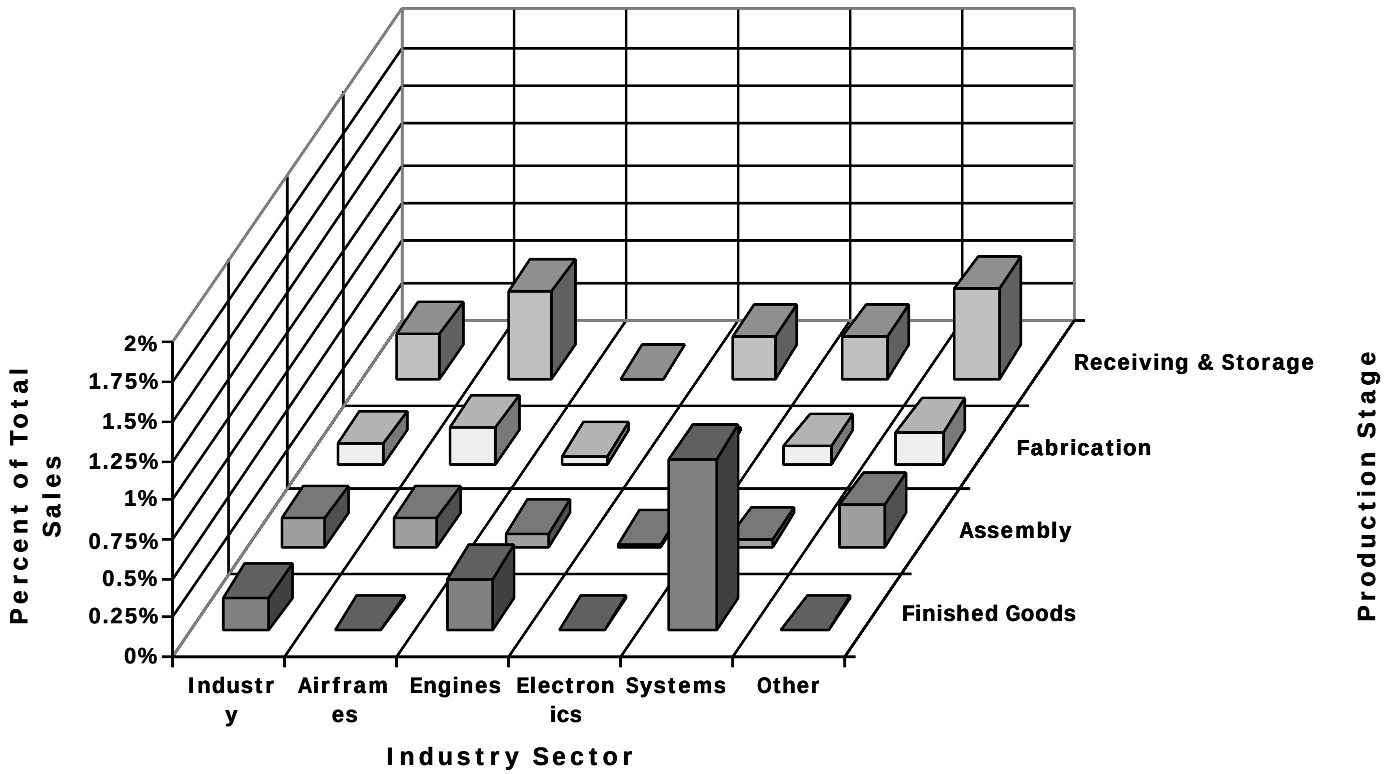


Figure 2.4: Obsolete and Excess Inventory as a Percent of Total Sales

2.4 Accounting Practices

A fourth section of the survey addressed accounting issues primarily from a management perspective rather than a technical accounting one. A fundamental question was asked at the start of the section: "Are figures readily available for the value of total inventory?" The answers were surprising - the industry average was only 91 percent (100 percent had been expected). The responses by sector are shown in Table 2.5.

Table 2.5: Figures Readily Available for Value of Total Inventory

Airframe	90%
Electronics	92
Systems	100
Engines	100
Others	83
Industry (all sectors)	91

Another area of interest in the accounting section 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. Traditional cost accounting has relied on numerous indirect cost pools from which indirect costs are allocated to processes or products on the basis of direct labor hours. As labor costs become a shrinking portion of the total, traditional accounting practices become more inaccurate in terms of measuring true manufacturing costs. In the modern manufacturing environment where positive tracking of material, parts, and labor is possible through computers and bar coding, almost all costs can be calculated directly. ABC does this by monitoring individual activities and attributing costs directly to each activity. ABC is increasingly being adopted in the commercial world, but its use for a number of reasons is still limited in the defense aerospace industry, as shown in Table 2.6.

Table 2.6: Percentage of Companies Using Activity Based Costing

Airframe	30%
Electronics	23
Systems	0
Engines	0
Others	33
Industry (all sectors)	22

Some companies cited the government's Cost Accounting Standards as barriers to adopting ABC. Others mentioned internal inertia as the reason. Still others expressed the concern that uncovering true costs would create embarrassment in dealing with government auditors, even leading to a situation where the government would force the company to accept any lower cost figures but would disallow true costs that were higher than those previously approved.

The Accounting Practices section also 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 2.5 displays these results and shows that the way in which an activity is accounted for does not align very well with the way in which the activity is actually performed.

2.5 Planning and Simulation

The Planning and Simulation section of the survey was designed to assess the extent to which companies were using common production flow control techniques and simulation tools in everyday operation. Nearly 95 percent of the respondents have production control schedules, and nearly three-quarters of those are fully automated.

Companies were also asked to identify the simulation tools used in their operations. The results are shown in Figure 2.6 which indicates that Manufacturing Resource Planning (MRP II) is the most widely used, followed by Critical Path

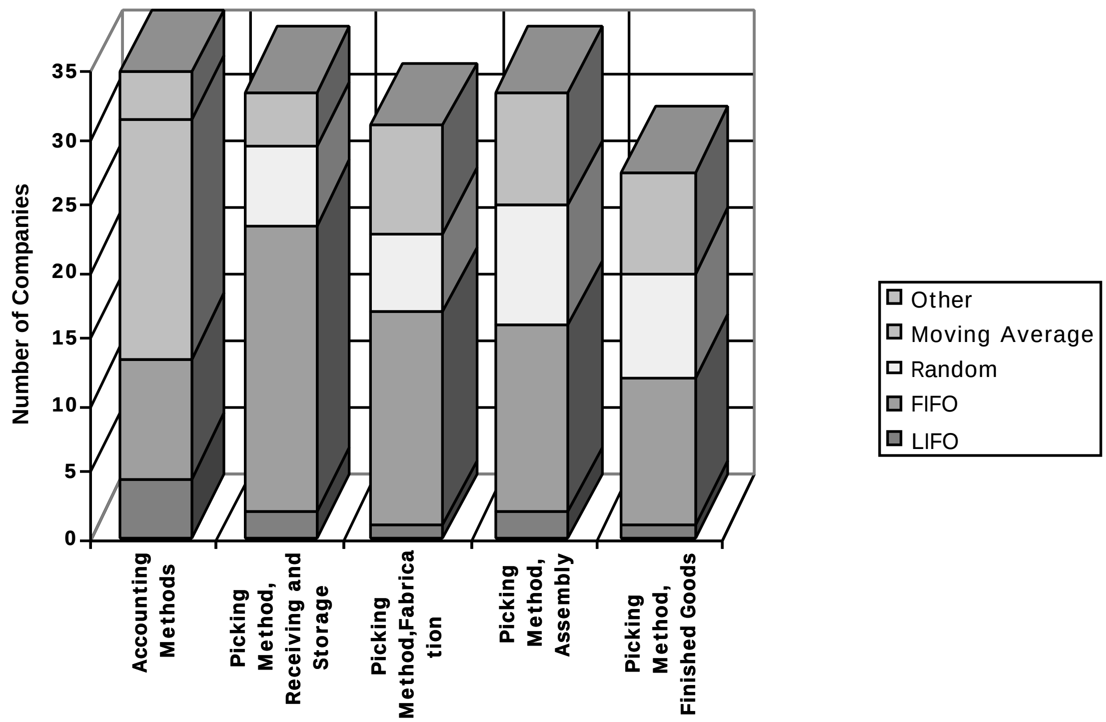


Figure 2.5: Inventory Tracking Practices, Actual vs. Accounting

Method (CPM), and Program Evaluation and Review Technique (PERT). Industry-wide, use of any of the simulation tools is about 60 percent.

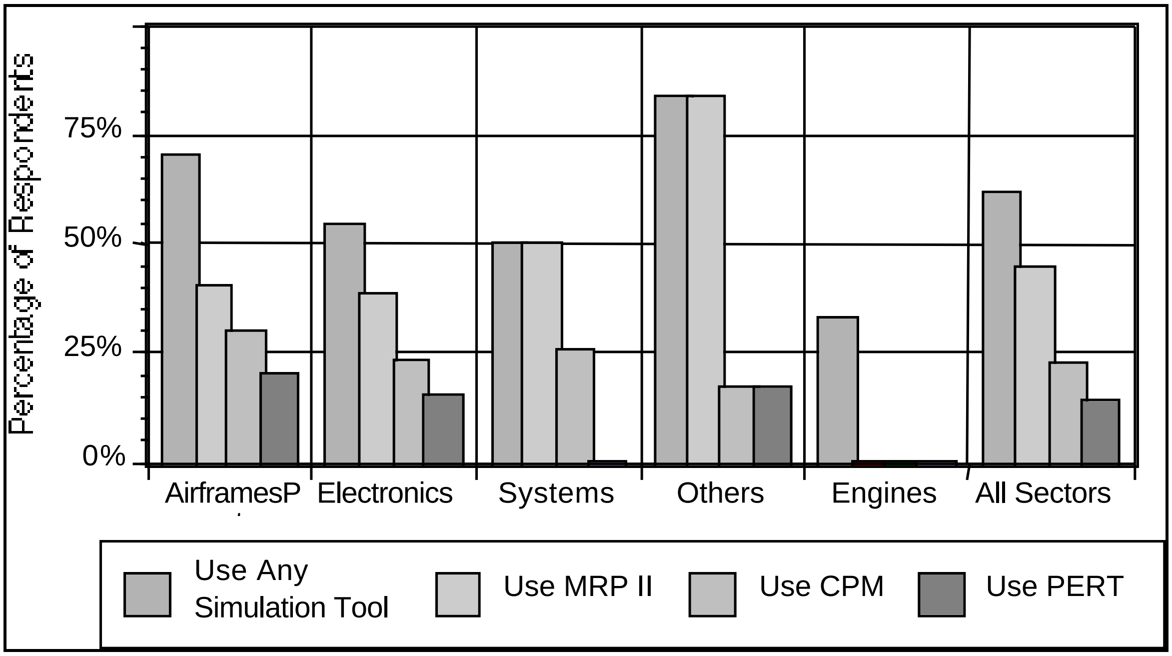


Figure 2.6: Use of Simulation Tools

2.6 Inspection and Defects

Companies were asked to identify the percentage of inspection performed by touch labor (see Figure 2.7). While the Engines and Systems sectors show a high percentage (up to 66 percent) of touch labor involvement in inspection, other sectors such as Airframe show relatively little. Those companies that use little touch labor for inspection continue to rely on full-time inspectors affiliated with the "quality control" organization. The government also conducts inspections, which are often redundant. Survey responses and site visits by the M.I.T. research team showed that both industry and government are moving toward process verification in lieu of end-item inspection. Nonetheless, cultural and regulatory barriers to this approach still exist.

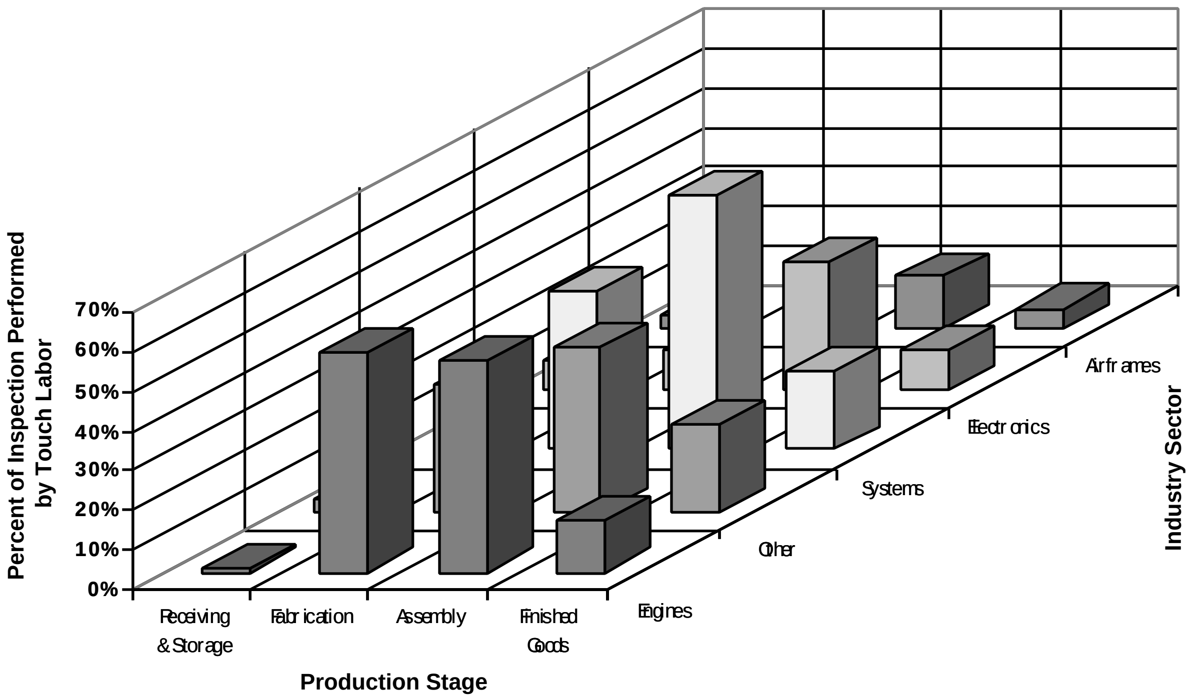


Figure 2.7: Inspection by Touch Labor

This section of the survey also queried participants on the length of time it takes their company to deal with the disposition of defective parts or products (i.e. the repair/scrap/use disposition cycle). The results (see Figure 2.8) show that the Airframe, Systems, and Engines sectors take about 5 days to resolve 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 determination.

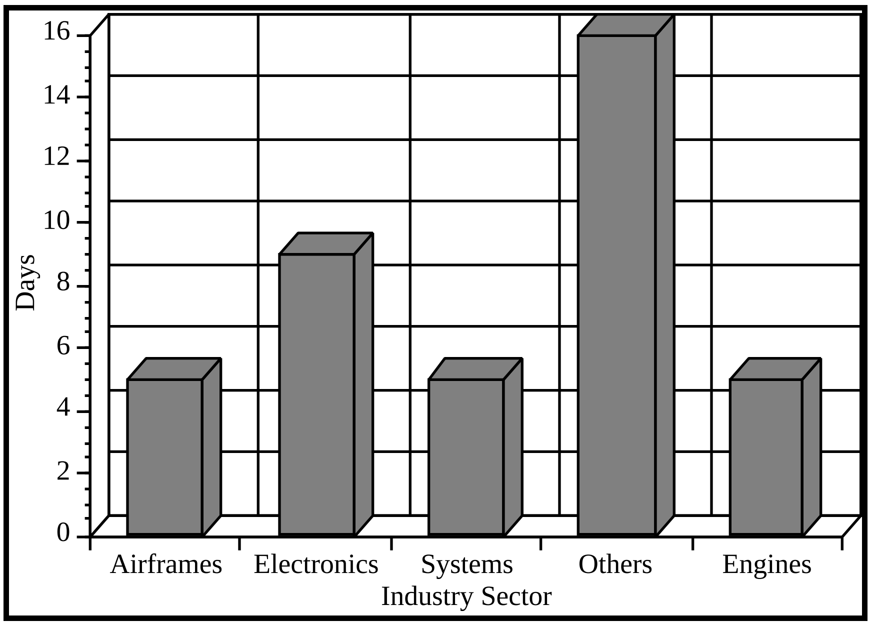


Figure 2.8: Repair/Scrap/Use Disposition Cycles

Another set of questions related to the use of Statistical Process Control (SPC) in production, a practice that is increasingly becoming the norm in commercial manufacturing. As shown in Figure 2.9, the use of SPC in the aerospace industry is quite limited, with the Electronics and Systems sectors showing the greatest use of this procedure. When asked why the use of SPC is not more extensive, respondents most frequently cited company resistance to change. Problems with implementing the technique with low production volumes, and government resistance to change were also cited.

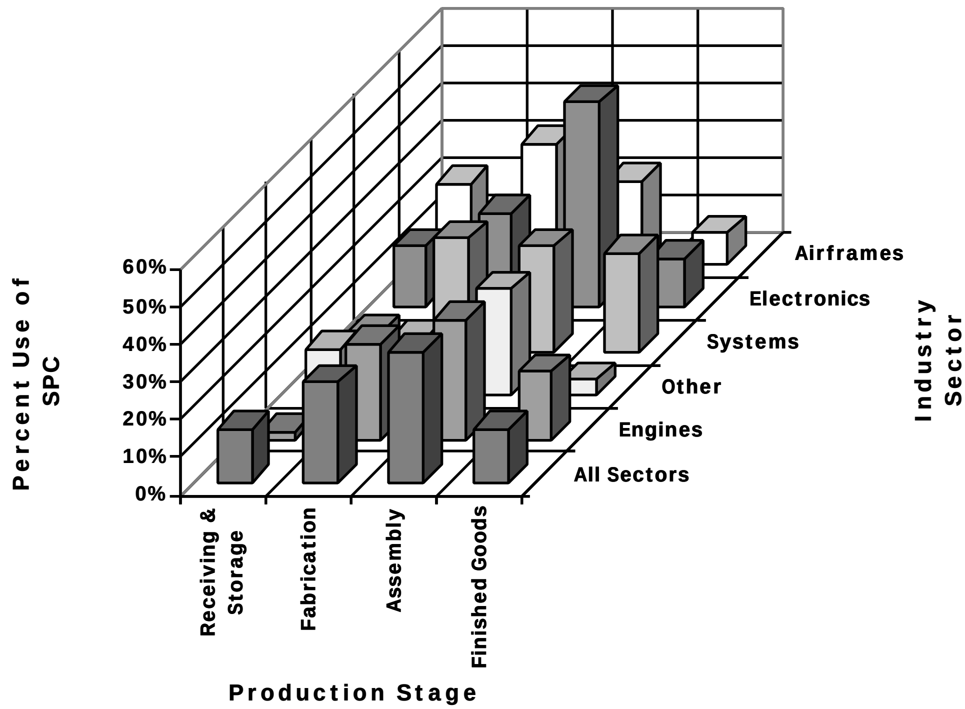


Figure 2.9: Use of Statistical Process Control (SPC)

Similarly, respondents were asked about their production defect rates. Knowledge of Defects Per Million (DPM) for <u>any</u> stage was extremely limited in most sectors (Figure 2.10). Even fewer companies (about 10 percent of those surveyed) had this information for <u>all</u> stages of production. The Systems sector was the only one in which all responding companies knew DPM for all stages.

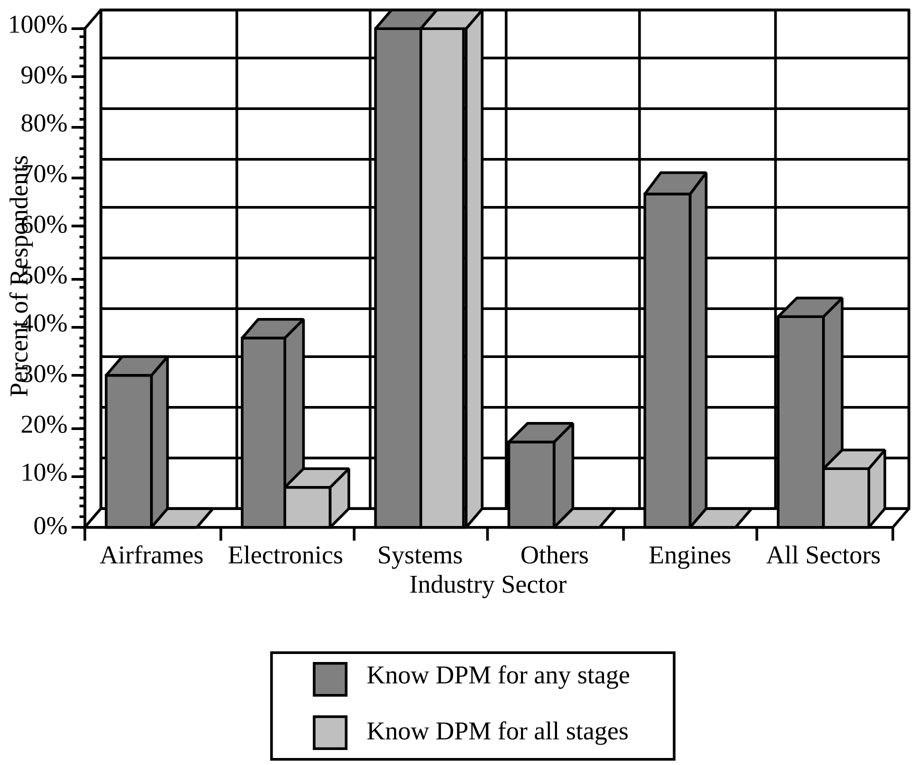


Figure 2.10: Knowledge of Defect Rate

Finally, companies were asked about inspections performed by certified suppliers. The repetition of these inspections by the receiving company was most prevalent in the Electronics sector, occurring more than 45 percent of the time, and least prevalent with the Engines sector at only slightly less than 5 percent of the time (Figure 2.11). A follow-up questionnaire indicated that many of the contracts in the Electronics sector were interpreted by both the government and company as

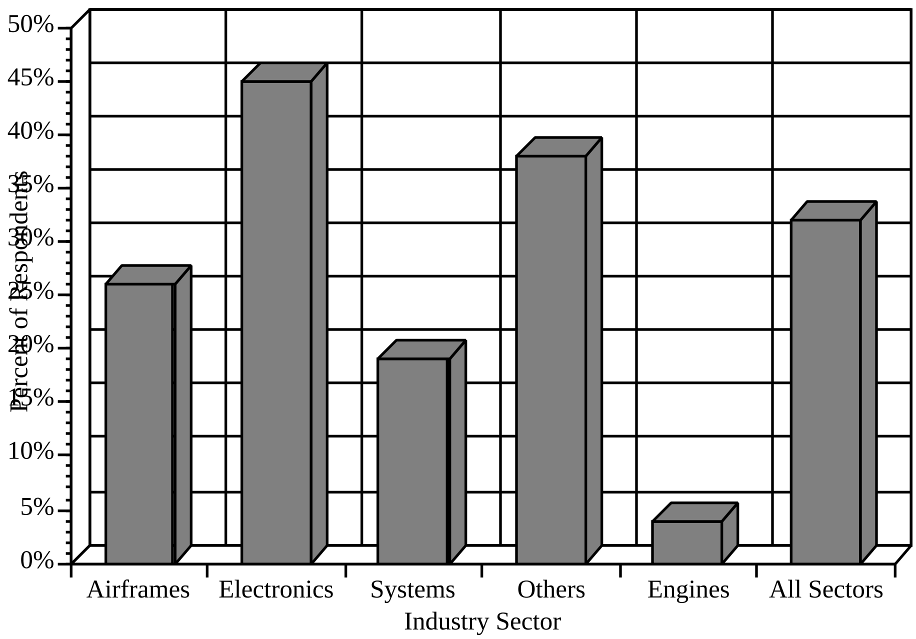


Figure 2.11: Repeat Inspections or Tests

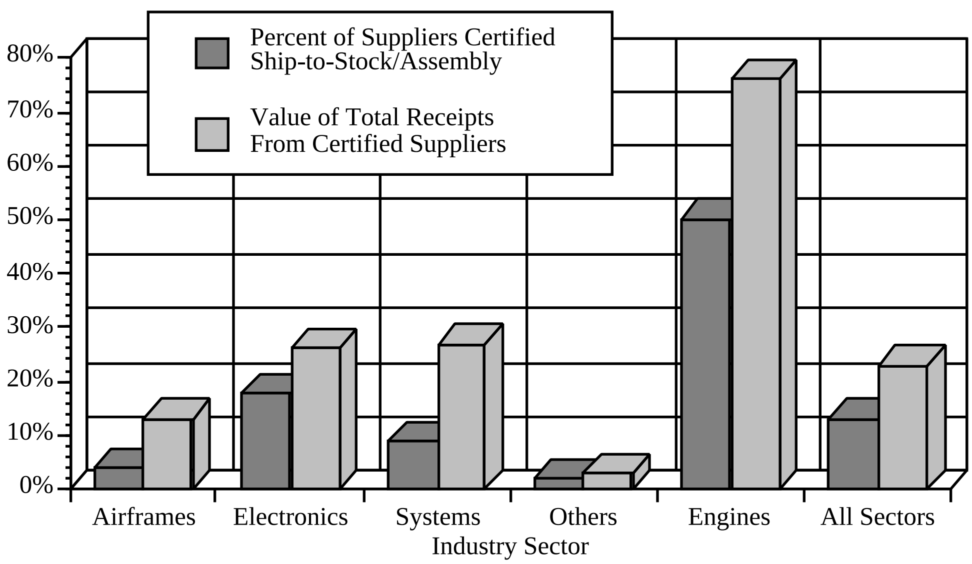


Figure 2.12: Use of Certified Suppliers

requiring inspection and certification of received items by the prime contractor regardless of prior certifications. Figure 2.12 portrays data concerning the use of

certified suppliers. An average of 50 percent of suppliers to engine manufacturers are certified for "ship-to-stock/assembly," accounting for more than 70 percent of the value of total receipts from suppliers for this sector.

2.7 Government Relations

This section of the survey dealt with industry reactions to various government standards and practices as they affected inventory on government contracts. The responses showed that quality-related standards (MIL-STD-1535, MIL-STD-1520, and MIL-Q-9858A), work measurement standards (MIL-STD-1567A), and government socio-economic procurement practices were considered unfavorable to optimal operations and inventory reduction. Some explained that the impact was in terms of additional overhead incurred and direct cost increases. Others responded that non-compliant deliveries from suppliers could require subsequent expedited deliveries and increased costs. This area requires further study to validate the responses and determine the true magnitude of the problem.

Additional questions in this section asked about differences in purchasing or acquisition between government and commercial contracts for various categories of inventory. In general, the responses indicated that ordering practices for government and commercial contracts were not radically different in these companies. Some sectors, such as Electronics, seem to have built in longer buffers (ordering farther in advance of actual requirements) than others such as Airframes and Engines do. Lead times for the industry as a whole are fairly short, but there is room for improvement as shown by best practices within the surveyed companies.

2.8 Comments Section

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. Companies were asked about the existence of inventory reduction programs within their organizations. Only two among the 36 respondents did not have such programs. The respondents were also asked to name

both company-originated and government-originated disincentives that drove them away from good inventory practices. The major company-originated disincentives mentioned were:

- **Company emphasis on schedule**
- **Problems with the supplier base**
- **Desire for quantity discounts**
- **Focus on bringing material in early**

The government-originated disincentives were:

- **Progress payments**
- **Fiscal year buy quantities**
- **Configuration and engineering changes made by the government after material procurement**

Finally, the participants in the survey were asked to name any accounting-related practices which inhibited good inventory practices. The most numerous responses were:

- **Separation of material by contract**
- **Accounting for inventory as an asset**

3. Internal Benchmarking

The survey data from the Inventory Pilot Project represent a snapshot of the participating companies during the summer and fall of 1993. The research team recognized that most of the companies surveyed were in the midst of change, not only in their organization and manufacturing practices, but also in corporate affiliations. However, at the plant level the survey data can be used as a baseline against which to measure future progress. The survey can also be used for comparisons with both internal and external benchmarks (indicators of best practices). This section uses a subset of the survey metrics to show how the respondents compared against each other in terms of lean practices.

3.1 Metrics for Comparison

At the August 1994 workshop of the Factory Operations (formerly Fabrication and Assembly) Focus Group of the Lean Aircraft Initiative, it was agreed to use a list of 22 metrics derived from the survey questions to compare respondents with respect to: (1) best practices among the entire survey population; and (2) best practices within their industry sector (e.g. Airframe, Electronics, etc.) The metrics agreed on were:

- **Touch labor force as a fraction of the hourly labor force**
- **Number of labor classifications**
- **Labor classifications today compared to five years ago**
- **Supplier lead time as a percent of total cycle time**
- **Inventory support employees as a percent of total number of employees**
- **Use of MRP II (Manufacturing Resource Planning)**
- **Number of inspectors compared to size of the touch labor force**
- **Inventory accuracy (%)**
- **Bill of material accuracy (%)**
- **Master production schedule accuracy (%)**
- **Supplier shipments ahead of purchase order schedule (%)**
- **Supplier shipments behind purchase order schedule (%)**
- **Use of Activity Based Costs for reporting**
- **Use of fully automated production scheduling**
- **Average disposition cycle for repair/scrap/use-as-is (days)**
- **Use of organized variability reduction techniques**

- Use of Statistical Process Control (SPC) as evidence of product quality
- Availability of data on defect rates
- Percent of certified supplier inspections repeated on receipt
- Percent of suppliers certified for ship-to-stock/assembly
- Value of items received on ship-to-stock/assembly basis as percent of total shipments received
- Value of total inventory as a percent of gross sales

These metrics were determined for each company from its survey responses, and the average, minimum, and maximum were calculated for the entire survey population (labeled as "Industry" in the survey results) as well as for each sector (e.g. Airframe).

3.2 The Composite Index

The metrics for evaluation were either low is best or high is best. The composite index evaluated each metric based on its most lean characteristic as the measure of composite index goodness. A single composite score was calculated for each company using the metrics above with the following valuation criteria:

Best in class	1.5
Better than average	1.0
Average	0.5
Below average	0.0
No data	-0.5

The absence of data was assumed to indicate lack of concern for this area of manufacturing and was penalized more than if the data were available but not favorable. In cases where the metric involved a "yes or no" response, a "yes" received a score of 1 while a "no" received 0. The composite score was determined by adding up the scores for each of the 22 metrics after the valuation criteria was applied to each metric. All metrics were weighted equally.[6] The composite scores

[6] This point was discussed at the August 1994 workshop of the Factory Operations Focus Group. It was agreed that, considering the composite metrics as indicators of need for improvement, it was more expedient to give equal weight to each metric rather than get into debates over the relative importance of each in lean manufacturing.

were then plotted as histograms, for all companies together and then for companies by sector. It must be emphasized that the composite scores are <u>relative</u> and not absolute. Thus, the score for each company <u>depends on the group in which it is being compared</u>. The theoretical maximum obtainable score in a given group is 30. That score results if the company is best in class in all categories and answers "yes" to all the "yes/no" questions.

The histograms which follow depict the frequency in which company scores fit within certain bands of composite index values. The bands depicted are rounded off values from a computer generated histogram subroutine.

3.3 <u>Industry Comparison</u>

The first comparison involves the entire survey population and includes a purely commercial division of one of the companies surveyed. The resulting comparison analysis in Figure 3.1 shows a histogram distribution and a tabular breakout by sector of the results of all respondents to the inventory survey. The highest composite index score of 20 was achieved by an airframe sector company.

A correlation analysis was done to show which metrics correlated best to high composite index scores. The results of this analysis resulted in the following ranking of metrics by order of highest correlation to high composite scores:

(1) Master production schedule accuracy (%) [high is best]

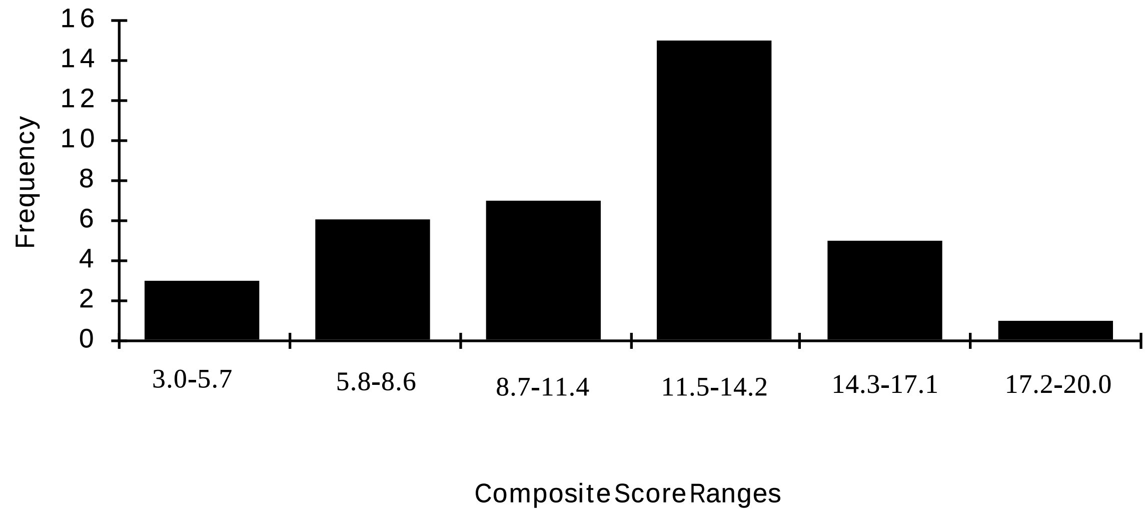
(2) Bill of material accuracy (%) [high is best]

(3) Average disposition cycle for repair/scrap/use-as-is (days) [low is best]

(4) Value of items received on ship-to-stock/assembly basis as percent of total shipments received [high is best]

(5) Inventory accuracy (%) [high is best]

(6) Use of fully automated production scheduling [in use]



GROUPING OF COMPOSITE INDEX BY SECTOR

	3.0-5.7	5.8-8.6	8.7-11.4	11.5-14.2	14.3-17.1	17.2-20.0
AIRFRAME			6	2	1	1
ELECTRONICS	1	6		5	2	
ENGINE				3		
OTHER	1	1	1	3		
SYSTEM				2	2	
TOTALS	2	7	7	15	5	1

Figure 3.1: Lean Aircraft Initiative Inventory Composite Index

3.4 Sector Comparisons

Sector analyses were also performed in which survey respondents in the same sector were compared to each other. The following composite score distributions were calculated: (1) airframe sector as Figure 3.2, (2) electronics sector as Figure 3.3, (3) engine sector as Figure 3.4, (4) others sector as Figure 3.5, (5) systems sector as Figure 3.6 and (6) a combination of system and engine sectors as Figure 3.7. The Electronics histogram (Figure 3.3) includes a commercial firm. The Engines histogram (Figure 3.5) has only one composite score grouping due to the small size of the population. Because of this small sample size the engines sector and systems sector were combined (Figure 3.7) to obtain a more meaningful sample.

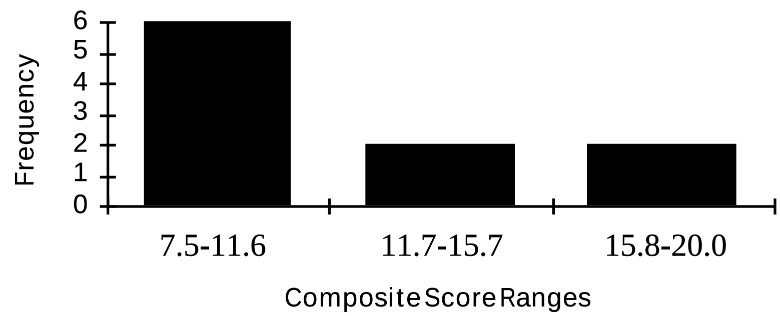


Figure 3.2: Airframe Sector Composite Index

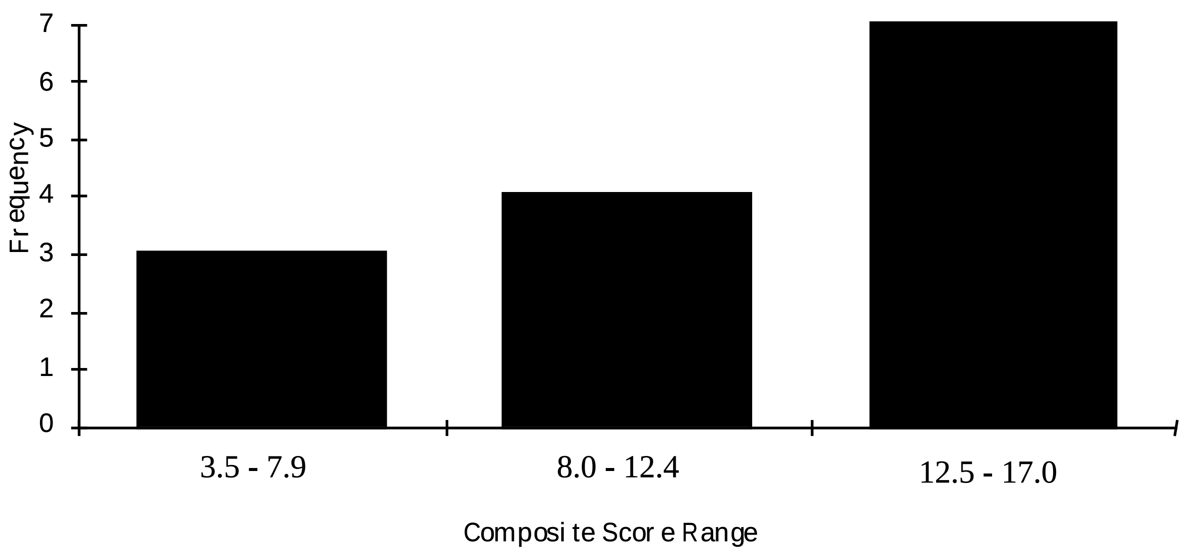


Figure 3.3: Electronic Sector Composite Index

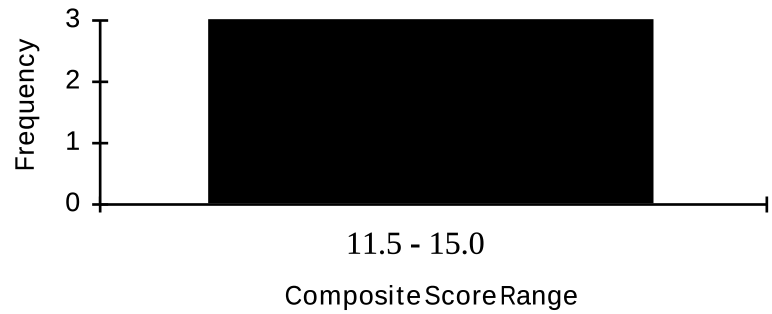


Figure 3.4: Engine Sector Composite Index

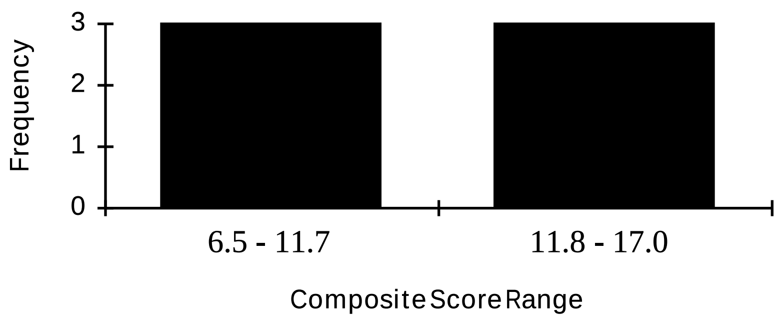


Figure 3.5: Others Sector Composite Index

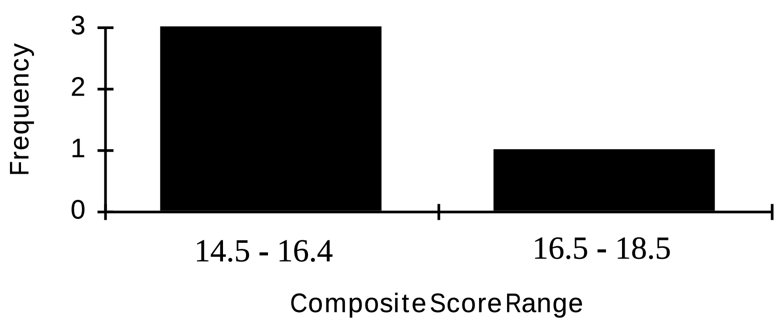


Figure 3.6: Systems Sector Composite Index

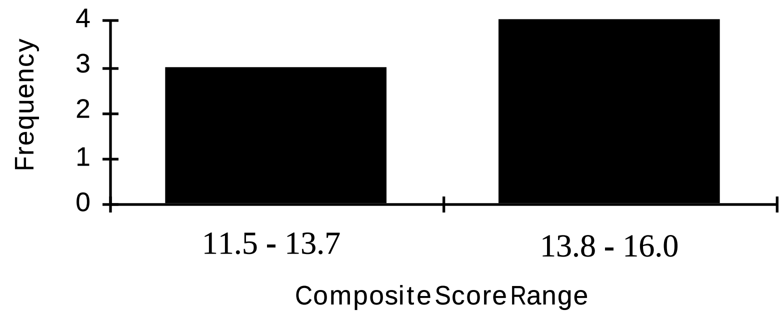


Figure 3.7: Systems and Engine Sectors Composite Index

3.5 Observations

- **The industry comparison shows that the median and the average composite score of all respondents is 11.25 and 11.33 respectively which would put them in the 8.7 to 11.4 grouping.**

- **The percentage of scores below the industry median/average by sector were:**

- Airframes	**67%**
- Electronics	**47**
- Other	**50**
- Engine	**0**
- Systems	**0**

- **The correlation analysis shows that having an accurate internal information system and good control over production operations tends to result in higher composite scores.**

4. Case Studies

One goal of the Inventory Practices Survey was to identify companies which had practices (good or bad) that warranted further investigation. Two such case studies were performed during the year following receipt of the completed surveys. The case studies were chosen on the basis of site visits as well as survey responses. This section provides summaries of the two studies.

4.1 Electronics Plant A

It was shown in Figure 2.2 that a large fraction of inventory on government contracts was held in the receiving and storage stage of production. This characteristic was especially noticeable in the Electronics sector where 49 percent of inventory was reported as being in receiving and storage. In order to study this feature in more detail, the research team contacted one of the respondents who agreed to participate in the case study on condition of anonymity. It is referred to here as Plant A. The case study was performed by Christina Houlahan as part of her Master's thesis at M.I.T. (see Footnote 2 on Page 12 for complete reference).

Plant A manufactures almost exclusively one product which represents between 90 and 95 percent of the plant's total annual business. This complex weapon system has remained relatively unchanged and has been manufactured in largely the same manner for almost two decades. One major component of the system has an 18-level Bill of Materials (BOM). The entire system has a 25-level BOM. In addition to manufacturing, Plant A is also responsible for integration and test of the whole system for the government. The facility has over 3100 employees and utilizes 2500 suppliers.

The Inventory Practices survey showed that Plant A had 45 percent (dollar value) of its inventory in receiving and storage. Furthermore, 80 percent of that inventory was more than six months old. Originally, this case study intended to focus on what could be done to improve this situation, but it quickly became apparent that Plant A was well on its way to solving the problem. Thus the case study concentrated on what happened to Plant A from 1987 to 1994 as an example of how a company can adopt lean practices within the existing Federal procurement system without disturbing such "sacred cows" as progress payments or the budgeting/procurement cycle. None of the changes implemented at Plant A took place overnight. The time line for their achievements is shown in Figure 4.1.

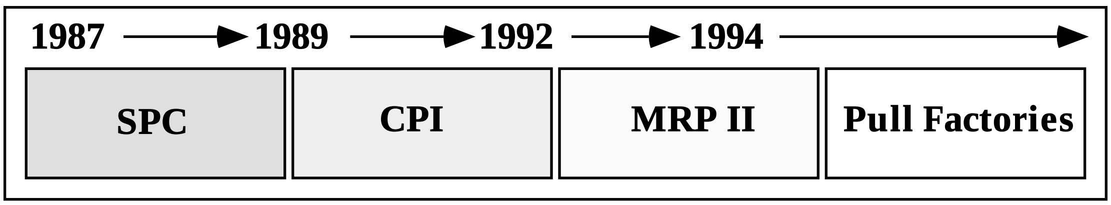


Figure 4.1: Timeline of Plant A Initiatives

4.1.1 The Catalyst for Change

Experience has shown that meaningful change usually does not come to an organization without a crisis occurring first. In the case of Plant A it happened in the late 1980s when a routine government audit found that a large portion (over $80 million) of the inventory could not be accounted for, and the yield, scrap, and shrinkage projections (traditionally based on data from previous contracts) could not be justified adequately. At one point, progress payments were to be withheld by the government until the situation was corrected. This led plant management to conduct a thorough review of their production and control practices. They found that the existing practices, although approved by the government, were in fact inadequate.

Plant A, in cooperation with the government, embarked on a drastic improvement program. On the company side, new initiatives were introduced, such as Statistical Process Control (SPC), Continuous Process Improvement (CPI), and Manufacturing Resource Planning (MRP II). On the government side, existing standards and practices were looked at in a new light by both the Defense Plant

Representative Office (DPRO) and by the company with some interesting results.

4.1.2 Company Initiatives

Plant A's management recognized that their manufacturing processes, which had remained relatively unchanged for so long, had not been checked in a rigorous and quantifiable manner. A consulting group was brought in to implement SPC, and to simultaneously involve the workers themselves in this process. Eventually, SPC spread from a pilot effort at one work center to the entire factory floor. Full implementation took about two years.

Following the successful insertion of SPC into their operations, Plant A began a complementing CPI initiative. Starting again on a small scale, the same work center as before was used as a pilot project. The workers themselves used normal production equipment to experiment with the process in controlled tests. This CPI initiative resulted immediately in cycle time reduction and reduction in scrap. All of Plant A's work centers were eventually included in the CPI initiative with the goal being to reduce cycle time by 50 percent and total production cost by 25 percent.

The company's goal was met. After two years of SPC implementation throughout the plant, a 30-35 percent reduction in defects was seen across all work centers. The combined effects of SPC and CPI resulted in a 10 percent per year reduction in the "cost of quality" - the cost associated with having to repeat poor work both in terms of labor and materials.

While SPC and CPI addressed the issue of process control, the third initiative which Plant A employed to address the recognized shortcomings of their manufacturing system focused directly on reducing inventory in the production process flow. The problems with their existing inventory management and tracking system were:

- **It did not allow tracking of residual material across all contracts in real time.**
- **It had no "owner," and inputs could be made by virtually anyone, with no idea of how their actions would affect the system.**
- **It was inflexible and did not readily accommodate schedule changes.**

- **It did not have any feedback between the consumption and procurement data bases.**

Plant A attacked these issues in two ways: they conducted a major internal analysis of their inventory practices, and they began plans to launch a new Manufacturing Resource Planning (MRP II) system.

One project undertaken by the internal analysis team was a look at the effective time phasing of inventory and the benefits associated with it. In a sense, this was a manual simulation of what the benefits of an MRP II system would be. Over $6.6 million in savings of inventory was quickly realized in the first-pass efforts of the team by modifying ordering plans.

The process of implementing MRP II took almost two years, and the system went on line in February 1994. Plant A's management conservatively estimates at least a 10 to 25 percent reduction in inventory across all stages of production as a result of the new system.

4.1.3 Government Initiatives

The Defense Department's Material Management and Accounting System (MMAS) and its ten primary guidelines have provided guidance on what is and is not an acceptable inventory management and tracking system. However, interpretation of the standards by various DPROs and companies has led to varying degrees of accountability in tracking systems. Following the problems that Plant A had in the late 1980s and early 1990s in justifying their inventory data, a stricter interpretation of many of the ten MMAS guidelines was agreed on and implemented by the DPRO and the company. For example, MMAS V requires 95 percent inventory accuracy. The DPRO and the company changed their previous interpretation from 95 percent accuracy on the <u>dollar value</u> of inventory to 95 percent accuracy on <u>piece count</u>.

The DPRO was also reorganized to consist of a program and technical support group, quality group, and contracting group. These new groups were tied together by a "program integrator." This arrangement allowed for a cross-functional look at

the manufacturing operation and stricter interpretation of the government's comprehensive management system criteria. This increased vigilance has led to strong governmental support for change at Plant A. In the opinion of many in the plant's management, the government's actions greatly aided company efforts in reducing inventory both through control processes and more effective information and inventory management systems.

4.1.4 Future Directions

There is still a great deal to be done in Plant A. The company recognizes that there are additional areas where more economies can be realized and is working to address them. Specifically, the company intends to move more towards a "pull factory" in which the internal customer requests, or "pulls," orders from upstream work centers. This approach contrasts with the "push" or "order-launch" system still being used in much of the defense aerospace industry. Finally, the company is paying a lot of attention to its supplier base, and efforts are being made to work with suppliers to form symbiotic and non-adversarial relationships.

4.2 AIL Systems Inc.

The survey results and site visits by the research showed that many of the plants' inventory problems reflected lack of control over production flow as well as absence of an integrated data base. One way to address these problems is to install a system that can integrate a master schedule with capacity and material requirements, reconcile an operational plan detailing production in terms of part units with a financial plan, and perform simulations to answer "what if" planning questions. The dynamic and flexible system that has these characteristics is known generically as MRP II (Manufacturing Resource Planning). The power of modern computers makes it possible to handle the necessary amount of data in real time - a task that was impossible to do manually, and difficult even a few years ago with early generation computers. MRP II is vastly expanded over MRP (Material

Requirements Planning) with which it is often confused. MRP is limited to inventory control and does not include the financial planning and simulation features.

AIL Systems Inc. was chosen for a case study because it had several years of experience with an operational MRP II system and because that system was installed during a period when the company was struggling to meet the demands of the largest contract in its history. The case study was performed by Renata Pomponi as part of her Master's thesis at M.I.T. (see Footnote 3 on Page 7 for complete reference).

AIL, a subsidiary of the Eaton Corporation, is a mid-size electronics manufacturer with an almost exclusively military product line. Major products include electronic warfare systems for the B-1B bomber and tactical jamming systems for the Navy's EA-6B. AIL's business volume has been declining steadily over the last few years. Sales totaled $191 million in 1993, down from a high of about $800 million 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.

4.2.1 Problems in the Plant

In the mid-1980s AIL's tradition of production flow management was 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, scheduled production for printed wiring boards was 250 units per day, but the WIP consisted of 13,000 boards. The tracking process was almost completely manual, and a large amount of time was spent finding and fixing problems.

Poor material control was especially evident in the stockroom. The bill of materials submitted by the planner did not indicate if parts were 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. 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 in disagreement with the physical count. Corrections, when performed, would fix the computer records without addressing the root cause of the problems.

When AIL started production on the largest contract in its history, it became apparent that the existing system for production management and inventory control was totally inadequate to meet demands. Gordon Corlew was sent by Eaton to be Vice President of Engineering and Production at AIL in 1985 with a mandate to bring the situation under control.

4.2.2 Building Critical Mass: 1986 to 1988

Conditions at AIL required urgent action from Corlew to start correcting the deficiencies, but he also realized from prior experience that MRP II was the system that would be needed ultimately to make AIL a world class manufacturing organization. Thus, while he worked to solve the immediate problems, he started to build support and expertise within the company to implement MRP II. AIL had purchased MRP II software in 1983, but there had been no commitment in the company to install it. After Corlew’s arrival, the MRP II software modules for bill of materials and shop floor control were installed as a temporary measure. Further expansion of MRP II was opposed within the company, due in large part to the attitude of his fellow managers who had heard of negative publicity surrounding one aerospace company’s dispute with the government over the accuracy of cost data generated by an MRP II system.

The introduction of the government's Materials Management and Accounting System (MMAS) provided a key breakthrough to overcome mistrust of MRP II in the defense industry. The nature of MMAS requirements made it hard for companies to comply without using MRP II. AIL was facing a situation where progress payments could be withheld by the government if the company did not start working in the same direction as the new government approach. At the same time, AIL management was gradually becoming aware of the problems created by lack of control and 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.

4.2.3 Team Endeavors: 1989 and 1990

The MRP II implementation team, organized as shown in Figure 4.2, was created in January 1989. The team's first step was to develop a master schedule which brought one production program on line at a time in order to maintain commitments to the customer. A 15-month deadline for completing the first round of implementation was chosen as the optimal timeline to sustain momentum and interest. A government liaison function was involved from the outset to coordinate joint training and to address specific issues relating to MMAS compliance.

The Policy and Procedure Committee served as the driving force towards company-wide acceptance of the need for change. Members, selected from all functions of the company, had enough managerial authority to make decisions without constant Steering Committee approval and yet were close enough to operations to maintain a balanced viewpoint. The Committee also developed a list of criteria to measure the success of the project.

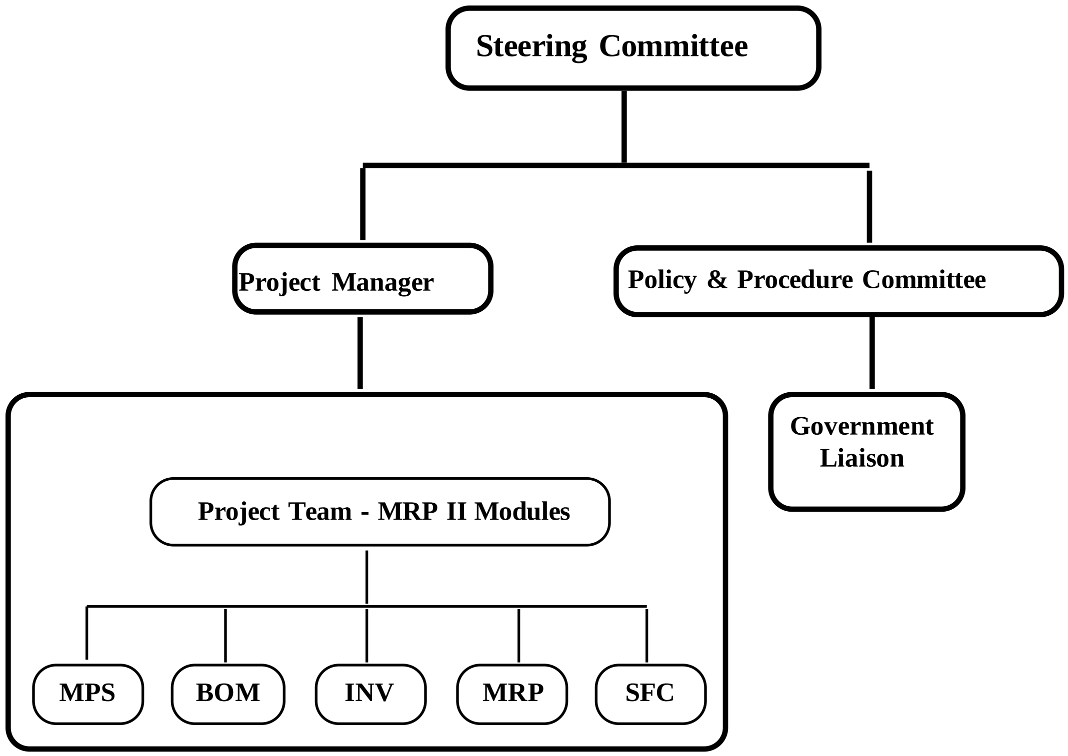


Figure 4.2: MRP II Implementation Team Organization Chart

Education and training were given a great deal of attention from the outset to insure a smooth transition from the existing system (also referred to as the legacy system) to MRP II. A full-time training director was hired to coordinate user education. 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 workers were generally more receptive to training by their peers. An advertising campaign was initiated to promote involvement and support across the entire organization. This company-wide commitment to change and improvement was seen as a key contribution to the success of the MRP II initiative.

AIL 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) received project updates, initially on a monthly basis but increasing to weekly as the program developed. Government representatives 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. Figure 4.3 shows the timeline for AIL's implementation of MRP II.

4.2.4 Reaping the Rewards: 1991 to 1994

MRP II has resulted in a radically different operational environment from AIL's previous system, mainly due to increased visibility and control of the manufacturing process from requirements through shipping. Table 4.1 summarizes the improvements AIL has experienced in several key areas of inventory management.

AIL management and users, now comfortable with the workings of MRP II, express great satisfaction with the performance of the system. Government representatives also appreciate the benefits of a manufacturing operation that is under control. Over the course of implementation, the company and government consciously worked toward a cooperative approach for mutual benefit. The company needed to comply with government standards to stay in business, and the government wanted to realize cost and schedule benefits. As a result of implementing MRP II, overhead costs have been reduced, less material needs to be purchased, and schedules are being met. AIL estimates that savings during the first year of operation paid for the costs of installing the system. In addition, AIL gives their government representatives full access to the MRP II system, thus eliminating the need for many manual audits and saving hundreds of hours a year in government auditing costs.

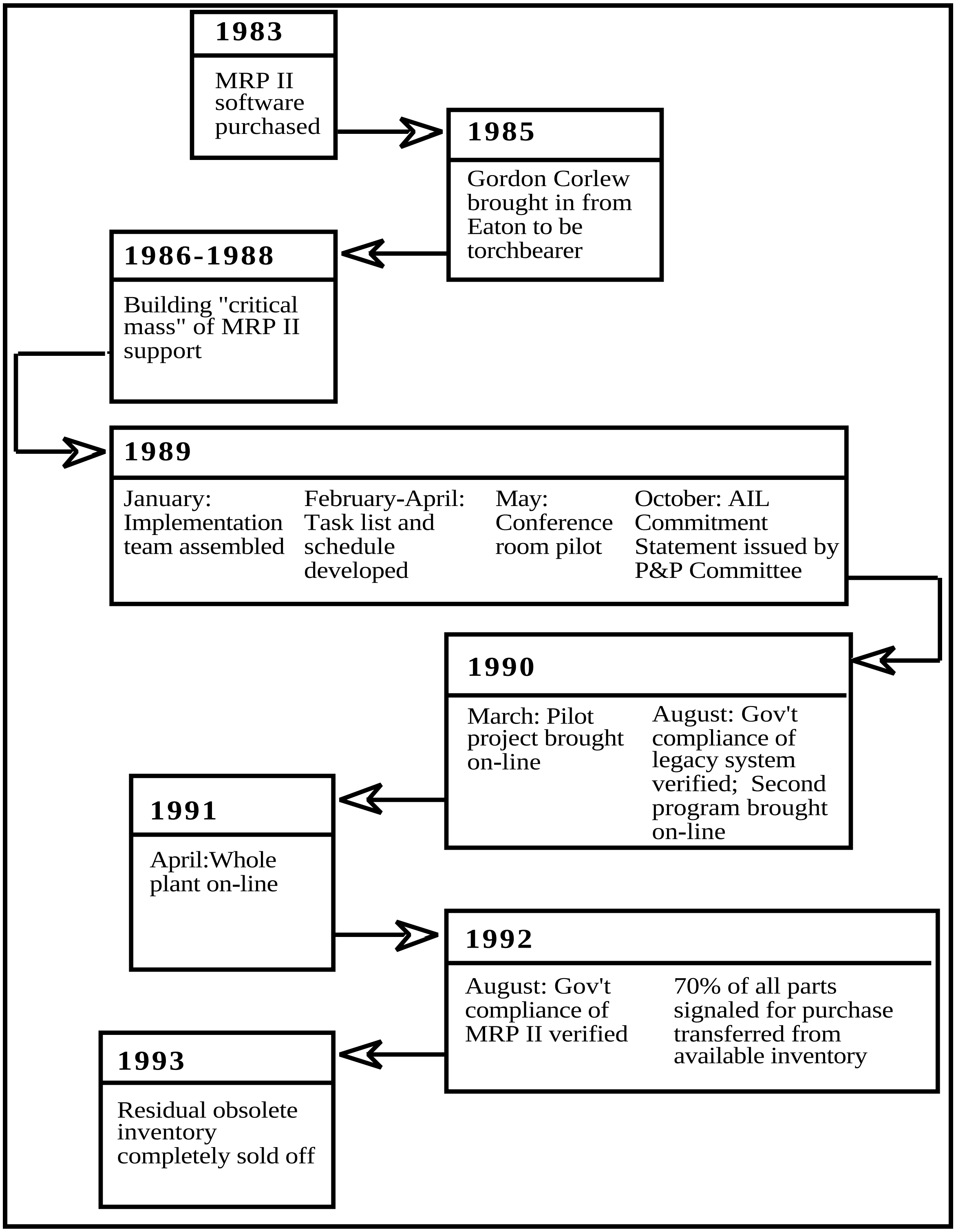


Figure 4.3: AIL MRP II Implementation Timeline

Table 4.1: 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 approximately 75 percent.

4.2.5 Barriers Along the Way

Despite the overall success of the project, the implementation was not without its stumbling blocks. On the technical side, software bugs in the updated version of AIL's MRP II software (C/PIOS, Contract/Production Inventory Optimization System, which is no longer on the market) caused some delays. A more substantial problem, however, was the initial lack of management commitment. In 1985, only two of the 17 vice presidents (Gordon Corlew being one) had heard of MRP II. This lack of awareness accounts for the long period of time it took to achieve a critical mass. Company practices are hard to change, especially in boom times, and it took a while for management to become receptive to the idea of revamping the approach to manufacturing. MRP II was not fully embraced across the company even after implementation was started, as evidenced by the sluggishness of some departments to dedicate people to the implementation team. The software debugging effort was severely hindered by consistently inadequate resources from the information technology group, and consultants were eventually hired to help get back on schedule.

Some departments, including finance, did not want to be involved with the program at first because they did not believe they would have any input into what they considered a manufacturing system. The existing corporate culture was clearly devoted to maintaining functional independence and preserving the status quo. Some engineers continued to work alone, thinking that the integrated team members from manufacturing were not technically capable of understanding design constraints. A "hero complex" also existed under the old system in which last minute expediting had made for exciting management - a situation which an efficient system would preclude. During the course of implementation, however, many issues came up which the recalcitrant departments did not realize they had. Often their token representative, who had been provided only to satisfy a corporate directive, turned into a valuable team asset who later promoted the system throughout the organization.

4.2.6 Benefits from the Engineering Perspective

From the engineering standpoint at AIL, the main advantage of MRP II implementation is increased visibility of all activities in the company. Engineering decisions can be based on a comprehensive set of data, so that the impact of changes can be assessed before they are made. The MRP II networked data base also facilitates integrated product development (IPD) in the engineering department by creating an environment in which everyone has access to a systematic flow of accurate information. 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. 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 expand the capabilities of the engineering side of operations.

4.3 Conclusions From the Case Studies

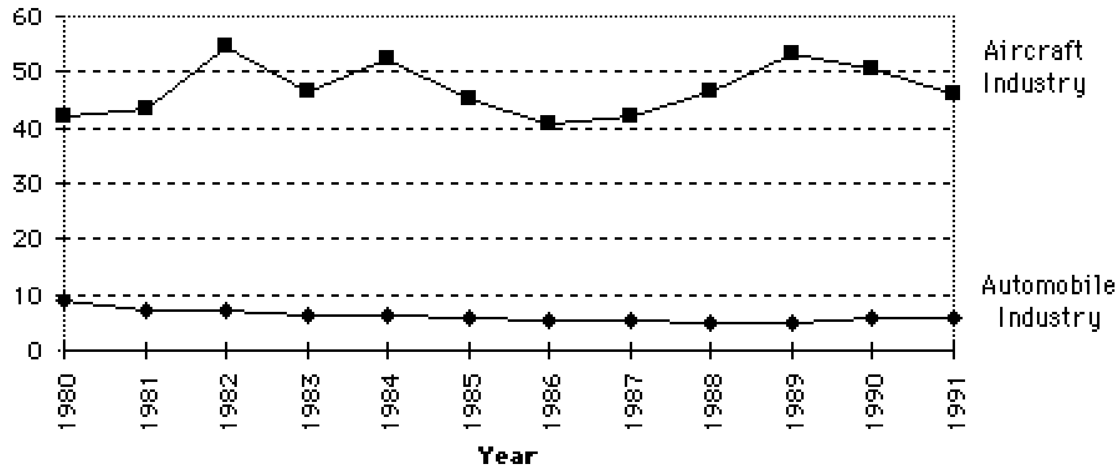
- **The motivation for change was extreme dissatisfaction on the part of the customer (Federal government) and potential loss of progress payments as a consequence.**
- **There was strong upper management support and clear assignment of responsibility for implementing change.**
- **MRP II was adopted as the solution to problems in integrating, controlling, and monitoring factory operations.**
- **Great emphasis was placed on employee motivation, buy-in to change, and training at all levels of the organization.**
- **Government plant representatives were kept informed and involved in the change process.**
- **The time frame from formal inception to initial operation of MRP II was $1^{1}/_{2}$ to 2 years.**
- **The cost of implementation was recovered within a year or two through reductions in inventory, support staff, and scrap and rework; improved purchasing practices; increased productivity in material handling; and decreased auditing effort.**
- **Benefits after MRP II implementation were a 16 percent improvement in inventory accuracy, a 43 percent reduction in floorspace for inventory, a 98 percent reduction in access time to obtain inventory items and about a 50 percent reduction in inventory staffing requirements.**

5. Motor Vehicle versus Aircraft Industry Inventory Comparison

Since the studies of the International Motor Vehicle Program (IMVP) and the book, *The Machine That Changed the World*, many United States automobile companies have started to use elements of lean manufacturing methods. Therefore, it is instructive to look at the level of inventory in the automobile industry over the last ten years to see how their levels of inventory have been reduced as lean manufacturing techniques were incorporated into their manufacturing processes. In contrast, the aircraft industry lags this transition to lean methods. Therefore, a comparison of the two industries might lead to some insight as to what might be expected in the aircraft industry as lean methods are adopted.

To accomplish this comparison, U. S. Department of Commerce data were used for the entire automobile and aircraft industries. The data were adjusted for inflation using constant 1982 dollars and then normalized by shipping value. The resulting data are shown in Figure 5.1.

Based on the gross data from this effort, it can be seen that over an eleven year period (1981-1991) the automobile industry has succeeded in reducing its inventory roughly 40 percent with a variance of +/- 5 percent. The aircraft industry inventory levels, over this same period, have remained steady. Therefore, if the aircraft industry should incorporate relevant lean manufacturing practices similar inventory reductions could be expected.



	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
■	42.3	43.4	54.8	46.4	52.3	45.2	40.7	41.9	46.4	53.4	50.6	46.1
◆	8.8	7.2	7.1	6.4	6.1	5.8	5.4	5.3	4.9	4.8	5.6	5.7

1982 Constant Dollars

Figure 5.1: Inventory As a Percentage of Shipping Value

6. Conclusions

The Inventory Pilot Project provided more than an assessment of inventory. Many factory operation issues were addressed in this survey. Answers to these questions provided a valuable insight into the state of factory operations at the time of the survey. Accordingly, the following observations and conclusions are offered:

- Many of the respondents were in the process of change, implementing recognized lean practices into their operations.
- The aircraft industry does not have a definitive lean producer. This is evident because there is a linear relationship between total sales and total inventory value (R^2=0.82). Therefore there is no "Toyota" in the aircraft industry to which to compare the rest of the industry. There do, however, appear to be pockets of lean operations scattered throughout the industry.
- Many of the respondents used process factory layouts sometimes characterized as "job shops." Fabricated parts were produced by being transported to each of the job shops until the part was completed.
- The "front end loading" of inventory could be an indication of the defense industry funding policies since this same inventory pattern was not evident in the commercial segment of the industry.
- Inventory level is an indication of the health of a factory operation. Programs specifically oriented at inventory reduction were less impressive than measures put into place that improved product flows or product yields.
- Redesigning factory operations to achieve single-pass flows, even at the risk of having dedicated machines with lower utilization rates, had a greater impact on cost and inventory reduction than technological fixes (e.g. automating inherently inefficient processes) or procedural fixes (e.g. just-in-time delivery imposed on an otherwise unchanged production system). In fact, the latter were likely to be counterproductive. Unfortunately, redesigning operations is a painful process

involving cultural change, and many firms have not had the resolve to do it in the absence of a threat to their existence.

- **Understanding the flow of products through a factory operation tends to lead to improved product cycle time through the factory. Companies that effectively implemented Manufacturing Resource Planning (MRP II) were able to achieve dramatic reductions in inventory and access to inventoried items.**
- **There is a large amount of scheduled buffer time in the overall product cycle time. This scheduled buffer contributes to all forms of inventory accumulation in the factory operation. Plants use scheduled buffers to reduce risk to the production schedule. The objective is to have a given part or assembly ready for the next operation when it is needed. From other studies and observations this objective can be met by controlling and optimizing the process flow through the factory operation. Of the two methods described, the most predictable method (and therefore the least risky) is the one that focuses on flow optimization.**
- **The use of inventory turns as a metric of inventory health has very limited application. It can be used to measure progress within a single company, but inter-company comparisons are not likely to be meaningful because the accounting bases are different between the companies.**
- **The emphasis on end-item inspection has to be replaced by process verification. End items need only be inspected on a sampling basis to verify that the process is in control.**
- **Many respondents did not provide information on their defect rates. Either the information was not available or the defect rates were available but not reported. In either case, without an accurate understanding of the experienced defect rates, measures cannot be implemented to resolve defect causal factors at their source.**
- **Companies competing in the commercial marketplace tended to be leaner than purely defense operations. The joint manufacture of both commercial and defense products tended to maximize the transfer of lean practices in a plant/division.**

- **CAD/CAM, 6-sigma design, precision controlled machinery and other technological advances are making dramatic changes in the fabrication and assembly of aircraft products. These technologies in conjunction with streamlined production operations will revolutionize the industry in the next five to ten years.**