Application of the Lean Aircraft Initiative Factory Operations Model to Case Studies in the Defense Aircraft Industry

by Michael John Pozsar

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Signature of Author ______________________

Certified by ______________________
Professor Stephen C. Graves
MIT Sloan School of Management
Thesis Supervisor

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

Accepted by ______________________
Dr. Jeffrey A. Barks
Associate Dean, MIT Sloan School of Management

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ABSTRACT

Companies within the US defense aircraft industry are experiencing increasing pressure to provide a smaller volume of higher quality products at lower cost. The MIT Lean Aircraft Initiative factory operations focus group developed a hypothesized lean manufacturing model to provide managers in this industry with a framework to better understand lean practices and to describe a method for how these concepts can be implemented. The hypothesized model presents a process for implementing lean manufacturing practices through the following four phases: 1) Lean Infrastructure Development, 2) Factory Flow Redesign, 3) Operations Management Development, 4) Process Improvement.

Three case studies of organizations undergoing lean transitions in the defense aircraft industry were completed for comparison purposes with the model. In all of the case studies, the following enabling practices have played a significant role in this process:

- Teams were a powerful mechanism for transferring information, problem-solving, continuous improvement and for learning.
- The reduction of variability led to greater control, improved planning, reduced risk exposure and greater efficiency.
- Leadership played an important role developing the manufacturing plan, motivating employees, breaking down barriers, providing coordination and creating change.
- Employee skills and responsibilities have been expanded to increase their flexibility and accountability in the workplace.

Each organization's lean transition utilized an overall sequence that possessed some similarity to the model but was definitively not identical to the model. Implementation differences highlight differences in the inherent nature of each organization and there are no discrete start/stop points between transition phases. However, the proposed implementation sequences and practices within each of the transition phases were generally supported by all of the case study companies.

Thesis Supervisor: Stephen C. Graves
Title: Professor of Management Science, MIT Sloan School of Management

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A special thank you is extended to Tom Shields at MIT LAI. Under Tom's direction, the factory operations focus group accomplished a number of objectives, including the development of the hypothesized lean manufacturing model which is described in this thesis. Tom played a critical leadership role in coaching me through numerous issues throughout the year.

I would also like to thank MIT professors Steve Graves and Stan Weiss. Their review of the thesis and case studies provided me with insightful feedback throughout this process.

A Thank You to the Case Study Companies

Northrop Grumman Corporation

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Raytheon Aircraft

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Hughes Missile Systems Company

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Table of Contents

List of Accronyms

ABC - Activity Based Costing
CAD - Computer Aided Design
CNC - Computer Numerical Control
COQ - Cost Of Quality
DFM/A - Design For Manufacturing/Assembly
DNC - Distributed Numerical Control
DoD - Department of Defense
EA - Equipment Availability
EDI - Electronic Data Interchange
EMD - Engineering & Manufacturing Development
EOQ - Economic Order Quantity
EPA - Environmental Protection Agency
EVA - Economic Value Added
IMVP - International Motor Vehicle Program
IPT - Integrated Product/Process Team
ISO - International Standards Organization
IT - Information Technology
JIT - Just In Time
LAI - Lean Aircraft Initiative
LEM - Lean Enterprise Model
LRIP - Low Rate Initial Production
MIT - Massachusetts Institute of Technology
MRP - Material Resource Planning
NC - Numerical Control
OEE - Overall Equipment Effectiveness
PCB - Printed Circuit Board
PDM - Predictive Maintenance
PE - Performance Efficiency
PE - Project Engineer
PFMEA - Process Failure Mode Effects Analysis
PM - Preventive Maintenance
QA - Quality Assurance
QC - Quality Control
QFD - Quality Function Deployment
RCM - Reliability Centered Maintenance
RQ - Rate of Quality
SPC - Statistical Process Control
TPM - Total Preventive Maintenance
TQM - Total Quality Management
VSA - Variation Simulation Analysis
WIP - Work In Process inventory

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APWI - Assembly Process Work Instructions
ATMCS - Automated Tool Manufacture for Composite Structures
CAM - Certified Assembly Mechanic
CAR - Corrective Action Report
CWI - Composites Work Instructions
ESP - Expert Systems Planner
FOE - Foreign Object Elimination
GD&T - Geometric Dimensioning & Tolerancing
ICAT - Innovative Concepts for Assembly Tooling
ISMT - Integrated Supplier Management Team
MDA - McDonnell Douglas Aircraft
MPDB - Manufacturing Process Data Base
MPVR - Manufacturing Process Variability Reduction
NADSARP - Northrop Aircraft Division Systems Architecture Plan
TIV - Transfer Inspection Verification
UGII - Unigraphics II

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AOG - Aircraft On Ground
BIT - Beechcraft Improvement Teams
EPA - Environmental Protection Agency
ERP - Enterprise Resource Planning
EVMS - Earned Value Management System
IMB - Issue Management Board
JPATS - Joint Primary Aircraft Training System
MFQE - Manufacturing Field Quality Engineer
VR/SPC - Variability Reduction / Statistical Process Control

Hughes Missile Systems Company

HMSC - Hughes Missile Systems Company
CEP - Career Enrichment Program
CM - Critical Material
cmi - continuous measurable improvement
CP - Critical Processes
LAT - Lot Acceptance Testing
MVP - Manufacturing Verification Program
POM/D - Proof Of Manufacturability and Design
SDWT - Self Directed Work Teams
WSP - Work Style Patterns

1. Introduction

During the 1980s, the defense aircraft industry was booming; spending was high and aircraft orders were plentiful. Many firms expanded factory capacity and built new high tech processing facilities to satisfy the demand of government contracts.

Today, the US defense aircraft industry faces monumental challenges: shifting defense priorities, massive spending cuts, and the need for defense conversion. It must become increasingly competitive and make significant improvements in productivity, quality, and affordability to succeed in this difficult and fast-changing environment.

As the industry structure undergoes considerable consolidation and downsizing, all firms are undertaking major transformations in order to survive and then succeed. Many firms in the defense aircraft industry have responded to these challenges by replacing their traditional craft production techniques with lean manufacturing practices. This thesis presents a hypothesized model for the lean transition of factory operations in the defense aircraft industry and compares it to three organizations in that industry that have achieved significant improvements in cost, cycle time, and quality.

1.1 Purpose of Thesis and Case Studies

The concept of this thesis was initiated by a need to develop a hypothesized model of lean manufacturing for the defense aircraft industry and to test the model with organizations that have undergone significant transformations in their application of lean manufacturing practices. The Factory Operations group of the Lean Aircraft Initiative research project at the Massachusetts Institute of Technology developed a model based on the results of previous industry research and inventory surveys, feedback from leading researchers in the operations management field and interactions with organizations that have undergone lean transitions.

The purpose of this thesis is twofold. The first purpose is to present a hypothesized model to the Lean Aircraft Initiative sponsoring companies that outlines a possible implementation sequence and characterizes practices, methods and enablers of each step. The second purpose is to compare three real-world lean transitions in the defense aircraft industry with the hypothesized model.

The three case studies were conducted at selected factory operations that have undergone a lean transition. The objectives of the case studies were to compare the practices, methods and enablers that supported each organization's lean transition and to test the organization's implementation sequence with the sequence proposed by the hypothesized model.

1.2 MIT Lean Aircraft Initiative (LAI)

The book, "The Machine that Changed the World," that resulted from the International Motor Vehicle Program's (IMVP) study of the auto industry spread the message of the lean enterprise across the world of manufacturing. In response to the great interest in that book and the monumental challenges facing the industry, researchers from the Massachusetts Institute of Technology (MIT) have joined forces with the US Air Force and 18 major aerospace companies to study and identify key factors for improvement and to launch pilot programs to drive changes in the industry through a consortium called the Lean Aircraft Initiative (LAI). LAI is a three-year, multi-million dollar research effort that focuses on the applicability of "lean" principles.

Through the development of a systematic knowledge base, the Lean Aircraft Initiative aims to create and implement roadmaps for change in the US defense aircraft industry and the broader manufacturing base supporting it. The LAI takes a broad view of the defense aircraft industry, encompassing all sectors of defense aircraft production, including airframe integrators and major supplier groups, such as producers of engines, avionics and electronic systems, and other equipment suppliers. The program has undertaken research in five major areas: Product Development, Factory Operations, Supplier Systems and Relationships, Organization and Human Resources, and Policy and External Environment. A sixth focus area, probing environmental issues and practices, is being explored. The LAI is concentrating research efforts in its final year of the phase one effort on the definition and implementation of a Lean Enterprise Model for the US Defense aircraft industry. It is anticipated that major strides in efficiency and quality, as well as enhancements in both the economic and technological viability of the industry, could be affected over the next decade.

The purpose of LAI is to: study the defense aircraft industry, understand how the lean concept applies to this industry, and make recommendations and give direction on how to implement lean practices in the industry. The program's mission statement is to: "Define and help implement roadmaps for fundamental change in both industry and government operations, based on best "lean" practices, resulting in: greater affordability of systems, increased efficiency, higher quality, enhanced technological superiority and, a stronger US defense aircraft industrial base."

1.3 Introduction to the Case Studies

Previous LAI industry inventory survey results have demonstrated that although some companies may have more efficient operations than others, there wasn't an equivalent "Toyota" that is dramatically different from the rest of the group. Toyota is often identified as the benchmark enterprise in many industries because the IMVP found its practices to be so much more efficient than any of its competitors. The defense aircraft industry, like almost all other industries in the United States, does not have one company that can be considered a lean enterprise. The companies studied in this thesis, however, are beginning to implement lean manufacturing practices in their factories as they strive to become lean enterprises.

1.3.1 Northrop Grumman Corporation

Northrop Grumman Corporation is the primary partner for the F/A-18 E/F which is produced by McDonnell Douglas Aircraft. Northrop Grumman Corporation supplies the center/aft fuselage for this product. This case study was based on the lean practices employed on the E/F compared to the C/D product which is manufactured on an assembly line located next to the E/F line.

Corrective Action Request (CAR) reports, which identify manufacturing problems, indicate that F/A-18 E/F manufacturing performance is significantly better than F/A-18 C/D. Assembly hours have been reduced by 19% from comparable shipset serial numbers on the

C/D line to the E/F line. The number of defects have been reduced in half by the fifth E/F ship compared to C/D.

The delay between the Engineering and Manufacturing Development (EMD) production and the Low Rate Initial Production (LRIP) production schedules is expected to limit full learning curve benefits under the new lean manufacturing systems. Current EMD production of 10 ships will ramp down in the spring of 1996 and LRIP production is scheduled to restart in 14 months. The expected E/F production rate is the following: EMD = 0.6 per month; LRIP1 = 1 per month (first 12 months); LRIP2 = 2 per month; LRIP3 = 3 per month; full-rate production = 4 per month. The current C/D production rate is 7 per month; 12 per month is the maximum capacity of that line.

1.3.2 Raytheon Aircraft

The focus of this case study is the cellularization process and variability reduction program that is currently being implemented in the metal cutting and sheet metal facility (Plant 1). The impetus for change at Raytheon Aircraft can be traced to two significant contributing factors. First, recent contract awards (including the JPATs training jet, McDonnell Douglas C-17 and Boeing programs) require Raytheon Aircraft to reduce variability in its processes in order to reduce costs and improve quality and schedule performance. Second, stricter EPA regulations have forced the company to modernize some of its processing equipment.

Many of the new manufacturing cells in Plant 1 are still under construction and consequently the changes discussed in this case study are either in development or are at the initial stages of implementation. This organization's manufacturing strategy is to implement lean manufacturing practices using teams. The implementation sequence that Raytheon Aircraft is following in its lean transition is: 1) optimize factory flow through cellularization, 2) reduce set-up times, 3) implement Kanban material flow systems.

1.3.3 Hughes Missile Systems Company

A major missile program, referred to as MXL, at Hughes Missile Systems Company (HMSC) has undergone significant operating changes that were largely driven by competition. The company has been in competition for majority sourcing of this missile during the bidding of each new phase. The most recent contract award provided Hughes Missile Systems Company with majority sourcing of that production lot. The current year production schedule which includes the manufacture of new missiles and the rework/refurbishment of older missiles is approximately double the previous year's production requirements.

The manufacturing requirements for this product have changed dramatically over the product's life. During the past eight years, direct labor requirements for MXL have been reduced significantly while monthly production has steadily increased by 150%. The large reduction in direct labor per missile is attributed to outsourcing, technological progress and the successful implementation of IPTs and PICOS™ events. Quality has also improved dramatically; initial inspection defects have been reduced by 85% over the past five years. As quality has improved and productivity has increased, overall unit costs have decreased by more than 70% since the first production unit.

1.4 Organization of Thesis

An overview of the hypothesized model is presented in Chapter 2. General conclusions from the comparative analysis of the model with the three case study companies are included in Chapter 3. The four main transition phases of the proposed model are then described in the subsequent four chapters. In each of those chapters, a description of the practices and methods of each phase is included, followed by an analysis or comparison of each of the case studies to the model. In the case study comparative analysis section of each chapter, I have utilized a clock diagram to graphically illustrate the practices and/or sequences observed at each of the case study companies.

2. Factory Operations Model

2.1 Introduction

The following model was developed by the factory operations focus group of the Lean Aircraft Initiative. This model represents the combined input and effort of all members of the team. The purpose of this model is to provide a framework for managers of companies with low volume / high complexity products to not just understand the Lean Enterprise (Depicted by the Lean Enterprise Model - LEM) but to also establish a method for how these concepts can be implemented. It is important to note that this is the team's best estimate of how lean concepts can be implemented on the factory floor based on their cumulative experiences prior to and during LAI. As such, it should be considered a hypothesized model which will change as further case studies deepen our understanding of how these concepts are being implemented in industry. Later portions of this thesis will begin the process of proving or disproving the hypothesized model.

The model divides the lean implementation process into four phases. These are the Lean Infrastructure, Factory Flow Redesign, Operations Management Development, and Process Improvement phases, later chapters of this thesis explain these phases in more detail.

2.2 Implementation Phases

2.2.1 Lean Infrastructure

This phase of implementation represents the foundation on which the other phases are built. Steps within this section include:

1. Identify Business Issues and Goals -

    Why does the organization want to become lean?

    What resources can be made available to effect the lean transition ?

2. Initial Comprehensive Benchmarking

   How lean must the company become in order to be globally competitive?

3. Information Technology Hardware and Software Strategy

   How can recent developments in information technology support the lean transition?

   What phase of information will be provided to employees in order to empower them to improve the company?

4. Identify current and needed skills

   What is the current skill base in the organization and how does it compare to others in the industry?

   Are all employees mathematics and comprehension skills above a grade eight level?

5. Fill skills gap with comprehensive corporate wide training

   Design and implement corporate wide basic skills training in order to provide the learning foundation for further lean training such as SPC and Taguchi methods

6. Breakdown stove pipe mentality and establish cross functional linkages

   Through all appropriate means attempt to break down functional barriers between all functions of the company, especially manufacturing, engineering, and purchasing functions.

7. Assess technology impacts to manufacturing processes

   Determine whether recent or near future technological breakthroughs will fundamentally change the current method of manufacturing for your products. For example wave solder drastically altered the way printed circuit boards were assembled.

8. Assess Make/Buy and Establish linkages with supplier and customer base

   To the greatest extent possible determine and align in-house activities around those that provide competitive advantage and purchase those components that do not.

Provide interface mechanisms between the supplier and the shop floor such that the supplier becomes an extension of the in-house manufacturing operation.

Within each of the following phases our model depicts the steps in a specific order. It is important to note that the hypothesized optimal order is not random and does have some logical reasoning to support it.

2.2.2 Steps within Factory Flow Redesign

1. Information Distribution

   Distribute relevant information to as many employees as possible regarding the manufacturing process, expected demand, quality phases, etc.

2. Product Grouping

   Identify products with either similar physical or processing characteristics (i.e. large shafts, extrusions, etc.) and then group them into families.

3. Process Standardization

   Develop a standardized process by which all parts within the group can be made or that can be applied throughout an aircraft assembly line. Note: Individual part cycle times may increase as result.

4. Part Flow Simulation and Process Center Layout Design

   Utilizing computer models or hand calculations simulate the product flow given the desired demand forecast and create a preliminary design base on the results of the simulations.

5. Factory flow design and cell linkages

   Determine which centers flow into each other and design a factory floor layout which optimizes inter-center part flow.

6. Redefinition and re-deployment of tasks around products and processes

   Redefine future employee tasks within the manufacturing center focused factory

7. Delegation of authority and accountability

   Empower and hold accountable the employees and management of the manufacturing centers to optimize their productivity and quality

8. Cell Construction through Kaizen events

   Once the rough redesign of the factory is developed and the new tasks have been defined, utilize cross functional teams and Kaizen events (or equivalents) to rapidly re-layout the factory, center by center

2.2.3 Steps within Operations Management Development

1. Worker Cross Training and Incentive realignment

   Realign employee incentives such that cross functional training is rewarded to provide increased workforce flexibility.

2. Reallocation of Support Resources

   Reallocate support staff from functional responsibilities (i.e. industrial engineering and maintenance) to center responsibilities in order to make the manufacturing centers as self sufficient as possible.

3. Information Management

   Provide mechanisms such as shop floor computers to assist in optimizing the manufacturing center's productivity and quality.

4. Finite Scheduling, Kanbans

   Develop finite scheduling models or detailed Kanban flows to clearly link and monitor the flow of products within and between manufacturing centers

5. Pull Type Production Management

   Once the manufacturing centers are in place, the workers have begun cross training, the support resources have been realigned, and the analysis tools are available then production can be shifted toward a pull type system.

6. Supplier Integration (Note: Suppliers should be going through a similar process in parallel and this step is last only as an integration step)

   Integrate suppliers into the production flow and move towards just in time production flow.

2.2.4 Steps within Process Improvement

1. Improve Process and Operations Predictability

   Through the utilization of tools such as SPC and standardized work processes identify those areas of variability within the process such that the process becomes predictable and consistent.[1]

2. Improve Process Quality

   Once the process is predictable, remove the cause of the variability, one area at a time to isolate the cause and effect of modifying that particular part of the process. Continue step by step until the process yields acceptable quality.

3. Increase Process Flexibility

   Once a predictable quality process is achieved then manufacturing center flexibility can be increased. Flexible tooling and machine technologies can be employed to enable additional production flow possibilities thereby enabling the center to increase throughput.

4. Increase Process Speed

   Once a predictable, quality, flexible process is established then the speed of the process can be increased utilizing faster machines, auto-loading, in process gauging etc.

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[1] This activity may have no impact on quality. The objective of this step is to hold the process in control irrespective of the process yield.

2.3 Lean Implementation Model Description

Now that the individual implementation phases have been briefly defined, Figure #1 presents a framework which depicts the interrelationships of the phases. The framework is presented as a foundational structure with the following hypothesized optimal sequence:

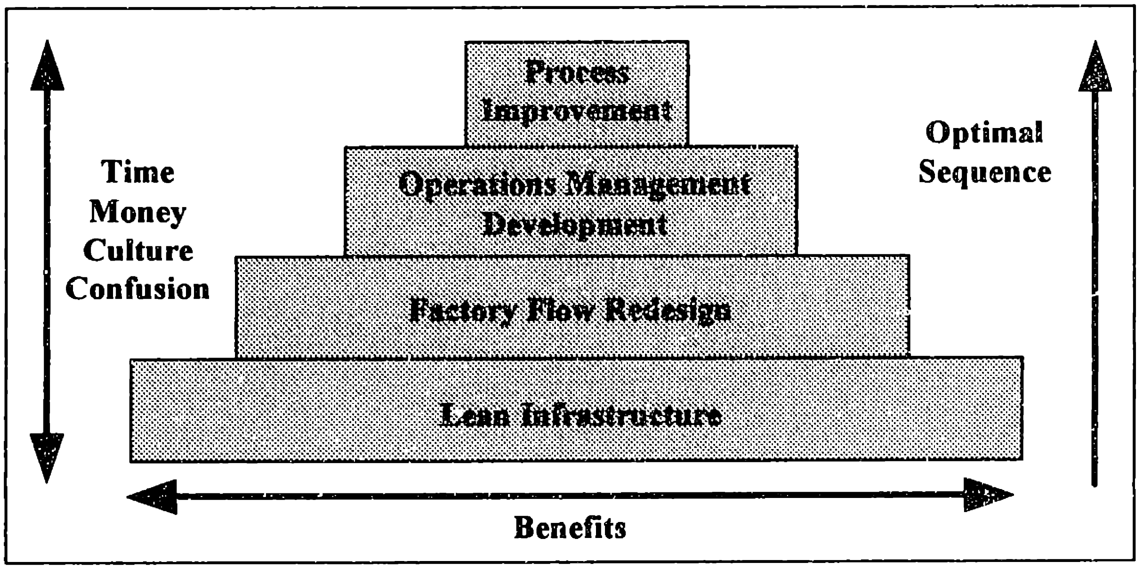
1. Lean Infrastructure
2. Factory Flow Redesign
3. Operations Management Development
4. Process Improvement

Further it depicts that the more phases accomplished, the greater the benefits received from the lean transition. Lastly, the model illustrates that each time a phase is accomplished the company incurs costs in the form of money, time, and "culture confusion".

The optimal sequence depicted is very similar to the process used by well known "green field" plant sites where every aspect of the operations organization is questioned and realigned to optimize the entire operation. GM's Saturn project is an excellent example of a plant which utilized this lean implementation sequence.

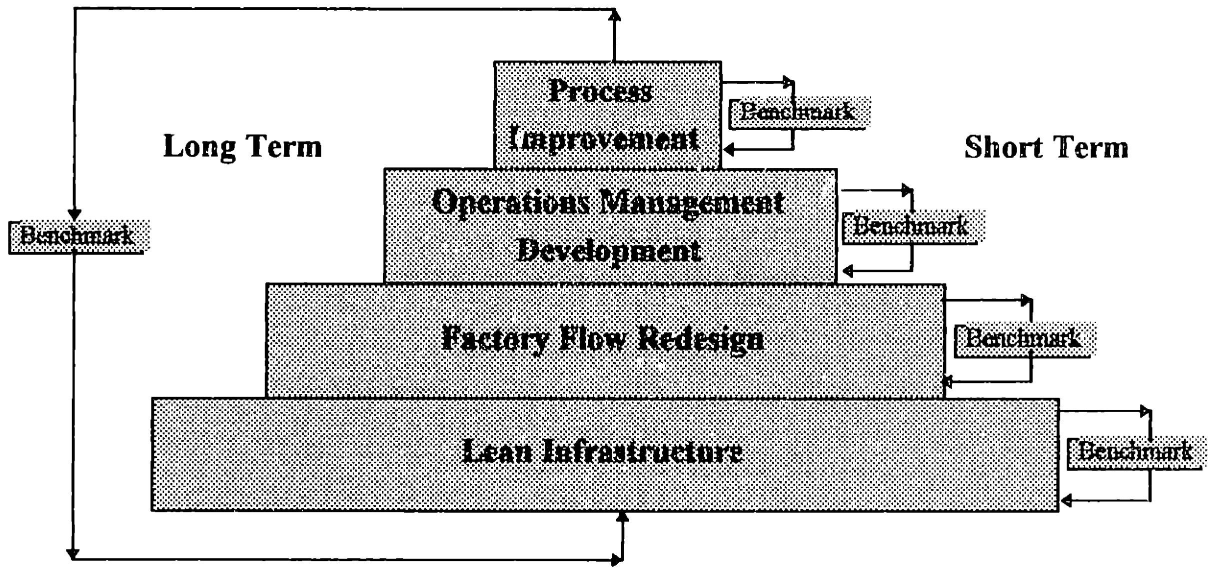
However, most aerospace companies and in fact most companies utilize the inverse sequence. They start by improving their manufacturing processes. This is followed by changes in how the factory is managed, which is followed by a rearrangement of the factory. Finally, the company deals with the underlying issues of how to become lean and what must be changed at a more basic phase to fully benefit from the lean transition. The reason for this is that for most aerospace companies the lean enterprise paradigm was not developed and companies experimented with the easiest lean phases first and became more deeply involved over time. This can be thought of as the "Brown field" lean transition process. There is nothing fundamentally wrong with this approach other than the fact that each time a company enters a new phase, costs are incurred in the form of money, time and culture shock. Ultimately the company should follow the optimal sequence in order to receive maximum benefits and if it followed the inverse sequence it may have doubled the costs of the lean transition.

Figure 1. Hypothesized Lean Implementation Model



It is important to understand that the steps listed earlier within each phase are not one time actions and in fact the steps should be iterating through each phase continuously. Similarly the lean enterprise paradigm will be continuously changing as well and as such the lean transition process must be iterating through as well. Consequently, Figure #2 provides an additional view of our model which accounts for the short and long term continuous improvement cycles and the relevance of benchmarking within the transition process.

Figure 2. Continuous Improvement Cycles



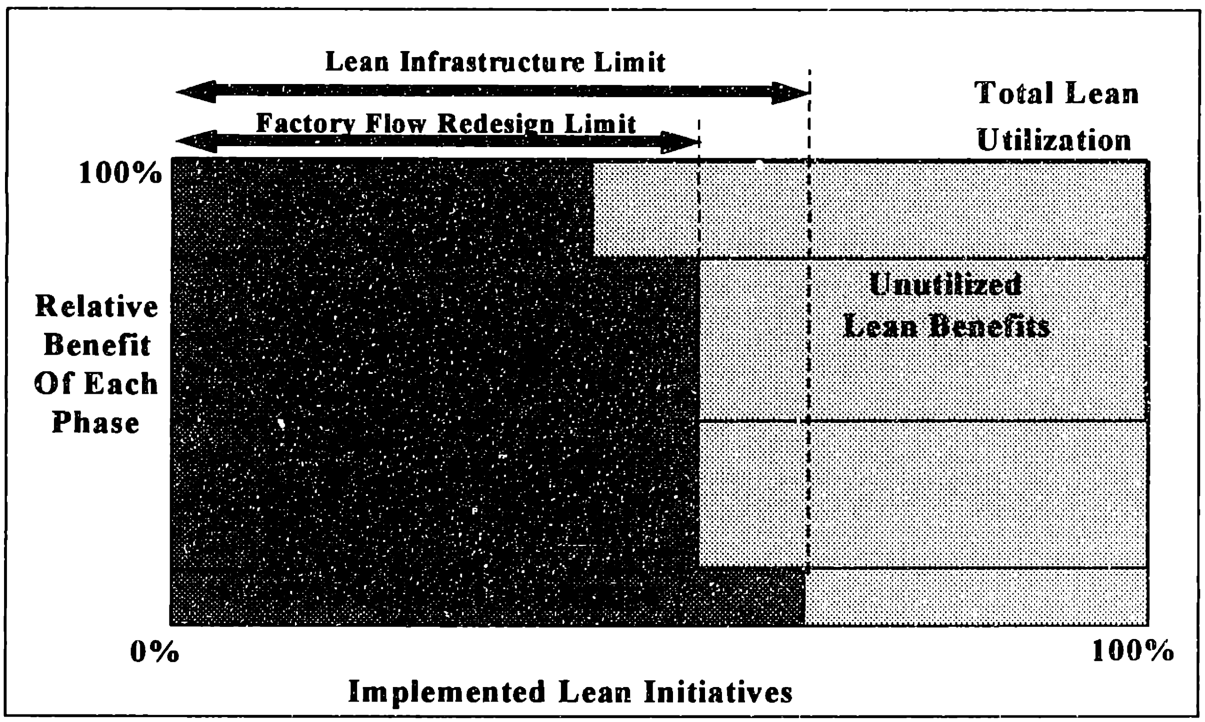
The final view of the hypothesized model depicted in Figure 3 accounts for the fact that each company when transitioning to lean has its own unique circumstances and may benefit from each phase differently. Additionally, this view of the model depicts the foundational nature of the phases more accurately than Figure 1.

This figure illustrates the relationship between transition phases. The hypothesis is that each phase is dependent on the phase below it. In this example, approximately 70% of the potential lean infrastructure initiatives were implemented. This implies that the degree of implementation of the later transition phases (e.g., Factory Flow Redesign, Operations Management Development and Process Improvement) are limited to 70%. The hypothesis implies that the potential benefits from the implementation of initiatives in these later phases are also limited to 70%. The degree of implementation of any lean transition phase restricts the potential benefits that may be achieved in any later phase by the degree of implementation of the preceding phases.

Similarly if the Factory Flow Redesign initiaves are only applied to 60% of the factory then the Operations Management phase, which includes the implementation of a pull type production flow, will be restrained by the remaining 40% of the factory which is organized and managed in the old manner. Consequently if a company wants to maximize its utilization of its lean transition then it must perform as many of the lean initiatives in each phase as possible. Furthermore, it reinforces the optimal sequence in Figure #1 since it makes sense to adopt the lean infrastructure initiatives first so as not to limit the potential of the factory flow redesign, operations management development, and process improvement phases. This should not be interpreted that all the lean infrastructure initiatives should be implemented before the first factory flow redesign initiative is started. Rather a parallel approach should be used where all the phases are being implemented simultaneously with the lower phases slightly ahead of the phases above them.

This view enables the model to provide for the unique circumstances of each company. The relative benefit of the phase is represented by the height of each of the phases. The larger the height represents an increase in the benefit the company will receive from that phase. For instance in this particular company the operations management development and factory flow redesign phases will provide significantly more benefits than the process improvement and lean infrastructure phases. However this does not mean that the latter two phases should be ignored due to the aforementioned foundational affect.

Figure 3. Foundational Effects and Company Circumstances



3. Conclusions

3.1 Overview

The three case studies differ in terms of the lean practices implemented, the focus of their lean transition phases and the implementation sequence they followed. Differences in the size, scope and nature of each of the organizations explain many of the comparative differences with the hypothesized model. Even though not all aspects of the hypothesized model are supported by the case studies, there does appear to be a number of recurring themes from the case studies that concur with the proposed practices and the general implementation sequence recommended in the hypothesized model.

Furthermore, it is not surprising that not all of the case studies support all aspects of the hypothesized model. The model proposed in this thesis should not be considered as the only definitive process that can be used to transition from craft to lean manufacturing. Instead, the hypothesized model should be regarded as one possible methodology that can be used to guide an organization's lean transition.

3.2 Supporting Practices and Enablers

The transition from craft and/or mass production to lean manufacturing is a difficult process. In all of the case studies, the following enabling practices have played a significant role in this process. Conversely, the absence of some of these practices can also be regarded as barriers to lean manufacturing because it limits the organization's realizable potential benefits.

- *Teams/IPT* - Teams were a powerful mechanism for transferring information, problem-solving, continuous improvement and for learning. All of the organizations studied have incorporated IPT into their organizational structure because it increased the firm's agility or its speed in responding to a changing environment. Teams were motivated by the implementation of their ideas or recommendations. Consequently, it was important to dedicate both human and capital resources to execute improvements.

- *Variability Reduction* - The reduction of variability in a process is similar to the elimination of inefficiencies or waste. It leads to greater control, improved planning, reduced risk exposure and greater efficiency. Variability reduction programs were a priority in all of the case studies.
- *Leadership* - In every successful lean transition program, leadership has played an important role. Effective leadership establishes the vision, motivates employees, breaks down barriers, provides stability and coordination and creates change. The lean transition process is not a bubble-up process where executives wait for ideas or concepts to bubble-up from their managers and employees. Instead, executives must be actively involved in developing the process and leading its implementation.
- *Crisis* - Most of the case study organizations experienced a crisis which precipitated their lean transitions. A crisis, whether it be a contract loss or increased competition, can provide the impetus necessary to mobilize the organization to change.
- *Focus* - The implementation of variability reduction programs and IPT was supported by the organization's transition from being functionally focused to being process focused. The case study companies also focused on processes that were important to their strategic goals.
- *Expanded Responsibilities* - The division of labor promoted by Henry Ford's mass production assembly line has been altered. Employee skills and responsibilities have been expanded to increase their flexibility and accountability in the workplace. Incentives have also been modified to support these work definition changes.

3.3 Implementation Sequence

Each organization's lean transition utilized an overall sequence that possessed some similarity to the hypothesized model but was definitively not identical to the model. The following list explains some of the general conclusions regarding the hypothesized model's proposed optimal implementation sequence.

- The proposed implementation sequences within each of the transition phases was generally supported by all of the case study companies.
- There are no discrete start/stop points between transition phases. For example, the Factory Flow Redesign phase should not be delayed until all of the practices from the Lean Infrastructure phase have been implemented. Most of the phases are actually processes that should be continuously improved.
- Customer specifications have often driven the implementation of lean practices at the case study companies. For example, all of the case study companies have recently implemented SPC and variability reduction programs in response to contractual obligations. These programs, proposed as the last transition phase by the model, have been implemented at the same time as other programs have.
- Implementation differences highlight differences in the inherent nature of each organization or its parent organization. The case study companies have initiated their lean transitions from different starting points and under different operating scenarios. Reasons for these differences are numerous and can vary from product/process maturity to availability of capital to operating requirements.
- Practices in the lean infrastructure phase, such as the execution of an information technology strategy, have lagged the implementation of other practices in this phase because of poor short-term financial returns.

The following implementation sequence is the approximate result produced by merging the three case studies together. Technology improvements and product redesigns were the common basis for early lean transition events. Enabling processes at this stage were Computer Aided Design (CAD) tools and Integrated Product Teams. Make/buy outsourcing decisions and some basic skills training usually either accompanied this phase or followed it closely. Process flow was then redesigned to remove waste and reduce costs. The development of teams also began at approximately the same time as process flows were redesigned. Employee involvement in this step was effective. This was followed by the implementation of SPC which was followed by the delegation of quality assurance responsibilities to production.

3.4 Review of the Major Transition Phases

3.4.1 Lean Infrastructure

The practices implemented in this phase shared the common objective of creating and reinforcing the organization's operating philosophy or culture. Each organization's business strategy was focused on integrating its business processes and eliminating barriers between functional silos in order to improve quality, delivery and reduce costs. In addition, most of the case companies have established ISO 9000 as an externally measured quality standard.

The organization's effectiveness in achieving their goals was dependent on the level of leadership committed to this end and to the incentives of the individuals involved. The degree of integration between the organization's operating and information technology strategies also varied, as did the quality of the information received.

The importance of an organization's supplier management programs depends on the level of vertical integration within the organization. There appeared to be a trend toward increasing the share of products outsourced to suppliers. One of the reasons for this trend is that outsourcing allows the enterprise to focus on their manufacturing competencies.

In all of the organization's studied, basic mathematics and literacy skills for shop floor employees were regarded as foundation blocks. These skills were necessary to implement statistical process control methods, continuous improvement teams, and other employee certification programs.

3.4.2 Factory Flow Redesign

All of the organizations have recognized the benefits of efficient process flow. These benefits include: reduced inventories, improved communications, reduced cycle times, and improved visual management. The steps proposed in this transition phase were generally followed except for part flow simulation. This step was not implemented at either of the assembly/integrator facilities, Northrop Grumman Corporation or Hughes Missile Systems Company.

The main difference between the hypothesized model and the Raytheon Aircraft facility was the method of execution. Raytheon Aircraft's aggressive modernization schedule may have limited their ability to transfer the incremental learning from the piloting or sequential implementation of cells over a longer time horizon.

The proportion of enterprise resources invested in this transition phase varied from organization to organization based on the degree of potential benefits achievable at each organization. Raytheon Aircraft's operation is a job shop that produces over 36,000 different part numbers in low volumes. Consequently, their process flow paths were too numerous and complex to manage effectively prior to their cellularization program.

3.4.3 Operations Management Development

Line based accountability was regarded as a critical lean manufacturing practice. All of the organizations were implementing or had implemented employee certification programs. These programs transfer quality assurance responsibilities to production operators. This step could only be implemented after production operators were trained in quality inspection techniques.

Team based management varied between organizations. MXL's extensive IPT organizational structure and active shop floor employee involvement enhanced information flow between groups which resulted in expedient problem resolution. IPTs and process improvement teams were also well established in the other two organizations.

None of the organizations had implemented Kanban or pull type production systems. They were still using MRP systems, or derivations thereof, to both schedule and control product flow through their factories.

3.4.4 Steps Within Process Improvements

Variability reduction is a common objective in the process improvement phase. The implementation of SPC and operator certification programs is widespread. Organizations are striving to realize capable processes with Cpk values greater than 1.33. A majority, but not all, of the processes that are measured have accomplished this process control objective.

However, with regards to the last two steps in this phase, there has been minimal investment to achieve increased process flexibility or speed. This supports the implementation sequence proposed in this phase which recommends the improvement of process predictability and quality prior to increasing process flexibility and speed.

4. Lean Infrastructure

4.1 Introduction

From the hypothesized model, the implementation of a lean infrastructure is the first major phase that must be undertaken when attempting a lean transition. A lean infrastructure represents the foundation that organizations can use to maximize the potential benefits of the successful implementation of later transition phases. Without the development of a lean infrastructure, the organization may not achieve its optimal level of lean manufacturing. For example, if the organization ignores the development of its infrastructure and focuses its efforts on process improvements, it may only be able to optimize the pre-transition potential of process improvements. Essentially, the implementation of a lean infrastructure greatly expands the potential benefits associated with the development of later transition phases.

In this section I describe processes that could be used to implement a lean infrastructure. I will also explain how the potential benefits of later transition phases increases after the implementation of a lean infrastructure. To support these propositions, I will present evidence from our case studies that describes some of the practices these companies have implemented and some of the benefits that accrue to a strong infrastructure.

4.2 Development of a Lean Infrastructure

4.2.1 Identify Business Strategy

Under the hypothesized model, the first step an organization must undertake before it can initiate a lean transition program is to identify its goals and business issues. A clear and well-articulated manufacturing policy provides the link required between operations and strategy that establishes a common vision for all employees in the organization. Manufacturing strategy must become integrated into the overall business strategy in order to develop and strengthen the interface between operations, engineering, finance, purchasing and marketing. These links will assist the organization in developing a competitive advantage in product development, manufacturing and customer support.

The lean organization must have a manufacturing strategy in order to make operating decisions regarding technology, human resources and management in a consistent manner. The organization's manufacturing strategy will form the basis for its operating environment. It is from this common basis that the entire organization will remain focused.

Once the organization's manufacturing strategy has been developed and integrated with the enterprise's business strategy, it will also require updating in order to incorporate changes in its environment. In light of a corporation's traditional five year business plan process, the company should review its manufacturing policy annually as part of a short term continuous improvement cycle.

Ever since C. K. Prahalad and Gary Hamel's article, "The Core Competence of the Corporation" (HBR May-June 1990), we have known that leadership rests on being able to do something others cannot do at all or find difficult to do even poorly. It rests on core competencies that align customer value with a special ability of the producer or supplier. This phase focuses on the firm understanding its core competence and developing an environment where it can be nurtured and exploited.

4.2.2 Benchmarking

Benchmarking is a key measurement process used to help the company understand its competitive environment. The establishment of a world-class standard provides the company with a visible target that can be used to keep the entire organization focused on its task. Without benchmarking, the company can not fully understand its competitive position within the industry nor can it understand what needs to be changed or how to change it. Management should continually compare itself to world-class leaders and use this benchmark information to improve itself. This process also helps the organization learn about new technologies or management processes from organizations both within and outside of their industry.[2]

Benchmarking assumes that it is possible that what one organization does, any other organization can do as well. And it also assumes that being at least as good as the leader is a prerequisite to being competitive. Benchmarking provides the diagnostic tool to measure the productivity of all factors and to manage it.

4.2.3 Identification and Acquisition of Required Skills

At the beginning of the transition from craft to lean manufacturing, the organization should identify both currently required skills and forecasted skill requirements. After identifying these requirements, the company should undertake the necessary provisions in order to comprehensively satisfy these requirements. It is beneficial to initiate enterprise-wide training that provides a common knowledge set and language across the organization. This level of training should utilize the organization's operating strategy and vision as a basis. The organization's strategy should be integrated into employee training programs in order to reinforce the company's objectives.

The acquisition of basic skills (e.g., reading and mathematics) at this phase of the lean transition is necessary in order for the organization to receive maximum benefits from later lean transition phases that include the application of Statistical Process Control (SPC). Without the acquisition of base knowledge during this phase, active employee participation will yield minimal benefits for two reasons. First, their motivation for participation will be low because of their lack of understanding and possible intimidation of the new operating requirements. Second, they will not have the skills necessary to effect change autonomously in their day-to-day operations that the lean organization requires. Consequently, the hypothesized model places significant value on the acquisition of basic skills.

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[2] Lambertus, Todd. "The basis of benchmarking" published by Incentive. Copyright 1995 UMI, Inc. September 1995.

4.2.4 Supplier and Customer Base Relationships

Liaison between the supplier and the organization should be strengthened in order to promote learning across both entities. The degree of investment required in this stage will depend greatly on the degree of vertical integration within the organization.

If the supplier base is ignored until the company implements all four lean transition phases, it may be exposed to significant operating risks that are not under direct management control. Once a risk materializes into a major problem, the abatement process may demand significant resources (i.e., labor, material and time). Therefore, as a proxy for direct control, the organization's supplier liaison representative should maintain open communication and direct monitoring of the supplier's capabilities and improvement progress in order to execute effective risk management.

Suppliers must attain the same level of process capability that is required of internal suppliers. Essentially, it is optimal for the supplier to implement similar lean transitions phases which could enable the simultaneous long-term optimization of the entire value chain using systems dynamics concepts.

4.2.5 Breakdown Stovepipe Mentality

Part of the implementation of a lean infrastructure includes the process of breaking down the stovepipe mentality that may exist. Strong leadership in this area is critical to the establishment of cross-functional linkages. The company's manufacturing strategy and vision must be clear to all members of the organization and they must be collectively focused on achieving the company's objectives. The Not-Invented-Here mentality that exists in many organizations must be replaced by a cross-functional organizational structure that supports the organization's common goal.[3]

The organizational structure that often emerges in lean enterprises is one that focuses its membership on customer satisfaction. Whether internal or external, excellence in quality,

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[3] Peters, Tom; Waterman, Robert; "In Search of Excellence." Published by Harper and Row, NY, 1982.

schedule and cost must be attained in order to satisfy the customer. The vertical levels of hierarchy, typical of large bureaucratic organizations, must also be reduced. Functional departments must refocus their energies from building barriers to breaking down barriers. Matrix organizational structures and integrated product/process teams (IPT) support the processes critical to the enterprise's success.[4]

4.2.6 Information Technology

Similar to the establishment of the company's manufacturing strategy, the organization should also adopt an information technology hardware and software strategy that will enable the successful implementation of other lean transition phases. The selection of hardware and software must be flexible enough to support future operating requirements.

In the hypothesized model, information technology systems are simplified into the following four areas: data acquisition, information transfer, data management, systems implementation. In the data acquisition area, the company should answer questions such as what information is needed, when is it needed, who collects the data and how is it collected. With respect to information transfer, the company should understand who requires the information, what they will use it for, and how they will use it. The answers to these questions will drive the method used for information exchange. Data management refers to data/information standardization, data storage, database management, and data analysis. Once these questions, along with many others not included in this list, are answered the company can then design the system to satisfy its strategy and conduct a make/buy decision analysis in order to initiate the systems implementation phase.

4.2.6.1 Importance of Integration

Companies need to make rapid changes at every phase of getting their products to the market. Therefore current operating requirements are driving the formation of links between materials, manufacturing, designers, finance and other support functions. The seamless

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[4] Klein, Janice; Susman, Gerald I.; "Lean Aircraft Initiative Organization & Human Resources Survey Feedback - Integrated Product Teams (IPTs)." White Paper - Lean 95-03. April 7, 1995.

integration of product data from design to resource planning to plant floor to outside suppliers to purchasing to anyone who needs it is often referred to as the Information Technology (IT) challenge. If a company's information systems are micro-managed at the functional level and are not integrated into an enterprisewide information systems strategy, the company will end up having islands of information that won't communicate. IT managers should understand how all their information systems fit together in order to maximize cross-functional synergies, overall efficiency and speed. Benefits in product development due to the integration of common data bases have been experienced in many industries.[5]

IT functions should become integrated with the organization's business strategy. Companies that are linking their manufacturing islands are companies where IT and Manufacturing personnel are working closely together. End users must drive the decisions about which design and manufacturing technologies to adopt, but IT staff must push if necessary to get in on the earliest planning stages. This requires a change in attitude. "The companies that seem to be successful tend to integrate their technology investment into some larger organizational change," says Richard Lester, a professor at the Massachusetts Institute of Technology and director of the Industrial Performance Center.

Redesigning the IT infrastructure is the same thing as redesigning the organization and organizational charts are all about who needs to talk to whom. Distributed processing is all about which computers need to talk to which ones. As IT executives install new information systems, they are helping recreate the organizational structure.

4.2.7 Technology

The effective application of technology can provide significant operating benefits via improved quality and cost performance. However, too often technology is incorrectly applied as the solution to many problems. Therefore, it is critical that the selection and

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[5] DeWitt, John W.; "CAD dreams come true." Published by Apparel Industry Magazine. Copyright 1994 Shore Communications Inc. April 1994.

application of technology be aligned with the organization's manufacturing strategy.

The company should utilize the benchmarking process to measure internal technological advancement with externally available technology. Internal technology development, including both applications and core technology development, should utilize as much commercially available technology as possible. As mentioned earlier, the benchmarking process increases the company's awareness of its competitors and of similar applications in other industries.

4.3 Case Studies

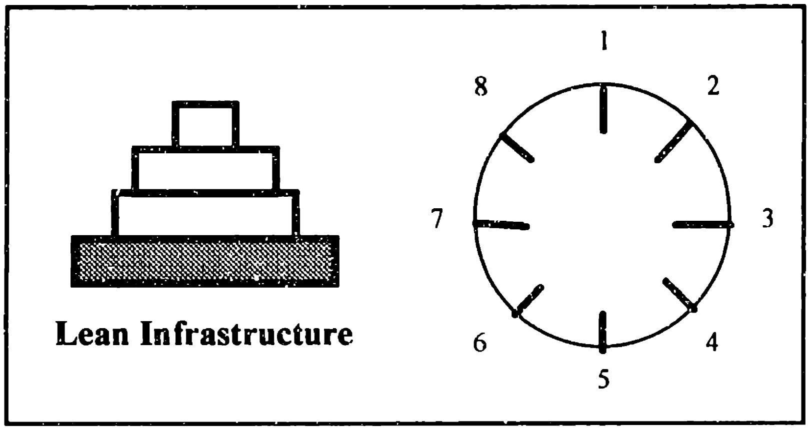
A comparative analysis is presented for each case study company at the beginning of each section. The analysis includes a brief summary of the major activities undertaken by the organization and a figure that depicts the practices implemented with notches by the appropriate number. In the Lean Infrastructure phase, there are eight major activities: 1) business strategy, 2) benchmarking, 3) identify needed skills, 4) acquire needed skills, 5) supplier/customer relationships, 6) stovepipe mentality, 7) information technology, 8) technology.

4.3.1 Northrop Grumman Corporation

Northrop Grumman Corporation has made significant investments in developing a lean infrastructure. Even though the F/A-18 E/F is a new program, most of the learning from the C/D program was directly applied to E/F. Consequently, Northrop Grumman has placed increased value on breaking down barriers between functional groups through the promotion of IPTs and through the coordination of its Manufacturing Process Variability Reduction program. The timing of the F/A-18 E/F program and the corporate decision to outsource sheetmetal and metal-cutting fabrication has led to: the execution of a comprehensive training program for all assembly mechanics, the development of a flexible and integrated information management system and, an increased focus on supplier management.

The lean manufacturing activities that Northrop Grumman Corporation have implemented closely parallels the practices proposed in the Lean Infrastructure phase of the hypothesized model. As the following figure illustrates, all of the practices proposed in the Lean Infrastructure phase were implemented. Northrop Grumman began implementing some activities from this phase over ten years ago and it should be noted, is still in the process of implementing other activities from this phase. Activities in this phase appear to have a long duration and are continuously being improved upon.

Figure 4. Lean Infrastructure Phase at Northrop Grumman



4.3.1.1 Business Strategy

Northrop Grumman's operating strategy is rooted in the Northrop Aircraft Division Systems Architecture Plan (NADSARP) which was developed in the mid 1980s. NADSARP was originally initiated to address: 1) concerns over the division's increasing investment requirements in information technology and, 2) the organization's loss of competitiveness illustrated by the F-16 contract award to General Dynamics. The resulting plan, however, addressed more than information systems. It envisioned an operating culture that described MRP, the Factory of the Future, Centers of Excellence, processes surrounding product definition and concurrent engineering. NADSARP was used on the B-2 and F/A-18 C/D programs and further expanded upon in the joint Northrop Grumman / McDonnell Douglas F/A-18 E/F manufacturing plan in 1993.

Many of the practices described in the F/A-18 E/F manufacturing plan have formed the cornerstone for Northrop Grumman's lean transition. In addition to this effort, the F/A-18 C/D program also began to initiate a Manufacturing Process Variability Reduction (MPVR) program in 1991-92. This program supplemented government requirements to implement top-level TQM practices and was carried over to the E/F program. MPVR is an organized, systematic approach for accomplishing variability reduction using process improvement and control methodologies. Its wide ranging objectives include the following: reduce cost and delivery time; improve product quality, customer satisfaction and competitive position; provide process capability information and; transition from an inspection oriented to a process control oriented method of operation. MPVR represented a major change in the organization's operating culture. While good quality and zero defects have always been common manufacturing goals, historically the emphasis was on cost and schedule. Employee empowerment and process ownership are critical to the success achievement of any of the MPVR implementation plans.

Northrop Grumman Corporation has focused its corporate manufacturing strategy on composites fabrication and airframe assembly. Executive management has made significant investments in composites manufacturing processes in order to become one of the premier composites fabrication companies in the airframe industry. Since the technological development of new airframes is demanding an increasing proportion of lighter weight and higher strength composites materials, one of Northrop Grumman Corporation's corporate objectives is to exploit its core competence in composites manufacturing technology as a source of competitive advantage in the competition for future airframe contracts.

Another Northrop Grumman Corporation corporate goal is to receive ISO 9000 certification. The specific requirements defined by this certification include the implementation of concepts like IPT and multi-skill jobs training programs which reinforces Northrop Grumman Corporation's efforts in these areas. The adoption of this objective reinforces the program's vision for all employees and clearly specifies the performance and operating requirements necessary to attain this level of certification. Since the organization has began rallying around the attainment of these objectives, a "new" operating atmosphere or culture based on change and continuous improvement has begun to transcend the firm.

4.3.1.2 Benchmarking

Before the corporation decided to outsource its machining and sheet metal fabrication in 1993, it had conducted a number of benchmarking trips to learn methods of improving its processes. Many of the practices observed on those trips were used to redesign the fabrication plant factory flow.

4.3.1.3 Basic Employee Training

Northrop Grumman Corporation has developed an internal training program that outlines specific mechanic qualifications. In order to attain Northrop Grumman Corporation's internal mechanic certification, all E/F assembly line mechanics were required to receive 240 hours of training in the following areas: Basic Skills, Basic Math & Precision Measuring Tools, Blue Prints, Process Specifications, Hole Preparation & Countersink, Fasteners, Trim & Drill Fundamentals, Sealant, Parts Handling, Foreign Object Elimination, Safety and Hazardous Materials, and IMPCA Systems. Mechanics using SPC are given eight hours of training leading to an SPC certification. Since the introduction of this program in 1993, most of the E/F mechanics have graduated. Currently, both E/F and C/D mechanics are being phased through the program.

4.3.1.4 External Supplier Management

As part of the execution of Northrop Grumman Corporation's corporate strategy to focus on composites fabrication, it has recently outsourced virtually all of its non-composites related fabrication capabilities and requirements. The decision to outsource fabrication was made largely on economic grounds. Even after the implementation of many lean practices, internal fabrication continued to be more costly than purchasing fabricated parts from external suppliers.

The processes of tool design and tool manufacture is also being combined to increase the tooling supplier's participation in the tool procurement value chain. The EMD phase of the E/F program was coming on-line at the same time that they began to outsource all metal fabrication and manufacturing requirements. This strategy has increased its focus on external supplier management.

Due to Northrop Grumman Corporation's increased reliance on external suppliers, it is currently consolidating its supplier base to a more manageable level. They have already reduced the number of machined parts suppliers from 300 to 65 and the overall number of suppliers from 1000 to 300.

To support the consolidation process, Northrop Grumman Corporation has established Integrated Supplier Management Teams (ISMT). ISMT is being implemented with all suppliers focusing initially on general procurement materials. The ISMT is composed of a buyer, manufacturing engineer, quality assurance representative and a supplier representative. ISMT improves all aspects of product management communication.

Currently, 27% of its suppliers are classified as "Key Plan Suppliers". The pre-qualifications of a Key Plan Supplier include the following delivery performance measurements: 99% fill rate, 98% on-time, 95% documentation accuracy. Suppliers that satisfy the Key Plan Supplier requirements receive: payment on receipt, first choice in new product sourcing and, the opportunity to receive sole source contracts.

The outsourcing of fabrication has subsequently increased the number of issued purchase orders from 4,000 to 18,000 while the number of materials management personnel has decreased. In an effort to improve the procurement process, Northrop Grumman Corporation has initiated a reengineering program focused on streamlining the auto-requisition and auto-change order processes. One of the objectives of this project is to reduce ordering lead-times as well as the variability surrounding ordering lead-times.

Inventory Reduction

Northrop Grumman Corporation tracks raw material inventory through six major categories and measure cost levels and turn targets for each: Castings & Forgings, Standard Parts (fasteners), Offsite Machined Parts, Raw Material, Purchased Parts, Equipment. On average, the goal is to turn average inventory three times per year. As a result of inventory reduction programs, purchased raw material inventory (inventory not accounted for by WIP or Finished Goods) levels have decreased by approximately 50%. Northrop Grumman

Corporation's receiving inspection process has also been modified such that standard parts are sample inspected by lot while machined parts are 100% inspected at the supplier. Virtually all parts are source inspected. It is believed that these performance results are due to improved supplier management practices and are not due to significant improvements in shop floor manufacturing policies.

Northrop Grumman Corporation has also experienced success in the reduction of inventory levels through the implementation of more frequent supplier deliveries. Deliveries are currently scheduled according to MRP II need date and product cost. Refer to Table 1 for specific details.

Table 1. Northrop Grumman Corporation Supplier Product Delivery Matrix

Product Costs	Annual Delivery Frequency
$ 0 - 1,000	1 time per year
$ 1,001 - 3,000	3 times per year
+ $ 3,000	per C/PIOS/MRP II schedule (E/F - once per month)

Furthermore, a recent executive management policy statement transferred inventory level management responsibilities from the materials management group to the individual program managers. The objective of this change is to motivate program managers to reduce excess inventory. Consequently, each program office must balance the tradeoff between the capital charge associated with carrying inventory and the risk of not meeting schedules. Each IPT has been assigned a materials procurement specialist that completes this tradeoff analysis and helps manage that particular IPT's supplier base.

As a result of the preceding changes, overall inventory levels have been reduced by 35% between 1992 and 1995.

Composites Fabrication

In the composites manufacturing facility, the autoclave equipment determines material loading schedules because they are very expensive to operate. Hence, Northrop Grumman Corporation has created "bus schedules" (with published departure and arrival times) which are used by the rest of the facility to schedule material flow. Due to low production volumes, the autoclaves are currently not operating at full capacity.

Even though most of Northrop Grumman Corporation's composites suppliers are local, the company stores large lots of perishable raw materials in freezers that have high operating costs. They have recognized the opportunity to reduce raw material inventory through improved JIT delivery schedules that utilize smaller lots.[6]

Customer Relations

Northrop Grumman Corporation's customer, McDonnell Douglas (MDA), has three levels of supplier certifications (Gold, Silver and Bronze) that imply various relationships. The evaluations subject suppliers to an analysis of the following weighted performance certification areas: Management Involvement, Process Focus, SPC Implementation & Documentation, Employee Involvement, Capability, Process Documentation, Criteria for Selecting Key Process, Selection of Process Characteristics. Northrop Grumman Corporation received bronze supplier certifications from MDA for SPC in 1993, for business management in 1994, for cost and performance in 1994. Northrop Grumman Corporation's objective is to receive MDA Silver preferred supplier status by the fourth quarter of 1996.

Northrop Grumman Corporation's customer requirements regarding processes and systems, including the implementation of SPC, have increased significantly over the past five years. In addition, management acknowledges that the receipt of future contracts become increasingly dependent on past performance.

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[6] Composites raw material used at Northrop Grumman has a shelf life of less than one year.

4.3.1.5 IPT (Integrated Product Teams)

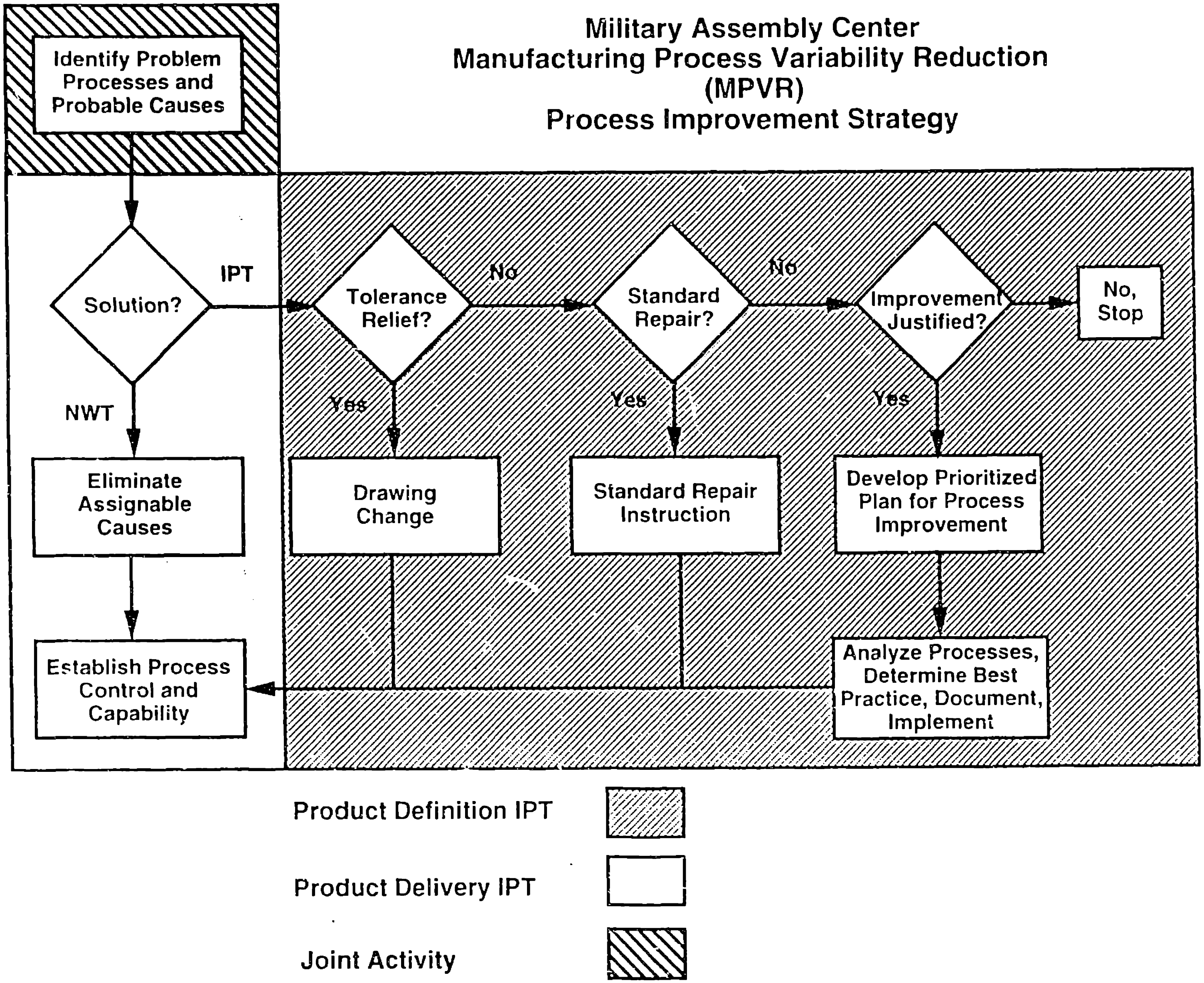
The IPT concept was driven by both Northrop Grumman Corporation's CEO and McDonnell Douglas Aircraft E/F program specifications. There are five major IPTs on the E/F line: Center, Aft, Forward-center, Aft-vertical fuselages and Systems/Sub-systems.

IPTs are created at different management/personnel levels: level four - team; level two and level three - team leaders; level one - program managers and others as needed. A level four IPT is composed of a product design engineer, manufacturing engineer (responsible to operations), tool designers, procurement specialists, offsite manufacturing engineers (responsible for suppliers), planners and expediters. Each IPT has a number of related subassembly and main assembly line cost centers assigned to it and each team program manager is responsible for quality, cost and schedule.

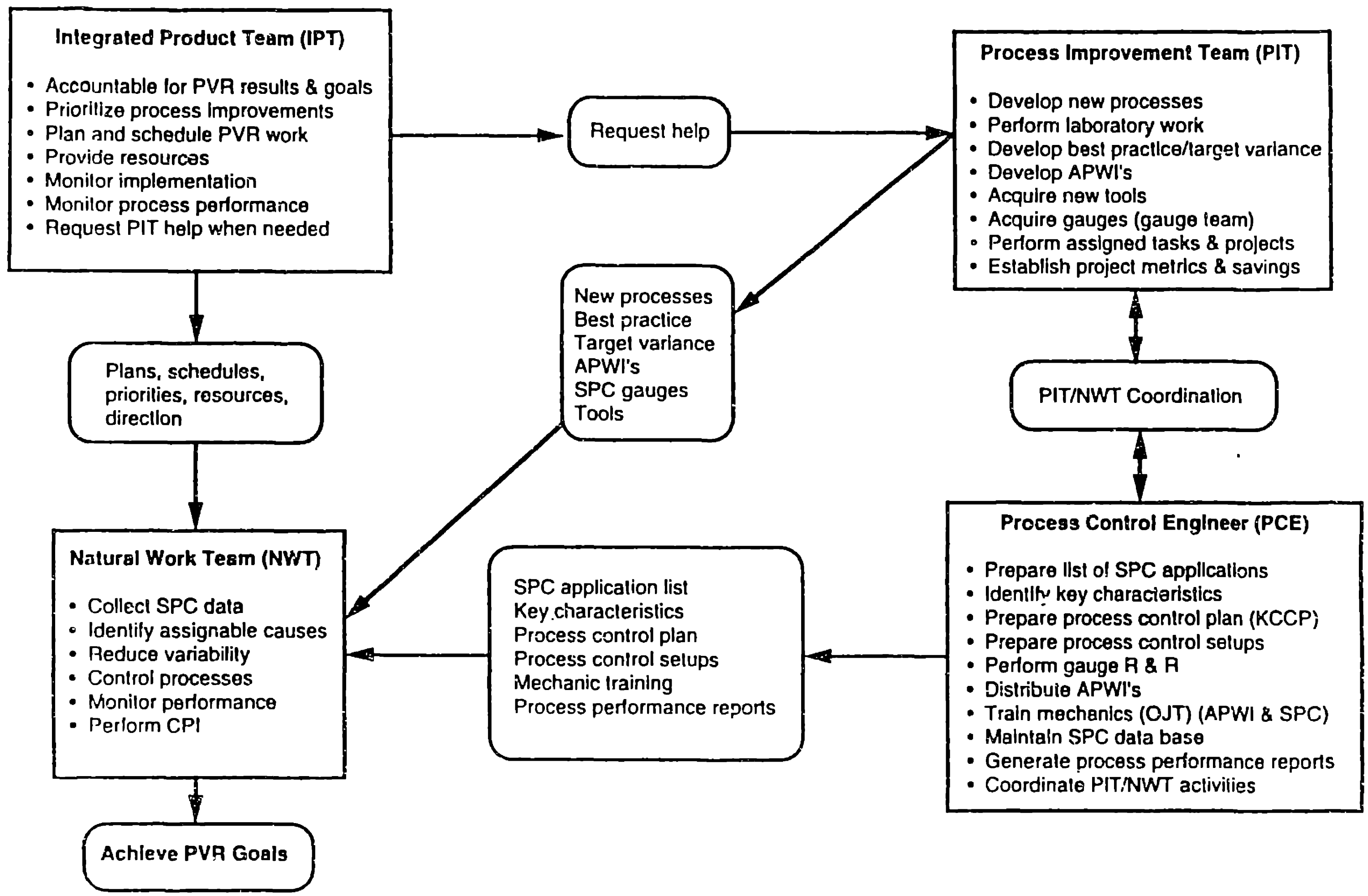
Included in the company's Manufacturing Process Variability Reduction (MPVR) plan is its definition of the roles and responsibilities of product definition IPT and product delivery IPT and those activities that have joint ownership. This definition has improved the E/F's transition from design to manufacturing. One of the challenges in this new system, however, is to modify the operating environment in order to better define the tradeoff in responsibilities between functional departments and integrated product teams. (See following exhibits on PVR Relationships for more details.)

The F/A-18 C/D program did not utilize IPT and therefore it was difficult to manage the transition between product design, manufacturing engineering and operations. The C/D program's stovepipe operating culture can be best illustrated by the following example of inefficient transition management on the C/D assembly line. In a recent international customer order, the final customer increased the structural stability specifications on the C/D fuselage from 7.5G to 9.0G. Product engineering accommodated the change in performance specifications by replacing the normal bulkhead material of aluminum with titanium. The company, however, did not make modifications to the manufacturing and assembly process in order to accommodate the different material bulkheads. Consequently, they had difficulty assembling the modified C/D and unfortunately were required to scrap the first assembly section and experience some production delays. This experience was

Military Assembly Center
Manufacturing Process Variability Reduction (MPVR)
Process Improvement Strategy



PVR Activity Relationships



exacerbated by the simultaneous occurrence of both an enterprise-wide early retirement program which negatively impacted the program's knowledge base and the outsourcing of fabrication. It is largely believed that the increase in the cost of quality surrounding this change would have been avoided on the E/F line due to the dynamics of IPT and MPVR.

4.3.1.6 Employee Incentives

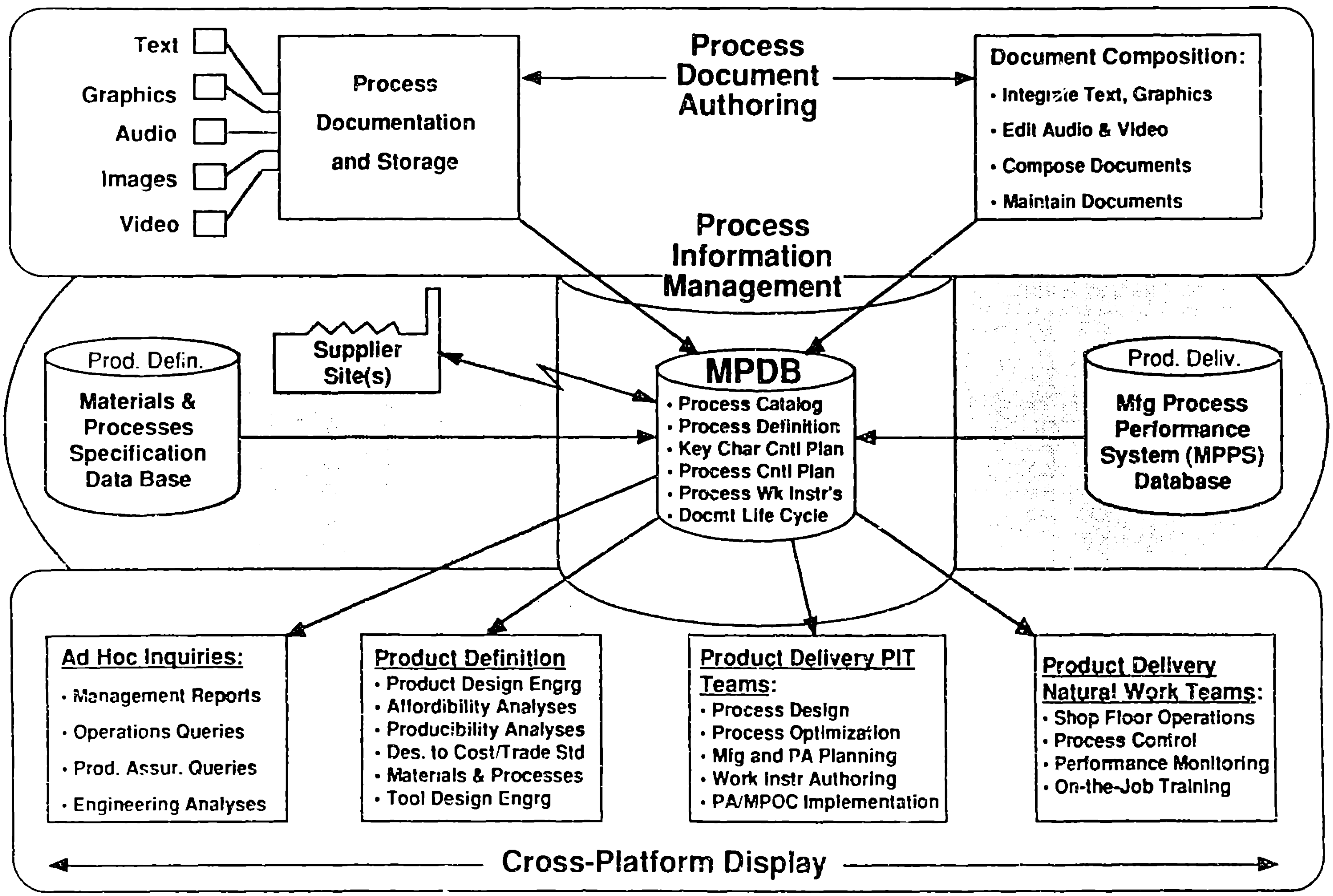
The mechanism for rewarding outstanding achievement has limited the potential benefits associated with IPT. Changes in the remuneration system have lagged changes in the functional operating environment. Hence, the current incentive system does not support the operating behavior that Northrop Grumman Corporation wants to achieve.

In addition, as the organizational structure continues to flatten, there are fewer hierarchical promotional opportunities for individuals to aspire to. Management recognizes that greater horizontal mobility and promotion should be incorporated in this structure in order to align personnel incentives with performance. The employee incentive structure should be modified to promote outstanding IPT performance while individuals should also be rewarded for work broadening or multi-skill development assignments.

4.3.1.7 Information Technology

The implementation of the company's MPVR program includes significant changes to the organization's information systems strategy. The organization's long-term goal is to replace its mainframe legacy systems with a common open systems client/server architecture that utilizes commercially available off-the-shelf applications software. Included in the MPVR program's goals for 1995 is the migration of the current SPC system to a UNIX/Oracle platform using RISC computers instead of personal computers. In conjunction with the SPC transition, Northrop Grumman Corporation also plans to acquire and initiate the development of a Manufacturing Process Data Base System (MPDB). The MIS group will implement common hardware, software and networking equipment across the enterprise utilizing an open systems platform architecture. Their systems implementation strategy is to procure as much commercially available software as possible in order to minimize in-house proprietary software development. Internal software development requires tremendous

Mfg Process Data Base (MPDB) Integration for Manufacturing Process Definition and Performance Management



resources in personnel and time and may not provide significant operating advantages.

The timeline for MPVR computer systems is the following: 1993 - develop requirements; 1994 - install DataMyte/Quantum SPC system and 51 data collectors; 1995 - migrate to UNIX/Oracle and add 30 data collectors; 1996 - train, load and deploy to shop floor.

Unigraphics II (UGII)

All product and manufacturing design was specified by MDA to utilize UGII CAD systems for development. UGII was cited as one of the most important enablers to the success Northrop Grumman Corporation has experienced in its process variability reduction plan. The company effectively applied tolerance stack-up and product variability analysis tools to reduce process variability and significantly improve first time capability.

Tooling engineers used UGII part data to develop and simulate tooling designs concurrent with product designers. UGII significantly reduced feedback lead-times between the two groups which enabled product designers to incorporate manufacturing concerns and requests into their designs. Three dimensional CAD data was critical to the successful first-time assembly of subassembly hydraulic tubing and other peripheral support system designs that traditionally applied craftsman fit-at-assembly skills. The right hardware and software enabled Northrop Grumman Corporation to achieve a Design-For-Manufacturing/Assembly (DFM/A) environment.

Weaknesses and Limitations of Current Information Systems

Northrop Grumman Corporation currently uses a separate timekeeping and earned value systems. Therefore, it requires a manual paper operation to correct mistakes on a daily basis and it is a time consuming manual process to provide operations management with how much was spent by cost center, by individual, by tool on a daily basis and the information that is currently available may not be accurate. The two systems are planned to be linked electronically prior to the first Low Rate Initial Production (LRIP) unit.

Another policy weakness that exists at Northrop Grumman Corporation is the large variability in reporting requirements from various managers. Charts and reports that are designed to suit individual preferences creates significant non-value-added work associated with input and format generation, especially if the system is not user-friendly. Standardized reporting formats with common performance metrics should be utilized to support organizational objectives and to simplify the low-value-added report generation process.

Northrop Grumman's costing system also played a role in the company's decision to outsource fabrication. Overhead charges were disproportionately allocated to fabrication thereby preventing the machine shop from successfully competing with external suppliers that did not have as large overhead charges.

4.3.1.8 Grass Roots Technology Development

Automated Tool Manufacture for Composite Structures (ATMCS)

ATMCS is a software product developed by Northrop Grumman Corporation under a United States Air Force contract from 1990 to 1994. This software product significantly improves first time process capability and reduces overall tooling development lead-time. It has composite tool design macros that converts UGII and CATIA part data into "best" eggcrate or other structural tool design. The expert knowledgebase for the system was the result of an industry survey (1990-93) on the best composites tooling design practices from the following organizations: Rohr, Bell, MDR, UCAR, Stadco, PDS Engineering and DOW-UT. This product was used to successfully design 105 production tools on the F/A-18 E/F at a $ 4 million savings to budget and 65% ahead of schedule. It is also used in production at many other companies.

ESP (Expert Systems Planner)

ESP is a software product developed in the late 1980s to expedite tube and weld manufacturing planning. This product assists designers in generating complete manufacturing process plans and work orders from a part description. The successful application of this product has reduced planning lead-times by 90%.

ICAT (Innovative Concepts for Assembly Tooling)

One of the projects that an ICAT process improvement team was used for was the development of an automated drilling gantry. This piece of equipment was developed by adding rails to an assembly jig which was mounted on a gantry. Relative positioning was determined by the application of a touch probe and a GE Fanuc CNC controller. This adapted technology reduces part-to-part variability by locating holes relative to datums on each specific part and removing operator variability from the drilling operation. ICAT teams also simplified assembly tooling designs by utilizing commercially available off-the-shelf components and lighter materials. These teams are created to address problems on an as-needed basis.

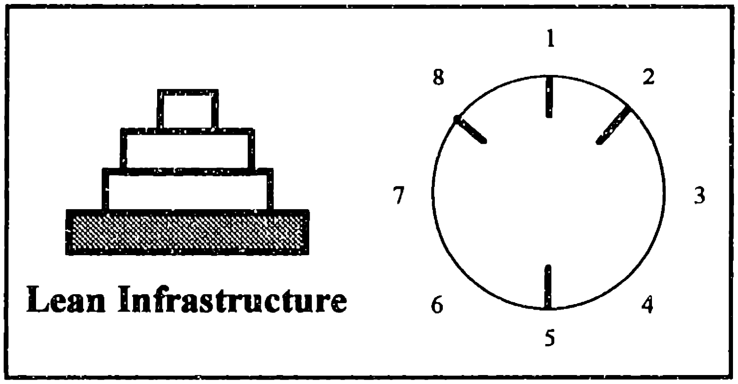
4.3.1.9 Impact of Technology

Northrop Grumman Corporation has attempted to design tooling that requires 3-axis NC equipment and not 5-axis NC equipment because of the significant operating cost differences between the two types of machining processes. Three-axis machining costs approximately $105/hr in southwestern California as compared to five-axis machining which costs $160/hr. The availability of five-axis NC machining is also severely limited in the local area.

4.3.2 Raytheon Aircraft

The initiation of Raytheon Aircraft's lean manufacturing transition began in 1991 with the introduction of their Variability Reduction / Statistical Process Control (VR/SPC) program. Their lean transition intensified in 1993 in response to executive management's five year 30% cost reduction objective. Their central focus in achieving that objective is their modernization program which is based on redesigning their factory flow. Consequently, some of the lean infrastructure initiatives proposed in the hypothesized model, such as information technology, have not yet been implemented to their maximum potential as illustrated in the following figure. Unfortunately, this case study was conducted in the early phases of their transition and it was not possible to determine whether the degree of implementation of the lean infrastructure phase limited the success of later phases.

Figure 5. Lean Infrastructure Phase for Raytheon Aircraft



With respect to supplier linkages, the company has historically placed less importance on its supplier management program due its comprehensive vertical integration. This trend may be changing as the company begins to focus on its core manufacturing processes and has begun conducting more frequent make/buy analysis.

4.3.2.1 <u>Total Quality Management (TQM)</u>

The implementation of Raytheon Aircraft's manufacturing strategy, which is based on Total Quality Management (TQM), evolved as the company learned more about TQM and incorporated the human element more fully into the program. One of management's current objectives is to use their TQM program to breakdown the stovepipe mentality that existed in the past.

Raytheon Aircraft's TQM hierarchy is composed of three levels. The first level is the steering committee which includes the Chairman's staff. The second level is the team council which meets weekly to set and review policies. It is composed of vice president appointees plus three union representatives. The third level is the Issue Management Board (IMB) which identifies problems, selects teams to address problems and prioritizes issues and assignments. The IMB is comprised of management and union representation at a department level.

The implementation of TQM at Raytheon Aircraft has evolved from an unsuccessful management edict into an environment that supports changes in the way work gets done. Furthermore, it appears that the company's employees are actively engaged in the cultural transformation transcending their workplace. Since the TQM process is in its infancy stage at Raytheon Aircraft, they are still working through a number of problems.

First, TQM was originally regarded as a "popular management science mechanism" that would help them achieve a 30% reduction in manufacturing costs. This objective was strongly resisted by the union and employees because the cost reduction terminology implied hourly and possibly salary layoffs. Consequently, Raytheon Aircraft was unsuccessful in its first attempt at implementing TQM. The key lesson learned by management from this experience was that TQM requires active employee participation and employees can not be coerced into participation. Employees must be motivated in a similar manner as management in order to successfully implement this type of program across the entire organization.

Second, the company made a large investment in employee training up-front before management had developed a clear definition of the TQM process and or how it should operate. This problem is important because it illustrates the manifestation of a less than optimal implementation sequence. It is very important that an organization develop a thoughtful and clearly articulated manufacturing strategy prior to providing employees with skills that they will not be able to use within a short-term horizon.

A third problem that is currently limiting the company's ability to receive maximum benefits from TQM is the inconsistency of employee incentives with expected behavior. Group managers support TQM but are not actively engaged in it because their incentives do not directly motivate them to support it. Supervisors are also not motivated to release operators from daily functions in order to work on team projects.

The fourth major implementation hurdle limiting Raytheon Aircraft's potential is the lack of resources to implement change. The company's engineering personnel are preoccupied with the plant reorganization and modernization effort and are therefore not readily available to facilitate and/or support shop-floor employee problem-solving and solution execution. Another restriction faced by shop-floor employees who have previously undergone problem-solving exercises is the inability to implement change due to financial constraints. One of the key lessons learned from successful Kaizen events is that employee motivation and participation is directly related to the level of impact their newly empowered positions will allow. In other words, if employee-developed process improvement changes are not implemented, the participants will probably view the process as wasteful in itself and will be less inclined to participate in future management-sponsored TQM events.

In order to mitigate some of the current problems with TQM, Quality Assurance (QA) has proposed many changes. One of the more significant changes is to restructure the IMB. The plan is to engage vice-presidents more actively in the TQM process by delegating the IMB chairman's responsibilities to them in core businesses. This represents a significant reorganization of the company's management structure. Each vice president will focus on performing a critical business activity that would support all product lines. The list of proposed activities includes: product development, product sales, product manufacturing, customer support and company support. The focus is on the company's day-to-day operating activities. The IMB would meet on a monthly basis and all IMB chairs would be required to report to the President's steering committee on a quarterly basis. These changes are expected to model the business after Deming's "plan, do, check, act" philosophy.

4.3.2.2 Benchmarking

The company has conducted a number of benchmarking activities in order to learn about lean manufacturing transitions that have taken place in other companies. These trips and consulting engagements have focused on strategic planning, information systems and factory flow redesign. As part of the company's factory flow redesign efforts, industrial and manufacturing engineering visited a number of manufacturing facilities that have undergone similar plant reorganizations. The knowledge gathered on these trips, combined with their consultants' experience and advice, formed the basic factory flow redesign process that they used in cellularizing their manufacturing processes. Benchmarking and plant visits expanded their knowledgebase which they leveraged in the planning stages of their factory flow redesign.

4.3.2.3 Linkages with Supplier Base

Raytheon Aircraft outsources approximately 20% of its products. Consequently, the company's supplier management program have not historically played an important role in the overall business. Recent contract awards have, however, initiated increased make-buy tradeoff analysis activities and the level of outsourcing is rising.

The organization's Factory Flow Redesign efforts have unveiled products that have unique process routings. The company's benchmarking exposure to John Deere has made them reconsider the value of producing a product that doesn't share common processes with other products and/or can not be grouped with other products or processes. The organization is adopting the philosophy that if a product doesn't "fit" with any of the organization's product groupings or process flows, then it should probably be outsourced.

Spare parts are also being increasingly outsourced because of the disruption they may cause in the entire manufacturing system. Since spare part demand is highly volatile and unpredictable, the actual cost of producing spare parts which includes disruption and inefficiencies in the current system may often be greater than the standard costing system estimate. Therefore, the profitability of the entire system may be greater if manufacturing of spare parts is outsourced in order to minimize disruptions due to spare part orders.

4.3.2.4 Breakdown Stovepipe Mentality

The company's transition to team-based operations follows two steps. The first step refers to a cultural change in the way they approach work. Their production focus is shifting from the number of pieces produced to the number of good pieces delivered when required. They are adding quality and schedule performance to their operating objectives. The second step refers to the "seamless" organization which is a longer term (3-5 year) transition process. In this step, functional titles will become transparent as employees work towards a common organizational goal.

In addition, Quality Assurance, Product Engineering, Manufacturing Engineering, Industrial Engineering and IPT (Integrated Product Team) personnel are collocated with each functional product in a matrix format. This system promotes learning and communication across the four aircraft assembly lines.

4.3.2.5 Information Technology

The shop-floor production control system used by operators to log process time currently does not differentiate between set-up and machining/processing time. Therefore, it is difficult to understand the costs of each step in the manufacturing process.

Raytheon Aircraft has recently begun to transition some of their processes from main-frame legacy systems to the client-server architecture. These new systems include a new cost accounting system, Enterprise Resource Planning (ERP) tools, Distributed Numerical Control (DNC) and nesting software for sheet metal processing. These activities are coordinated through their information systems group.

4.3.2.6 Technology

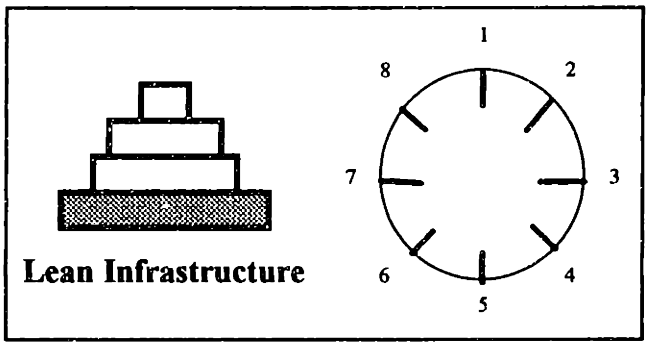
Raytheon Aircraft has recently purchased high speed CNC milling machines justified on cost savings in the time required to machine parts and on capital avoidance. The cost savings due to capital avoidance compares the equipment cost of high speed machining with the equipment cost of performing the same operations with traditional machining. In the case of the high speed milling machines, the throughput of each high speed milling machine is equivalent to three traditional milling machines.

4.3.3 Hughes Missile Systems Company

The competitive bidding for missile contracts on an annual basis has driven Hughes Missile Systems Company to focus on cost reduction programs. The application of technology and the outsourcing of fabrication have played a significant role in those programs. Outsourcing has led the program office to invest heavily in supplier development and certification programs. After assessing work methodologies in other organizations, MXL management began investing in people systems and team development to nurture a culture that supports interaction between product and functional groups.

The MXL lean infrastructure phase supports the hypothesized model in three ways. First, all of the activities proposed in the model have been implemented as illustrated in Figure 6. Second, the annual lot competition forced the organization to react quickly to its competitor. The program office has refocused its manufacturing strategy on its strengths and has outsourced the parts of the value chain which were not competitive. It has also invested in developed technology to achieve large cost reductions. Second, the organization's investment in training and people systems preceded its implementation of the Factory Flow Redesign transition phase. This is an important point because it supports the model's hypothesis that the benefits from factory flow or process improvements are better leveraged if the operating culture is supportive of change. Similar to Northrop Grumman, the implementation of Lean Infrastructure activities has been ongoing for a number of years.

Figure 6. Lean Infrastructure Phase at HMSC MXL Program



4.3.3.1 <u>Business Strategy</u>

The MXL mission statement is to focus on continuous measurable improvement (cmi) as it sequentially executes the following objectives: 1) create a fulfilling work environment, 2) produce quality products/services, 3) exceed customer expectations, 4) increase market share, 5) increase financial returns.

The product's inherently flexible design has also expanded the number of applications that MXL can fulfill. Even though MXL was originally designed for a specific mission, another customer has recently expressed a strong interest in purchasing MXL missiles for a different mission. Hughes Missile Systems Company innovation in the hardware/software navigation module has enabled the realization of this product application.

Leadership in this program has also played an important role in determining the level of success the enterprise has achieved in its lean transitions. Previous MXL program managers continue to implement change in other parts of the company built largely on the lessons learned from the MXL program. Leadership has enabled change by: providing resources, breaking down barriers and simply by walking the talk.

The MXL program accelerates learning by doing benefits for design and manufacturing by doubling historical pre-production rates. Adjusted pre-planned production lot sizes range from 25 to 30 units. Computer simulation analysis of the manufacturability of missiles is limited therefore HMSC relies on the actual Proof of Manufacturability and Design (POM/D) test. Accelerated production uncovers manufacturing and design problems at an earlier stage in the product's life cycle thereby reducing overall product life cycle cost and improving product quality. The customer supports POM/D as a risk mitigation tool.

4.3.3.2 Benchmarking

Before IPT was implemented, the MXL operations management team visited a number of companies that had successfully redefined employee responsibilities and job functions.[7] These educational visits increased management's awareness of the potential improvements that could be achieved by changing their work methodology. If Hughes Missile Systems Company did not benchmark their human resource management system against other organizations (especially those outside of their industry), Hughes Missile Systems Company would not have made as many significant human resource policy changes and consequently would not have received as many benefits.

4.3.3.3 Enterprise-wide Basic Skills Acquisition

The HMSC workforce is composed of two major demographic units segregated by age groups. Since the younger workforce has been educated more recently than the older group, retention of math and comprehension skills is greater among the younger workforce. Therefore, the younger employees have enhanced quantitative capabilities and are better able to apply statistical methods to problem-solving.

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7 MXL program management visited many organizations outside of the aircraft industry such as, Motorola and Alcatel.

The older group was initially intimidated by the knowledge gap because it reduced the traditional importance associated with older employee experience and clearly identified this group's inability to work in a modern manufacturing environment. Hughes Missile Systems Company recognized this problem and subsequently co-developed courses with Pima Community College, as part of its Career Enrichment Program (CEP), that enabled the older employees to take refresher courses in high school mathematics in a more supportive environment.

As a result, overall literacy has improved significantly since the introduction of basic communications and mathematics courses at Pima Community College. This increase in base knowledge has enabled HMSC employees to further apply their abilities in more complex tasks requiring tools such as SPC and problem-solving.

4.3.3.4 Supplier Relationships

Each MXL missile is assembled from more than 5,000 parts of which a large number are outsourced. Therefore, supplier management plays a critical role in the manufacture of this product.

The Project Engineer (PE) on each IPT coordinates both internal and external supplier activities. The PE chooses suppliers by completing a "readiness plan" which is used to analyze a potential supplier's capability. The company also provides SPC training for its suppliers in the same format that it provides to its own employees. In this way, the company creates a common knowledge base and language to address problems.

Similar to Northrop Grumman Corporation, delivery frequencies are driven by product unit costs. Currently, the program's direction is to increase the number of purchased parts delivered directly to dispatch which is one step prior to point-of-use. Total inventory is estimated to turn twice per year. The program office is also responsible for carrying its own inventory and its profitability is negatively impacted by excessive inventory.

Many of the program's suppliers are large-scale commercial suppliers that prefer to support large-scale commercial customers (e.g., Packard Bell) over Hughes Missile Systems Company due to the commercial customer's larger volumes and lower quality and engineering requirements. Commercial orders may be as large as 2 million units while a typical defense order may only be 500 units.

The drive to use commercially available products, under the DoD Acquisition Reform program, has been difficult to achieve. Electronic components in particular, that have high reliability requirements demand intensive screening and certification before successful application. This fact combined with its low buyer power makes HMSC commercial supplier programs more difficult to manage.

Example of Active Supplier Management

An example of Hughes Missile Systems Company's active supplier management program is the turnaround completed on the program's rocket motor supplier. Initially, one motor out of approximately three hundred had a major problem that caused the missile to fail Lot Acceptance Testing (LAT). A failure on LAT impacts the MXL manufacturing process at Hughes Missile Systems Company.

When Hughes Missile Systems Company investigated the supplier, they discovered that the supplier did not fully understand the numerous SPC charts he was producing nor did he understand his process. Consequently, the company relocated a PE to the supplier's location for over six months to help the supplier improve his process capability. The PE utilized Quality Function Deployment (QFD) techniques to prioritize the problems that needed to be addressed. This allowed him and the supplier to focus on the major problems.

The results of this effort have been quite significant. Since the PE has returned, the supplier has delivered over two thousand motors defect-free. The rocket motor supplier has received increased rocket motor purchases from other missile programs and Hughes Missile Systems Company has received a 50% cost reduction in rocket motors during the past six years. Even though some of the benefits of improved process capability may be shared with its competitors, Hughes Missile Systems Company believes that the benefits they receive still outweigh the relative gains their competitor may receive from their investment in developing this supplier's process capability.

4.3.3.5 Breakdown Stovepipe Mentality

The MXL program office at Hughes Missile Systems Company clearly defines the operating environment that it is attempting to achieve in a document titled, "Commitment To Our People" which is included in Appendix A. This document forms the cornerstone of their efforts to break down the walls or barriers that were created between people who operate under the traditional functional "homeroom" mentality. This program is currently being piloted at MXL. Strong leadership that has been promoted from MXL to corporate positions is expected to transfer the MXL operating culture throughout the company. At this point in time, the reorganization around teams displayed on the MXL program has not been widely adopted by other missile programs.

4.3.3.6 Technology

In a number of instances the program has experienced significant benefits (i.e., improved quality, reduced costs, improved throughput) through the implementation of new technology. By reengineering existing systems using new technology, the company has achieved larger benefits more quickly than may have otherwise been attainable. Value Engineering projects, such as the following example, take advantage of the development of new technology. The justification for Large Scale Integration (LSI) integrated circuits is based on the elimination of discrete components and their assembly into an integrated printed circuit board. Furthermore, the technology investment decision analysis can usually be computed in economic terms.

An example of the impact technological progress has had on this program is illustrated in the history of the Transmitter module. The continuous evolution in design of these printed circuit boards (PCB) from hand solder based designs to the current polyimid thru-hole wave solder based design and the replacement of point-to-point wiring with ribbon cable assemblies has helped reduce touch labor in this cell by 90%.

5. Factory Flow Redesign

5.1 Introduction

The second lean transition phase hypothesized by the LAI model is the Factory Flow Redesign phase. Many of the elements of the Lean Infrastructure phase should be implemented prior to this phase in order to maximize the potential impact of this phase. Practices implemented during the Lean Infrastructure transition, such as the elimination of functional barriers and acquisition of skill, can be leveraged in this phase in order to optimize the process.

In this chapter I propose a sequence of activities that should be followed in order to implement synchronous manufacturing. These common sense steps require disciplined implementation and sufficient resource allocation in order to receive maximum participation and benefits. The development of the first cell should be treated as a pilot cell in order to learn from it before redesigning the entire factory. In the case study analysis section I have attempted to compare the sequence of steps that each company followed with the hypothesized model in a sequence diagram. The sequence diagram is a measure of both the steps executed and the order of execution; it does not illustrate the effectiveness of each step.

The degree of implementation of the Factory Flow Redesign transition phase varied from company to company due to the differences in scope at each company. Northrop Grumman Corporation and Hughes Missile Systems Company are primarily airframe assembly operations that produce variations of one product. These facilities have different expectations of the benefits associated with redesigning their factory flows than the Raytheon Aircraft factory we visited which is a large sheet metal fabrication and metal cutting facility with thousands of different products and process flows. The relative benefits from this transition phase are greater at Raytheon Aircraft than at the other manufacturers and they have therefore invested significantly more resources toward the implementation of cellular manufacturing.

5.2 Factory Flow Redesign Process

The following sequence of steps are based on a compilation of experiences from members of the MIT Factory Operations focus group. This is a hypothesized sequence and should not be misconstrued as the definitive implementation methodology for cellular manufacturing.

5.2.1 Information Distribution

It is important to distribute all pertinent data to each team member that will participate in the factory floor redesign project in order to fully enable team members to think creatively about the process. Information distribution also means the allocation of computing hardware and software on the shop floor that will be used by team members. Team members must possess sufficient tools and skills to accomplish their objectives.

5.2.2 Product Grouping

Products which have similar part geometries or have similar processing requirements should be grouped together. Using these two methods of segregating parts, one can establish part families. Part families can then be ranked or ordered according to the clustering group technology method.[8]

5.2.3 Process Standardization

After all parts are grouped into part families, manufacturing processes can begin to be modified with the objective of achieving standardized process flows. In this step, operator work methods and/or responsibilities may require redefinition in order to fully optimize the factory flow.

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[8] There are many part clustering methodologies available in the public domain. For example, Chun Hung Cheng, Ashok Kumar and Jaideep Motwani have published "A comparative examination of selected cellular manufacturing clustering algorithms" in Vol. 15 of the International Journal of Operations & Production Management in 1995.

5.2.4 Cell Design and Simulation

Industrial engineering should utilize the standardized process flows and part families to design the manufacturing cell. This cell layout could then be optimized through the application of simulation software. The simulation trials should be analyzed using the following historical and forecasted data: demand levels, demand variability, machine capability, machine availability and space constraints. Cell design and simulation is an iterative process that will require numerous adjustments in order to establish optimal cell design. Software simulation of cells is a relatively inexpensive and easy way of testing a cell design before the cell is physically constructed. The simulation analysis should be conducted under various operating assumptions in order to measure its maximum operating potential. During this process, the systems designer should determine the location of bottlenecks and their impact on part flow in the cell.

5.2.5 Link Manufacturing Cells

Once each cell has been constructed, the next step should be to analyze product flow through the entire manufacturing operation. By examining the linkages between cells, industrial engineering can further optimize the overall process flow.

5.2.6 Redefinition of Work Methods

The new manufacturing cell may have been designed under operating assumptions that are different from those of the original system. If so, then shop floor tasks should be redefined and redeployed around products and processes to satisfy the new cell's requirements. Authority and accountability for the cell should also be delegated to the operating area.

5.2.7 Implementation

After the engineering groups have developed a proposal, the organization should sponsor a change event, like a Kaizen workshop, to solicit ideas from the shop floor and execute the actual layout changes. It is best to actively involve those individuals who have the most direct experience and who will be most affected by the changes. The engineering staff's proposal is based on their prior knowledge base of the entire organization but it may be lacking pertinent operating data specific to certain pieces of equipment or tooling.

Employee support and active participation in these events is important to the success of the factory flow redesign. Shop floor employees should receive adequate training prior to this event and should understand their new operating responsibilities.

5.2.8 Visible Part Flow

Once the cell is designed, it is important to make product flow visible and obvious within the cell. The objective should be to achieve single piece flow or at least continuous flow within the cell, such that product flow satisfies demand takt time. The synchronization of manufacturing within the cell will minimize work-in-process inventory.

5.3 Case Studies

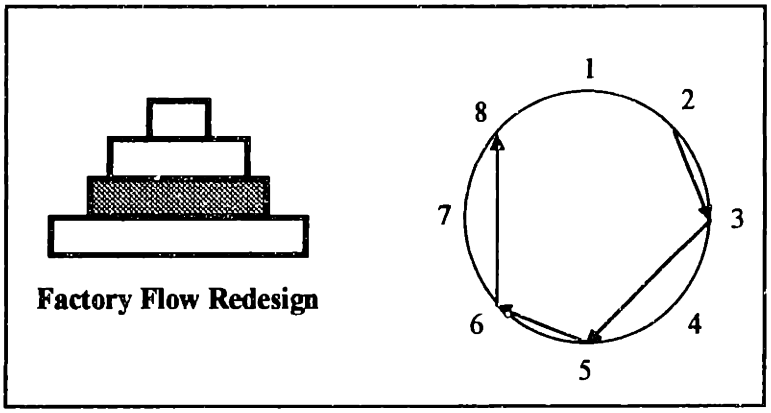
5.3.1 Northrop Grumman Corporation

Since the F/A-18 E/F program is relatively new and has just completed the EMD phase, Northrop Grumman has not redesigned its factory flow. It has, however, completed an initial assembly line design for EMD that was largely based on lessons learned from the C/D program.

One of the significant layout characteristics of the E/F line is the collocation of subassembly lines with the main assembly line which was driven by manufacturing. This action provided Northrop Grumman Corporation with major benefits. First, the lot sizes used in most subassembly cost centers is limited to one unit. The elimination of the subassembly inventory crib has reduced subassembly WIP inventory by approximately 60 days. Second, communication regarding both products and processes between the main line and the subassembly departments was greatly improved. Third, the reduction of lot sizes to one unit has promoted the application of visual management practices. Northrop Grumman Corporation expects to implement a "pull" inventory system using WIP inventory as the visual control mechanism in the future. Northrop Grumman has also collocated subassembly cells with the main assembly line on the C/D program in order to take advantage of some of these benefits.

The following exhibit illustrates the sequence that Northrop Grumman Corporation followed in redesigning its product flow.

Figure 7. Sequence Diagram for Northrop Grumman



5.3.1.1 <u>Transfer learning from C/D to E/F</u>

The development of the E/F model assembly line allowed Northrop Grumman Corporation to work out any problems experienced on the C/D and transfer this learning to E/F.

For example, structural assembly of skins, bulkheads, longerons, etc. is completed at an earlier stage on the E/F assembly line than it is on the C/D line for the following reasons:

1. The assembly of structural components at an earlier operation on the assembly line has enabled Northrop Grumman Corporation to reduce Foreign Object Debris from 100 pieces per shipset on F/A-18 (A/B) to approximately 0.1 pieces per shipset on F/A-18 (E/F). This result is due to a reduction in the number of low visibility physical locations where debris had traditionally collected on the C/D model.

2. Subsystems are modified or redesigned more frequently than the overall structure changes therefore, it is commonsense that product areas requiring increased flexibility should be located as close as possible to the last operation on the assembly line. Problems associated with variable product options can be minimized if the assembly of options is located closer to the end of the assembly line than the beginning.

3. Earlier assembly of the standard structural components implies that less subsystems infrastructure (i.e., hydraulics, electrical, etc.) work-arounds are required.
4. International customers are sometimes allowed to execute offset contracts which transfers some of the assembly processes and the custom installation of their own subsystems at their location.
5. Fewer small components are damaged if the small components are assembled after the large structural parts are already assembled.

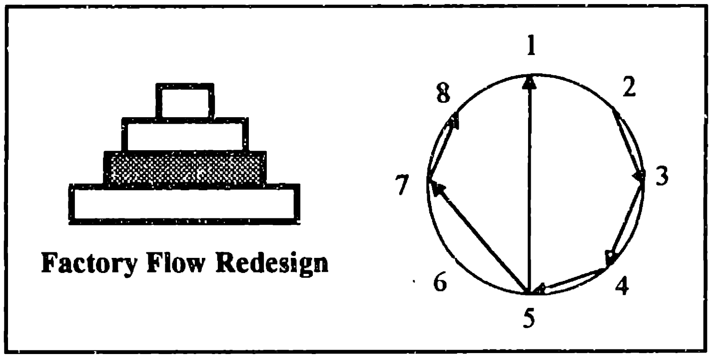
Another example illustrating the transfer of experience from the C/D line to the E/F is the process and tooling design for the last three operations. On the C/D line, the shipset is moved in the same fixture on the Norail. Even though the same datums may be used, fixture variability from station to station becomes "built into" the final product. In order to reduce tool-to-part variability on the E/F line, the shipset is not removed from the holding tool because the holding tool and product are transferred together from station to station. The E/F holding tool is mounted on air bearings that allow the shipsets to be moved more easily which also minimizes overhead crane requirements on the assembly line.

Simulation on the E/F EMD phase tooling was not completed because the government had an option to cancel the program after that phase. Northrop Grumman is committed to complete simulation analysis of the assembly line during the LRIP phase. This activity is expected to improve the company's ability to achieve level work loading.

5.3.2 Raytheon Aircraft

Raytheon Aircraft's approach in redesigning their factory flow supports the hypothesized model fairly well. Substantially all of the steps within the model were performed by Raytheon Aircraft. There were two differences between Raytheon Aircraft's approach and the hypothesized model. First, they designed all of their manufacturing cells and attempted to optimize the linkages between the cells prior to physically moving any machinery. The modernization program had an aggressive project schedule that did not support an extended pilot program. Second, since product and demand variation were so great, the simulation analysis performed on cell designs was focused on measuring the degree of cellularization as opposed to a traditional throughput or cycle time metric.

Figure 8. Sequence Diagram for Raytheon Aircraft



5.3.2.1 Introduction to Raytheon Aircraft's Factory Floor Changes

The Raytheon Aircraft facility we visited performs both metal cutting and sheet metal processing. The pre-transition factory floor layout philosophy squeezed similar pieces of equipment into areas where there was empty floor space. The linkages between departments were not considered during layout development. Consequently, the various manufacturing departments were not coordinated to optimize process or part flow paths.

For example, the vertical milling machine department in the pre-transition layout was located amongst Hydroform and chemical processing equipment and was not located near other machining operations like drilling, deburring, etc. The process flow paths for a particular part that required vertical milling often looked like spaghetti laid on top of a factory layout.

In 1994, Raytheon Aircraft began a major modernization program whose objectives were to reduce the environmental hazards associated with their chemical processing operations. Increasingly stringent EPA regulations forced Raytheon Aircraft to scrap some of their old equipment, purchase new equipment and modify some of their operating practices. The modernization of their processing equipment provided the company with the opportunity to perform a major transformation on the entire facility.

The investment capital and moving expenses associated with the large-scale layout changes were justified on economic returns except for the new chrome plating and chemical treatment equipment costs which were justified by EPA requirements. The company's overall cost reduction target for the project was 30% and its inventory reduction objective was 50%.

Machine Shop Cells

The machine shop departments process over 6,000 different part numbers annually on 140 machines. Most of the equipment in the machining areas could be moved fairly easily. Prior to the factory floor redesign project, the machining departments were located in three different areas of the plant. Since the machining departments were not located in close proximity to each other, machined parts often traveled large distances and suffered significant delays in processing.

Sheet Metal Cells

The Sheet Metal departments perform many varied operations on 160 machines. Sheet metal fabrication produces approximately 30,000 different part numbers annually in mostly low quantities. An important characteristic that identifies this area is the term "monuments". "Monuments" are large pieces of equipment, such as hydroform presses, that are difficult to incorporate in layout design changes because they are prohibitively expensive to relocate.

5.3.2.2 Cellularization Process

Since Raytheon Aircraft manufactured a large number of different parts in a large variety of part geometries, they could not establish significant part families that would assist them in developing manufacturing cells. Instead, Raytheon Aircraft's manufacturing cell design is based on grouping parts that have similar product routings. The machine shop was originally laid out by grouping similar processes together (i.e., vertical milling, lathes, grinders, etc.).

Unfortunately the various machining cells appeared to be randomly dispersed throughout the plant and products often traveled significant distances and required long lead-times between operations. In the new layout design, engineering has analyzed process routings and attempted to group machinery in cells in order to optimize the different product flow paths linked across manufacturing cells. They have also integrated debur processing operations into each cell thereby eliminating the requirement of transferring WIP to a separate debur cell. In essence, they defined operations in cells relative to products with similar processing requirements, e.g., parts do not necessarily require similar geometries in order to be processed in the same cell. Additionally, they have also minimized part travel distances by locating cells that have parts with similar processing requirements adjacent to or near each other.

The company could not, however, adopt a greenfield approach. Many of its existing sheet metal processes could not be moved and consequently constrained the overall plant layout. These "monuments" included hydroform presses and many of the plants chemical processing operations. For example, chemical milling utilizes hazardous materials that are difficult to collocate with other types of manufacturing operations for environmental reasons.

Table 2. Creation of Process Flow Identifier for Part Number XXX in the Machine Shop.

Part Number	Operation	Department	Subsection	Work Center
XXX	10	1	011	115
XXX	20	101	013	219
XXX	30	801	014	201
XXX	**Total**	**903**	**038**	**535**

In the grouping process, an identifier for each part was created based on department number, subsection number and work center number. Each unique resource at the factory is defined as a work center in a department. The following table illustrates how the identifier was generated by summing each of the descriptive fields and concatenating this series of sums into one number. In Table 2, the identifier for part number XXX is 903038535. Using this methodology, 1,139 families and 13,000 flow paths were identified in Plant #1.[9] This initial process ignores the sequence of operations and the occurrence of multiple operations on the same machine.

Once this process was completed for each product flow, all of the identifiers were compared against one another for duplication. Duplicate identifiers were grouped together to create a process routing family. These groupings were further optimized by comparing additional fields: number of operations and hours of processing required per year. In Table 3, four different part numbers are sorted by pareto analysis by the number of hours of processing required per year. In this example, part numbers XXW, XXX and XXZ would be grouped together in the same process family called Hydroform. By focusing on the part numbers that require significant annual operating resources (approximately 20% of all part numbers), the company has maximized the potential benefits (80% of required resources) of cellularization.

Table 3. Analysis of Resource Requirements for Process Identifiers.

Family	P/N	Dept.	Subsect.	Work Center	No. of Ops.	Hrs/Yr.
Hydroform	XXW	903	038	535	5	250
Hydroform	XXX	903	038	535	6	130
Vertical CNC	XXY	813	58	200	8	95
Hyrdroform	XXZ	903	038	535	6	65

5.3.2.3 Simulation and Analysis of Cell Design

Raytheon analyzed the different families of parts based on which resources were required. They then developed cells around the family that required the greatest number of hours. The

9 A flowpath is a unique method of processing a part. There are 13,000 unique ways of processing parts in both the sheet metal and machining areas.

company did not model their redesigned cells with software simulation tools. They did, however, develop a metric to measure the degree of cellularization in each cell. The performance metric measures the percentage of parts within a family that are completed within that cell. The company uses pareto analysis techniques based on loading factors to select the family with the highest percentage as an optimal cell design and then incorporates other families into that cell. The goal is to achieve at least 90% cellularization in a cell design. This implies that 90% of the parts that flow through a cell are completed in that cell.

In sheet metal fabrication, part numbers that were processed by monuments were analyzed to identify the other operations that were performed on those parts. The monuments became the key operations within the model cells and supporting processing operations were subsequently placed around the monuments to complete the cell design. Models of cells were developed to determine the cellularization percentages. The company measures the degree of cellularization in sheet metal fabrication cells as the percentage of parts within a family that "touch" a monument within that cell. Capital planning improvements were then linked to these models. This process is referred to as the "commonsense about monuments" approach to cellularization.

5.3.2.4 Execution of Layout Changes

Each proposed plan was developed by a team of engineers and managers and was further rationalized by shop-floor operators. Initially, operators were engaged in cell redesigns at an earlier stage in the process, but this was counter-productive because the operator-populated teams became bogged down with numerous detail tasks. Even though some of these tasks, which included the selection of the department microwave oven and lunch cooler locations, were important to the operators, they were not directly salient to optimizing process flow. The company realizes that this outcome may have been avoided if the team's objective and timeframe had been more clearly outlined. This would have allowed team members to stay focused on their assignments.

Subsequently, engineering and management designed the cells and operators helped determine the best part flow within the cell. Unfortunately, some of the other layout details, such as tool crib set-up and incoming/outgoing material locations, have not been addressed by the master plan due to limited engineering resources.

Another area of concern with respect to the company's cellularization process is that the learning from one cell is difficult to incorporate in the design of other cells. Since work cells are being developed and implemented almost simultaneously, it is difficult to analyze the learning from the first cell in order to optimize later cell designs. The hypothesized model recommends the implementation of pilot cells in order to maximize learning from them before optimizing the entire factory operation. It is also very difficult to redesign the entire factory flow while attempting to satisfy normal production requirements.

5.3.2.5 Redesigned Hydroform Cell

An example of a redesigned cell is the Hydroform cell. This cell processes 676,981 total parts under 7,196 different part numbers annually. Approximately, 29% of all sheet metal operations performed in the facility are assigned to this cell.[10] The company measures successful cell definition and grouping by measuring the percentage of required work completed on a product in a cell. In the Hydroform cell, 90% of all operations required to be completed on any product routed through this cell is completed within the cell.

5.3.2.6 Summary

The Factory Floor Redesign process at Raytheon can be summarized by the following major steps:

1) Group parts by creating an identifier for each flow path,
2) Incorporate realization factor into process families,
3) Prioritize part number families by annual resource requirements (i.e., greatest annual processing requirements implies highest priority),
4) Solicit operator input for optimal internal cell design,

[10] The remaining 71% of sheet metal operations do not require processing by the Hydroform presses and are therefore processed in other cells.

5) Repeat process using iterative simulation analysis with various operating assumptions.

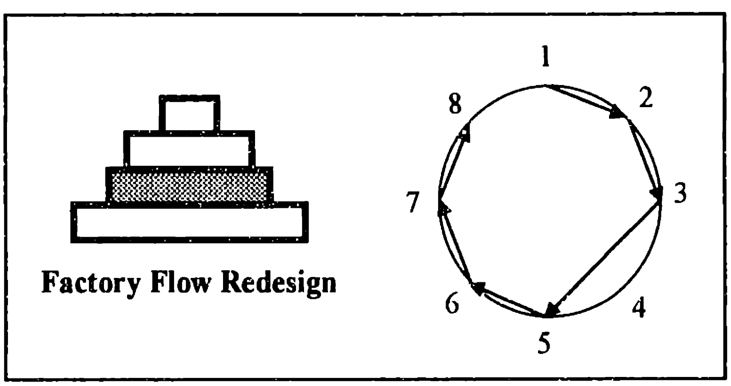
This cellularization process is only the first step in Raytheon Aircraft's overall optimization process. Their typical product optimization plan can be best illustrated by the Rudder Pedal Arm (P/N 50-524326-35). The first step is cellularization. By moving the machining cells closer together and linking them, part travel distance is minimized and inter-cell communications are improved. The second step is to utilize CNC equipment more effectively by increasing the number of machining operations completed per set-up. This involves the consolidation of process routings. Third, the debur operations are integrated into the operation or cell that created the burr. The fourth step is focused on reducing set-up times and requirements. The fifth step is tool path optimization. The company is currently in the process of implementing the first three steps.

A complete listing and description of the metal cutting and sheet metal fabrication cells is located in Appendix B.

5.3.3 Hughes Missile Systems Company

The Hughes Missile Systems Company refers to their Factory Flow Redesign transition as a PICOS™ process. Their process, similar to the other case studies, supports most of the process flow transition practices hypothesized by the MIT LAI model. There are four natural hardware groupings in MXL and the processes in each of those groupings are standardized.

Figure 9. Sequence Diagram of Hughes Missile Systems Company (MXL)



Similar to Northrop Grumman, the company has placed little emphasis on simulating process flows in their cell designs. This is probably due to the fact that both companies produce a standard product with minimal design variation between units. In addition, the overall process flow in both companies is an assembly routing sequence where the linkages between cells are well coordinated and product flow is visible. One of the unique features of the PICOS™ process is that the level of shop-floor employee involvement appears to be greater in the MXL program than proposed in the hypothesized model or in either of the preceding case studies.

Production at the MXL manufacturing facility has exceeded its maximum design capacity based on a two shift/day, eight hour/shift, five day/week operation. At the HMSC, factory flow was designed such that the test equipment, purchased by the customer, would be the bottleneck in production in order to achieve maximum utilization of the most capital intensive equipment. Current product lead-time through the factory is approximately one month.[11]

5.3.3.1 PICOS™ Events

PICOS™ is a three day workshop process in which a combined supplier/customer team examines a current operation for the purpose of identifying and eliminating waste and non-value-added activities. Once problem areas are identified, synchronous manufacturing principles are used to design an improved, more efficient operation. PICOS™ can be applied to any area that uses sequential processes. PICOS™ was the streamlining mechanism implemented by Ignacio Lopez, ex-VP of Worldwide Purchasing at General Motors, in order to reduce its supplier costs. This process has since been applied directly to internal GM operating units.

The key to the PICOS™ workshop format is similar to that of Kaizen events. It emphasizes immediate, dramatic change and the elimination of waste. Tangible improvements are produced in just days, not weeks or months. The objectives of a PICOS™ event are to: 1)

[11] Manufacturing lead-time excludes supplier procurement lead-times which may be up to nine months.

eliminate waste, 2) reduce WIP and 3) reduce floorspace. In a typical workshop, Day 1 is used to define the current state of a process and to brainstorm an improved future state. On Day 2, the change proposal is refined as needed and the changes are literally implemented overnight. On Day 3, the new process is started and initial results are measured and reported.

Four primary metrics - productivity, inventory, lead-time, and floor space - are used to chart the success of the changed process. The average improvements achieved from PICOS™ workshops held to date at Hughes have been impressive: 85% increase in productivity and reductions of 71%, 63% and 35% in inventory, lead-time, and floor space usage, respectively.

PICOS™ events require pre-event training, information dissemination and commitment from its participants. People are committed to the process because they visually observe the immediate changes resulting from these events. Knowing that the results are driven by themselves has directly impacted their level of motivation. Employees have been less threatened by the reduction in touch labor requirements resulting from MXL PICOS™ events because of the growing need for direct labor in other missile programs at HMSC. However, as productivity in other missile programs increases, employee job security is expected to become a more important issue in the future.

Example of a PICOS™ Workshop

Two 11 member cross-functional teams were coordinated by a workshop facilitator and facilities facilitator to achieve the following results: floorspace was reduced by 32%, lead time was reduced by 27%, inventory was reduced by 50%, productivity (pieces/man/day) increased by 66% and distance traveled decreased 56%. These results were achieved by streamlining the flow of hardware, grouping hardware assemblies into cells, centralizing linestock, eliminating 12 work stations, eliminating air pollution generators and improving operator access to test. During the brainstorming session, the groups identified 37 immediate improvement ideas, 70 short term (0-3 months) ideas and 18 long term (3-6 month) ideas. Most operations at HMSC use modular work benches that increase overall process flexibility and work balancing capability.

6. Operations Management Development

6.1 Introduction

After the company has invested in lean infrastructure projects and redesigned its factory flow, our hypothesis is that it can begin to profit from the implementation of additional lean manufacturing practices that are centralized around Operations Management Development. The implementation of Operations Management Development practices recommended in the hypothesized model should enable the company to capitalize on previous transition phases. During this phase, the organization should focus its efforts on rethinking the way work gets done. The tools in this phase support the organization's efforts in optimizing work design and both process and information flow.

After the organization has successfully completed the previous "foundation" transition phases, it can now begin to focus on maximizing the potential of its human assets. In the Lean Infrastructure transition phase, the organization's leadership began to nurture a work environment that transcended functional silos and clearly communicated common objectives and knowledge to all members and affiliates of the organization. In the Factory Floor Redesign transition phase, the organization's physical process flow was redesigned. In this phase, the softer elements associated with work flow and information flow will be redesigned.

6.2 Implementation Plan

6.2.1 Employee Cross Functional Training & Incentive Realignment

In order to accelerate the organization's synergistic momentum, it is important to mobilize employees into teams that are focused on product or process management. Employees operating at an individual level reacting to supervisory instructions and predefined tasks must be retrained in order to interact with other individuals on teams focused on the organization's overarching goals.

During the earlier lean transition phases, employees became indoctrinated into lean manufacturing and have since begun to appreciate real changes in their operating environment with the implementation of cellular manufacturing. Now it is time for shop floor employees to become fully engaged in the execution of the organization's business strategy. In order to become fully involved, employees in a lean manufacturing environment must become as flexible as the processes they operate. Employee flexibility can be enhanced by providing cross-functional training and mitigating traditional work classification barriers. Similar to the "Breakdown Stovepipe Mentality" step that was focused on functional silos among salaried and management personnel in the Lean Infrastructure phase, shop floor employees must also begin to work together operating under a common goal.

Throughout this relearning process, team-based management practices should be reinforced in order to capitalize on the synergistic benefits of teams. Teams are supportive networks of individuals that collectively optimize the contribution of each individual's relative specialization. This umbrella charter can be expanded into smaller components that usually stretches beyond what one person could possibly become expert in. Their job descriptions and responsibilities will expand as they begin to excel at multiple tasks in their new operating environment. Cross-functional training also allows each person to become adept at more than one discipline, allowing members to absorb variability in work demands.

The employee gains recognition and respect when working in teams because he/she is given the opportunity to think for themselves. Teams also provide a mechanism that individuals use to identify themselves through their association

The development of a multi-tasking environment reduces system redundancy. This form of waste elimination can be optimized only after employees have received cross-functional training and are executing team-based management practices.

Incentives must also be modified in order to support the desired employee behavior. Successful team behavior must be reinforced with recognition that builds pride and with possible economic incentives. Pride and peer pressure are the two major forces that motivate employees operating on teams.

6.2.2 Reallocation of Support Resources

Autonomous Quality

When workers are given more freedom over their work, they must also be given increased responsibility. In order to empower employees and achieve successful results, the employees must be held accountable for their actions. On the shop floor, this implies that employees directly involved in assembly or manufacturing operations are responsible for the quality of the products they produce. Consequently, employees must begin to monitor the quality of their processes using statistical methods like SPC.

This step transfers the quality control responsibility from the Quality Control (QC) department to the manufacturing department. By building quality into the product instead of inspecting quality into it, the company can eliminate large inefficiencies associated with the QC department. During this transition, QC personnel should provide instruction and training for operators and can also be used as auditors to ensure the standards are maintained.

Autonomous Maintenance

Many military aircraft plants face the same economic circumstances; declining military sales have forced organizations to implement cost reduction programs that have reduced maintenance staffs below the levels necessary to properly care for the plant and its equipment under traditional maintenance operations. Reduced staffs have only three alternatives to avoid asset deterioration and its attendant decay in quality and service. They are: 1) improve maintenance worker productivity; 2) reduce the frequency of maintenance exposures; 3) utilize non-maintenance resources.

Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is the logical goal of departments facing such situations because it is designed around the three remedies to avoid deterioration. Elements of TPM improve maintenance worker productivity, reduce exposures, and bring in operators to supplement maintenance activities. Before TPM, most maintenance departments spent most of their time "firefighting" breakdowns.[12]

TPM is productive asset management. It assesses current performance, identifies problems, sets targets for more effective equipment use and implements a program to bring about the improvement required. TPM involves production and maintenance people working together to achieve its aims. It is autonomous production operator maintenance that attempts to optimize the operator's skill and knowledge of his own equipment to maximize its operating effectiveness. It establishes a schedule of cleanliness and preventive maintenance to extend the equipment's life span and uptime. It requires the involvement of every employee from top managers to the individual team members who participate in the system. TPM's dual goal is zero defects and zero breakdowns.

The decision to install TPM should come from top management so nobody questions the decision and everybody executes it. Top management must be committed to TPM and fund it adequately. TPM installation consists of three phases: planning and preparation, pilot installation, plant-wide installation. The implementation of TPM usually takes at least three years depending on size and complexity of operations.[13]

TPM should not only focus on the machine and the operator but it should go beyond maintenance to address "overall equipment effectiveness" (OEE). Essentially, OEE is defined by three things: how much time is the equipment actually available; what is its performance rate when it is available; and what is the quality of the output when it is performing. OEE = Equipment Availability (EA) x Performance Efficiency (PE) x Rate of Quality (RQ).

Reliability Centered Maintenance (RCM) helps the maintainers and operators decide on suitable routines to achieve the goals. The process consists of answering seven questions - What are its functions? In what ways can it fail? What causes it to fail? What happens when

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[12] Levitt, Joel, "Shape preventive maintenance programs to support TPM", Plant Engineering, October, 1994.

[13] Hill, Scott. "Zen maintenance; machinery maintenance" published by Process Industries Canada. July 1990. Copyright 1990 Zanny Ltd.

it fails? Does it matter? Can anything be done? What should we do if we cannot prevent the failure? Some organizations refer to this process as Process Failure Mode Effects Analysis (PFMEA).

Preventive Maintenance (PM) is a series of tasks that extend the life of an asset by deferring critical wear through proper lubrication, cleaning, tightening, and adjustment. PM extends asset life by detecting critical wear and predicting failure in time to fix the problem. A PM system also includes record-keeping to track PM, downtime, slowdowns/stoppages, failures, and equipment utilization. Procedures must also exist for performing minor or short (less than 30 minute) repairs. The PM program should also be equipped with a method for using the frequency and severity of failures to refine PM task lists. A way to continually upgrade skills and improve the process should be part of the system.

TPM requires a PM level most maintenance departments would find impossible at current staffing levels. The only large pool of talent available to carry out task lists are operators. The operator is also the logical person to carry out PM. Operators are closest to the equipment and have a vested interest in the outcome of such an effort. In many plants, TPM operators effectively provide a 20% increase in hours for first line PM. In a TPM environment, common PM tasks are divided between operators and maintenance technicians. Some functions that might be assigned to the operator include tightening anchor bolts, adjusting fan belt tension, and adding oil to a circulating pump. Inspection tasks might be shared by the operator and maintenance technician. Looking for water leaks in the plumbing system is a shared responsibility. Major overhaul activities such as removing and replacing a pump would remain within maintenance.

Another strategy is to assign daily, weekly, and possibly monthly PM tasks to the operator; and quarterly and annual tasks to the maintenance technician. The advantage of this approach is having routine work handled by someone who is in close contact with the machine. Less routine work is performed by a person with more extensive diagnostic skills. The quarterly inspection can also serve as an audit of the operator's routine work. Breakdowns are typically handled by the maintenance technician with the operator assisting.

Having an operator perform routine tasks has advantages and disadvantages. On the one hand, the operator knows his machine and, in most cases, takes ownership of it. Taking on added responsibilities increases his value as an employee, gives him more control, and increases his motivation to do a good job. On the other hand, he may not relish extra work, may not like to clean the machine, and might not perform the assigned tasks. He typically has less training and mechanical know-how. The approach could be inadequate PM management.

A major purpose of TPM is to reduce breakdowns. Traditional PM pays more attention to inspecting and detecting critical wear and loose components and focuses less on machine cleanliness. However, a study done by a Japanese plant engineering society found that, even in clean plants, more than half the breakdowns were caused by dirt and loose components. Therefore, cleanliness and tightness should be keystones of a TPM-driven PM system.

TPM brings the elements of good PM together under the banner of increased equipment effectiveness. The operator is a key player, supported technically by a skilled maintenance worker. Given corporate downsizing and the philosophy of doing more with less, maintenance departments are forced to rely more and more on people outside of maintenance. Even in profitable industries, maintenance departments are being squeezed.

Maintenance is not well understood in many plants. Top management often assumes if maintenance would just work a little harder, it could do more with even less. By removing the stovepipe mentality that separates operations and maintenance, the whole organization might benefit from the knowledge found in the minds of maintenance professionals.

6.2.3 Information Management

As manufacturing organizations transition towards agile competition, they must be enabled to mobilize their embedded corporate knowledge. Organizations can not afford to reinvent the same solutions over and over again and they can not afford to make the same mistakes over and over again. The learning from one program must be easily and quickly transferred to the next. Information leverage comes from reusable knowledge, reconfigurable for different applications across the entire corporation. Peter Drucker believes that the principle asset in a corporation today is its collective knowledge. The value of that asset is, multiplied by its mobility within the corporation. Most companies today have not thought about themselves as learning organizations - the knowledge base, the changes it undergoes, and how it gets deployed at points that need it while it still has something to offer.

The ability to gather, arrange, and manipulate information with computers has given organizations new tools for managing. Few of today's information needs are new and conceptually, many of the "new" measurements have been discussed for many years and in many places. What is new is the technical data processing ability. The explosive growth of computer power and expansion of communications technology has done more than simply enable executives to do the same tasks better. They have changed the very concepts of what a business is and what managing means. To manage in the future, executives will need an information system integrated with strategy, rather than individual tools that so far have been used largely to record the past.

Technologies that reduce costs and increase flexibility, such as client/server and open system environments have the highest perceived importance. Also considered top priorities are communications capabilities like enterprisewide electronic mail (E-mail) and voice mail (V-mail), and technologies that promote data/systems integration and improved supplier interfaces, such as bar-coding and electronic data interface (EDI). Programming technologies and those that assist engineering and manufacturing also are considered important.[14]

In order to address this step, companies may have to hire outsiders to help them. To think through what the business needs requires somebody who knows and understands the highly specialized information field. The sources of information are totally diverse and since this industry is driven by rapid changes in technology, outsiders have advantages in benchmarking and in resources. Another reason there is a need for outside help is that the information has to be organized so it questions and challenges a company's strategy.

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[14] Keenan, Tim; Deloitte and Touche Management Consulting's Automotive Industry Group survey; Ward's Auto World, July, 1994: "Information highway has potholes: study shows supplier systems need resurfacing." Copyright 1994 Ward's Communications Inc.

6.2.3.1 Material Flow

Material Requirements Planning (MRP) systems provide easy access to and visibility of information on the stocks and flows of material within the supply chain and the physical capacities of selected operations. Such a window of simplicity can only be achieved, however, if part numbers, bills of material, stocking procedures and engineering change notice updates are meticulously defined and data integrity scrupulously maintained. A further enhancement of MRP systems is the simulation of flows limited by finite scheduling capacity specifications.

6.2.3.2 Accounting Systems

Activity Based Costing (ABC)

Many organizations in other industries have already shifted from traditional cost accounting to activity based costing, which records the cost of the total process of providing a product or service. ABC integrates what were once several activities -- value analysis, process analysis, quality and costing -- into one analysis. Traditional cost accounting defines the total manufacturing cost as the sum of the costs of individual operations. Yet the cost that matters for competitiveness and profitability is the cost of the total process which is what the new activity based costing records and makes manageable.

Traditional cost accounting measures what it costs to do a task. ABC also records the cost of not doing, such as the cost of machine downtime, the cost of waiting for a needed part or tool, the cost of inventory waiting to be shipped, and the cost of reworking or scrapping a defective part. The costs of not doing, which traditional cost accounting cannot and does not record, often equals and sometimes even exceeds the costs of doing. Activity-based costing therefore gives not only much better cost control, but increasingly, it also gives result control.

Economic Chain Costing

A company should also know the costs of its entire economic chain. It should work with all the other businesses that contribute to the final product, which may require compatible accounting systems and information sharing across companies. Traditionally, military aircraft companies have started with costs, put an acceptable profit margin on top, and arrived at a price. The military aircraft industry is currently beginning to realize that it is important to understand the cost of the entire economic chain. As the defense budget continues to decrease in size and scope, even Congress is driving towards price-led costing. In the development of the F/A-18 E/F, it mandated the maximum price of the E/F not to exceed 125% of the price of the C/D.

Knowing the cost of your operations, however, is not enough. To succeed in the increasingly competitive global market, a company has to know the costs of its entire economic chain and has to work with other members of the chain to manage costs and maximize yield. Companies are therefore beginning to shift from costing only what goes on inside their own organizations to costing the entire economic process, in which even the biggest company is just one link.

Increasingly managing the economic cost chain will become a necessity. James P. Womack and Daniel T. Jones, authors of the "The Machine That Changed The World", argue in their article, "From Lean Production to the Lean Enterprise" (HBR, March-April 1994), that "executives need to organize and manage not only the cost chain but also everything else -- especially corporate strategy and product planning -- as one economic whole, regardless of the legal boundaries of individual companies."

6.2.3.3 Economic Value Added (EVA)

EVA is based on profits, the money left to service equity, which might not actually be profit at all. Until a business returns a profit that is greater than its cost of capital, it operates at a loss. Even if the company pays taxes as if it generated profits, its reported profit still might not have exceeded its cost of capital.

By measuring the value added over all costs, including the cost of capital, EVA measures, in effect, the productivity of all factors of production. It does not, by itself, explain why a certain product or a certain service does not add value or what to do about it. But it does help managers understand what needs attention and whether they need to take action. EVA could also be used to find out what works.

6.2.4 Synchronous Manufacturing

As we have seen, lean manufacturing includes the formation of manufacturing cells, flexible teams and autonomous quality control. The result is the elimination of job specialties and hierarchical classifications and a reduced need for inspections by quality controllers. And in addition to these changes, inventory has also been significantly reduced in lean manufacturing organizations. Some organizations that have undergone lean transitions have replaced their large inventory supplies with kits that only contain the parts necessary for a cell to complete a particular task.[15] Since the kit is often bubble-wrapped by a transparent cover, it is immediately obvious if a part is missing. Once the cell starts using a kit, another is automatically called for to replace it, 'pulling' stock through the system in a Japanese Kanban technique.[16] This sharply reduces the volume of parts held in stores, and completion rates rise because there are fewer shortages. A control mechanism can be set up at the end of each manufacturing cell to direct high-value parts. These "regulators" may consist of dunnage which circulate among the cells and each contains only enough materials for one aircraft; when the box arrives empty at the supplier cell, it represents a "fill me and pass me on" signal.[17]

Synchronous manufacturing systems are "pull-based" production systems which draw parts forward on the line as they are required rather than "pushing" them from behind and causing bottlenecks and waste. The Kanban can be footprints marked on the floor at work stations that contain only one of the production items to be passed on to the next station or taken up from the previous station. It can also involve cards to be attached to and passed on with the item, but should otherwise eliminate much paperwork.[18]

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[15] British Aerospace's Samlesbury facility is an example.

[16] Kanban, meaning "ticket" or "signal" in Japanese, is a management tool in general use in Japan and developed by Toyota from US company Sears' tickets for limiting public access to its store.

[17] Gray, Bernard; Financial Times, December 18, 1995: "Special Report on British Aerospace: Managers must have the courage to trust their people." Copyright 1995 The Financial Times Limited.

[18] Pohling-Brown, Pamela; International Defense Review, April 1, 1995: "No time for banners: UK companies develop lean production with Japanese advice." Copyright 1995 Jane's Information Group Limited.

Similarly, JIT manufacturing implies a pull system of production where the demand at subsequent work centers drives the production at a given work center. Production batch size is small, resulting in low WIP and raw material inventory. In a JIT system, demand imposed by work centers downstream triggers production at any work center. If a work center is busy, demand is stored in a queue called the demand list until it may be satisfied. JIT systems are disciplined systems that include a constant devotion to problem solving and continuous improvement, the sharing of production planning and scheduling information, and good housekeeping.

In these types of systems, input storage areas for each work center are designed to minimize the amount of inventory that could be stored at any station. One benefit of the system has been an improvement in material handling. Before using the system, it was material handlers who would know where to take parts in the shop and, therefore, they would be responsible for most of the material handling. The upfront planning has eliminated this and now each operator transfers material from one station to the next. In job shop environments, the operator uses computer generated process routings to transfer products through the plant.[19]

Michael Cusamano, Professor of Management at MIT Sloan School of Management, notes that sometimes it may become impractical to let the manual exchange of kanban cards pull new orders of components into the production system and relay all production information. There may be better methods available (such as the use of bar-code readers and other electronic forms of moving information) for plants with very high levels of variety -- which covers many factories in the defense industry.[20]

6.3 Case Studies

The three case studies illustrate that the first two practices in this phase have been

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[19] Mukherjee, Amit; Huber, Ernest; American Machinist, July, 1994: "Just-in-time control works at tool and die shop." Copyright 1994 Information Access Company, a Thomson Corporation Company, Copyright 1994 Penton Publishing Inc.

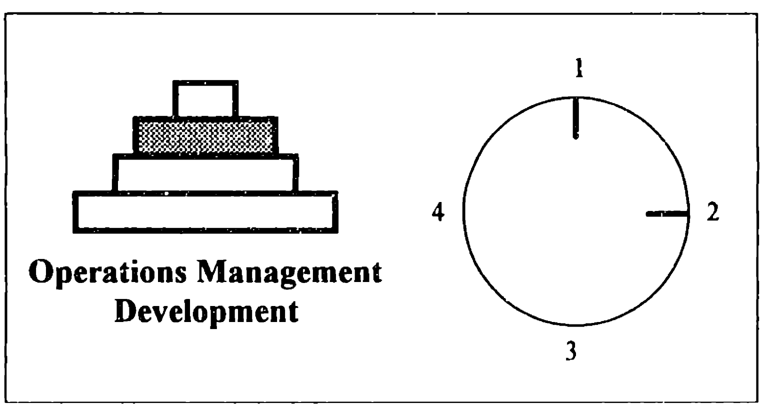
[20] Cusumano, Michael A.; Sloan Management Review, June 22, 1994: "The limits of lean." Copyright 1994 Sloan Management Review Association.

implemented but the latter two have not. The case study organizations have placed greater emphasis on the implementation of team based management, line based accountability and the reallocation of support resources than they have on synchronous "pull" manufacturing and information management. This may imply that there is a natural sequence of activities within the Operations Management Development transition phase.

6.3.1 Northrop Grumman Corporation

As depicted in the following figure, Northrop Grumman Corporation has implemented two of the four activities proposed in this phase of the hypothesized model. Northrop Grumman Corporation is so convinced that product quality is a manufacturing responsibility and not a quality assurance responsibility that they have created four parallel paths that transfer quality responsibilities to manufacturing. This evidence strongly supports the model's proposition of line based accountability. There was, however, little evidence of TPM or Autonomous Maintenance activities. In the areas of Information Management and Synchronous Manufacturing, the company has begun to implement some of the elements from these areas. This may imply that the latter two activities proposed in this phase of the model require a longer time horizon and are implemented at a later stage than the first two activities.

Figure 10. Operations Management Development at Northrop Grumman



6.3.1.1 Product Assurance "Transition to the Future"

Northrop Grumman Corporation has initiated four major processes that will support the transfer of quality assurance responsibilities from the quality control department to the assembly department. The transition from an inspection oriented to a process control oriented operation has already resulted in a savings of $3.5 million in the commercial aircraft division. The four "critical path flows" are detailed in the following exhibit.

During this 3-4 year process, employees undergo an internal training program in order to receive Product Assurance Personnel Certifications from the American Society of Quality Control. Before quality assurance responsibilities are transferred to the employee, the Quality Control department continues to monitor employee performance until the employee achieves a 99.5% process yield. Northrop Grumman Corporation has also adopted a Certified Assembly Mechanic (CAM) program that was jointly developed with a local community college. Functional hole processing training, however, occurred on-the-job because class-room hole-processing on flat surfaces is not comparable to the real-world process completed on curved surfaces on the main assembly line.

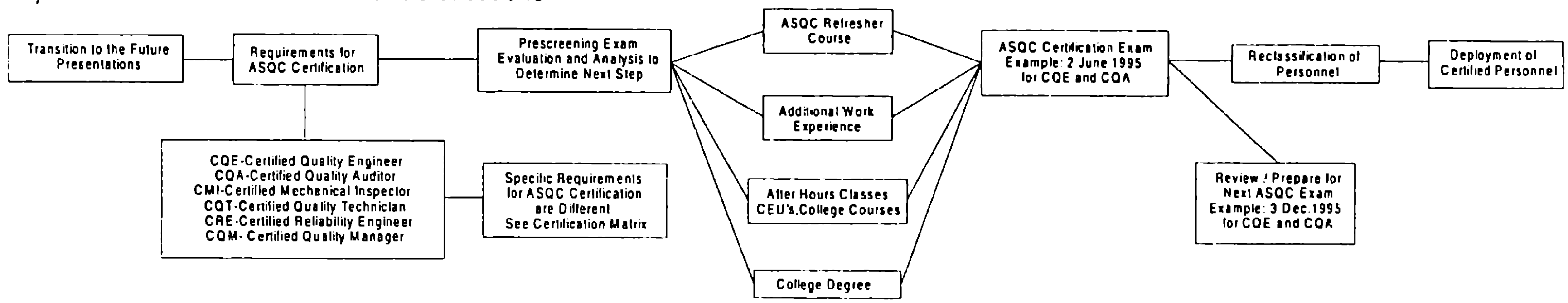
In addition to these certification programs, Statistical Process Control has also become a required training course for all mechanics who collect or utilize SPC data. The shop floor computer system will not allow mechanics to log on to a job requiring SPC data collection unless the appropriate level of certification has been achieved. The successful implementation of these processes, along with the fulfillment of contract requirements, will guide Northrop Grumman's Transfer Inspection Verification (TIV) program.

There are two major assembly operator classifications: subsystem mechanics and structural mechanics; both classifications receive the same training. Employees within cost centers are cross-trained. This increases management's flexibility in satisfying variation in the build schedule. The E/F workforce has received more training than the C/D workforce and can therefore handle greater production variability. E/F employee responsibilities have been expanded to include the cleanliness of their work areas. It is believed that this has contributed to the success of the E/F Foreign Object Elimination (FOE) program.

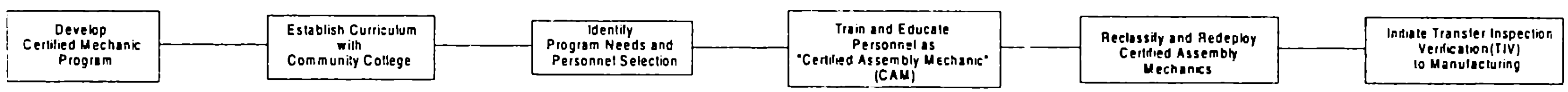
Product Assurance " Transition to the Future "

Four Critical Path Flows

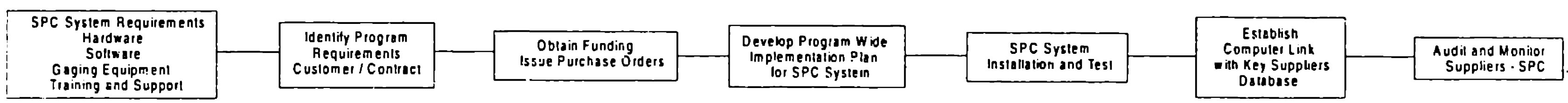
1) Product Assurance Personnel Certifications



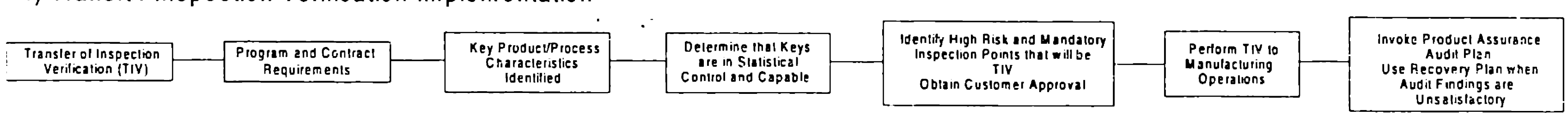
2) Certified Assembly Mechanic Program



3) SPC System Implementation (PVR)



4) Transfer Inspection Verification Implementation



6.3.1.2 Information Management

MRPII System

C/PIOS is the MRPII system used by Northrop Grumman Corporation to control all material flow in the factory. The development of this system began in 1986 and was implemented in 1992. This system is driven by the master production schedule which is controlled by Industrial Engineering.

Mechanics provide shop floor feedback to the MRP II system through a paperless system called IMPCA. At the end of each job, the mechanic logs into the shop floor control system and inputs his/her status for that particular shipset. IMPCA performs status functions, instructs the mechanic to perform the next highest priority operation or task and provides the mechanic with APWI to complete the next operation. Mechanics can also request quality control inspectors via an IMPCA call board function. IMPCA, however, does not change the MRPII system because the MRPII system is a separate data base.

IMPCA was developed approximately 12 years ago with government funding in an effort to establish a paperless factory. It took 4-5 years to bring it on-line. Three employees are currently dedicated to managing IMPCA and graphics capability is being added to supplement its other functions.

Cost of Quality

The Cost of Quality information system was driven by the requirement to provide more relevant and timely information for management decision making. The current accounting system can not provide the required information in a timely fashion and the transition to an enterprisewide Activity Based Counting (ABC) system is not supported by current final customer policy and contracts. Consequently, the organization began implementing its own Cost of Quality program in January 1996. The focus of this system is on capturing cost data in five categories: Prevention, Appraisal, Internal Failure, Northrop Grumman Corporation costs due to Supplier Failure, and External Failure (Escapes).[21] These five categories are

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[21] Prevention and appraisal costs currently represent one-third of Northrop Grumman's Cost of Quality.

encoded by two digit dash numbers on the shop order to create 32 different quality classifications. This system will provide more detail than the current system and will be used as a proxy to an ABC system. This effort satisfies the need for an integrated system that provides accurate and timely information in a format that maximizes usefulness.

6.3.1.3 Synchronous Manufacturing

Northrop Grumman Corporation has initiated three major activities in order to take advantage of the benefits of synchronous manufacturing. One of the practices implemented was the relocation of its subassembly cells closer to the main assembly line as discussed in the previous chapter.

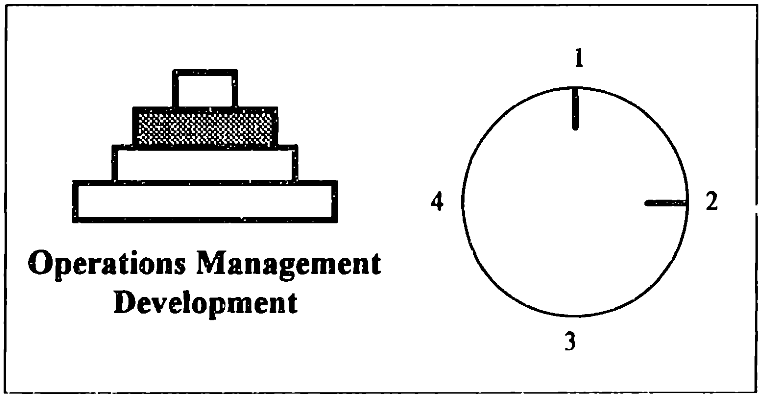
The second major practice implemented by Northrop Grumman Corporation was the use of kitted parts on the assembly line. Parts required in each assembly operation are kitted by materials handling personnel in order to minimize the amount of inventory located at each assembly station. Many of the kits are bubble-wrapped in clear plastic in order to avoid floor loss and allow easy identification of parts. The kitting philosophy is based on a modified Kanban where the mechanic is provided with the required materials at the required time. Management tracks kitting performance in order to reduce production delays on the assembly line. The kitting process maintains 1-2 shipsets of WIP ahead of schedule.

The company has also begun to implement JIT delivery programs with its suppliers. In the next phase of E/F production, suppliers are expected to stock material bins at their point of use at Northrop Grumman.

6.3.2 Raytheon Aircraft

Raytheon Aircraft is still in the midst of its Factory Flow Redesign phase and therefore has not initiated full-scale implementation of the practices outlined in the Operations Management Development transition phase. Management's earlier decision to focus the organization's energy on redesigning the factory's flow tends to support the model's hypothesis that the optimal transition to lean manufacturing does follow a sequence of phases. Practices from the Operations Management Development phase, such as Kanban, are predictably absent in the current organization because it is not rational to expect management to focus on JIT material flow when the factory flow is still being redesigned.

Figure 11. Operations Management Development at Raytheon Aircraft



However, similar to Northrop Grumman, the company has placed a relatively high priority on the implementation of line-based accountability. It is currently certifying operators in SPC in anticipation of redefined operator responsibilities after the Factory Flow Redesign phase is competed. In addition, production has also begun to assume greater control of the tooling and CNC programming groups which supports the model's hypothesis regarding the reallocation of support resources. Figure 11 illustrates the implementation of Raytheon Aircraft's implementation of teams and reallocation of support resources.

6.3.2.1 Redefined Employee Responsibilities

Shop-floor employees are segregated by a number of different pay grades. High pay grade employees can be assigned to perform low pay grade tasks, but low pay grade employees are contractually restricted from performing high pay grade employee tasks. The company is also attempting to expand the responsibilities of workers by assigning multiple work centers (machines) to each operator.

In addition to these changes, Raytheon Aircraft is also currently in the process of transferring Quality Assurance (QA) responsibilities from the functional QA department to the shop floor production departments. In order for QA to certify a process, the operators are required to take a 12 hour SPC training class and then pass a written test. Inspectors and engineers are required to take a 24 hour SPC course. It is too early in the process to measure the relative success or failure of this program.

Each cell has an hourly planner or "crew chief" who schedules machinery based on the daily production plan and on interactions with management and other expediters. Each cell also has a set-up person who assists in performing external setup elements, such as the procurement of tooling and other set-up materials. Most operators are expected to preset cutting tools and set-up their individual jobs. Target flow times for products entering a cell are three days or less. Material flow is sometimes interrupted by expediters. For example, running set-ups are only broken down (interrupted) by "hot" parts once per week in the vertical CNC cell.

6.3.2.2 Training

The training process at Raytheon Aircraft remains largely uncoordinated and decentralized. The human resources department is only responsible for providing basic technical and supervisory management training; this level of training is similar to that proposed in the Lean Infrastructure section. Any supplementary training that may be required to support any of the lean transition phases, such as topics in the areas of cellular manufacturing, TQM, statistical methods, communications, problem-solving, etc. must be coordinated and provided by the sponsoring functional groups.

In the assembly area, unskilled operators receive some basic sheet metal training but rely primarily on on-the-job training. Since work instructions in these areas are regarded as "tribal knowledge", it is unclear how much cross-functional skill development has been achieved and whether the company has received any increased employee flexibility benefits in this area.

6.3.2.3 Reallocation of Support Services

Two Manufacturing Engineering and two Quality Assurance personnel support the sheet metal and machining areas. The increased collocation of CNC programmers, tooling engineers, and tool planners within the fabrication plant has enabled manufacturing to assume greater control over these areas. This is an important change because one of the biggest problems they face is reducing tool shortages. By controlling the areas with the greatest influence over tool shortages, production should be able to reduce delays due to tool shortages.

An example of the impact of employee cross training was witnessed in the improvements in tooling pre-sets. Experienced machine tool operators were reassigned to the tool room displacing the employees who previously performed these tasks. Since the new tool room personnel were the previous customers of the tool room, they were able to directly utilize their machine tool experience and translate it into improved tooling pre-sets.

Autonomous Maintenance

The company has implemented autonomous maintenance practices in some chemical processing areas. In the Chemical and Painting cells, operators routinely change filters, check tanks and wash down scrubbers. Since the operators have begun performing these tasks, the supervisor in the area has noticed increased up-time performance on this equipment. In this same area, the operators have also been actively involved in the design of racks, baskets and other tooling. Post-layout change processing capacity for this cell has increased by 50% with no additional operators.

6.3.2.4 Information Management

As part of the Raytheon Aircraft's recent JPATS contract award, the company is committed to adopting an Earned Value Management System (EVMS) which will measure cost and schedule together. Historically, management was not measured by performance to schedule. In the long term, this system will be implemented enterprise-wide. This system is currently being developed. The company is also in the process of developing and implementing nine standard measurements which will serve as barometers to assist in the reductions of lot sizes and lead-times.

6.3.2.5 Synchronous Manufacturing

Material Control

Plant #1 manufactures over 5,000 machine parts and 25,000 sheet metal parts to support the entire Raytheon Aircraft product line. One of the major bottlenecks in the assembly facility is part shortage driven largely by missing details from the Plant #1.[22]

In the assembly facility, only 50% of scheduled assembly orders are pre-sold orders when the plane begins on the assembly line. Consequently, the planning department's forecast accuracy is a critical element of the entire scheduling system. All assembly option items are forecasted by product planners and built/stocked to forecast plan. The company has also reprocessed the final assembly of option items to the shipset until the later stages of the final assembly line in order to minimize rework and increase process flexibility.

The Material Resource Planning (MRP) system determines the lot size for each order from an adapted EOQ formula that is calculated on 250,000 part numbers. The MRP system assumes: 1) an infinite manufacturing capacity and, 2) that the maximum lot size will not exceed nine months of production requirements.[23] Manufacturing Production Schedule information is inputted directly into MRP which generates shop orders that push material through the manufacturing system. The shop orders are printed by production planners who are hourly union employees. On the shop floor production is controlled by operators who swipe personal identification badges at stations located in their cells in order to log the work they have completed on an order. Each lot or order has a bar code on its production plan docket which is scanned into the system by the operator.

The crew chief in each cell prioritizes material based on AOG (aircraft on ground), number of delinquent days, due dates and intuitively by the number of days the material has been in the cell. The targeted amount of time that a job spends in a cell is less than three days. The company currently does not measure flow times or track flow time performance other than by measuring the aging of jobs in cells.

6.3.3 Hughes Missile Systems Company

Similar to the other case studies, the first two activities proposed in this phase of the

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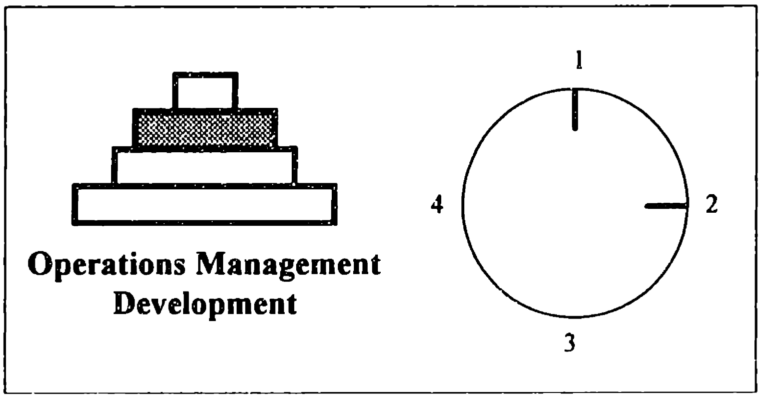
[22] Plant #1 supplies 80% of parts used by the assembly facility.

[23] Lot sizes range from 0 to 9 months of production.

hypothesized model have been implemented by the MXL program as illustrated in the following figure. Team based management is the cornerstone of the MXL program's operating philosophy and it has been fully embraced by all program employees. The incentive system for shop-floor employees was also recently revised to better support the program's operating strategy. The program is also implementing line based accountability via its MVP certification program. These practices are identical to those proposed in the hypothesized model.

Figure 12. Operations Management Development at HMSC MXL Program



Support resources have been reallocated as per the development of IPTs. However, the incentive system that motivates support personnel operating out of enterprise functional groups has not been realigned to fully support MXL's operating philosophy. Furthermore, since MXL's operating philosophy has not been adopted throughout the company, barriers separating centralized functional "homerooms" and the program still exist.

6.3.3.1 <u>Support Resources</u>

Homerooms are the centralized functional departments which provide support services, such as product engineering, maintenance and material control, to the production facilities. Support resources are centralized throughout the company. The previous and current operating philosophy is to allocate resources to the various program offices on an as-needed basis.

The rest of the enterprise is transitioning from a functionally based organization to a process team based organization structure. Incentive programs and career path planning are being modified to support this transition. The alignment of individual and team incentives with this transition will play an important role in determining HMSC success in this transition.

6.3.3.2 Career Enrichment Program (CEP)

The company has also implemented a Career Enrichment Program (CEP) which is a "pay-for-knowledge" program. CEP was established in 1987 in a joint management-union effort to give workers greater job enrichment opportunities and provide the company with a more skilled, flexible workforce. Employees are eligible to qualify for additional job units and pay increases by successfully fulfilling predefined educational requirements.

The number of job categories have been decreased from 146 to 60 in five functional job families. Within each family, the units are arranged in levels of increasing knowledge, skills and abilities, with movement to higher, better-paid levels dependent on successful completion of company-funded courses offered at Pima Community College. Employees must successfully pass tests in order to receive credit.

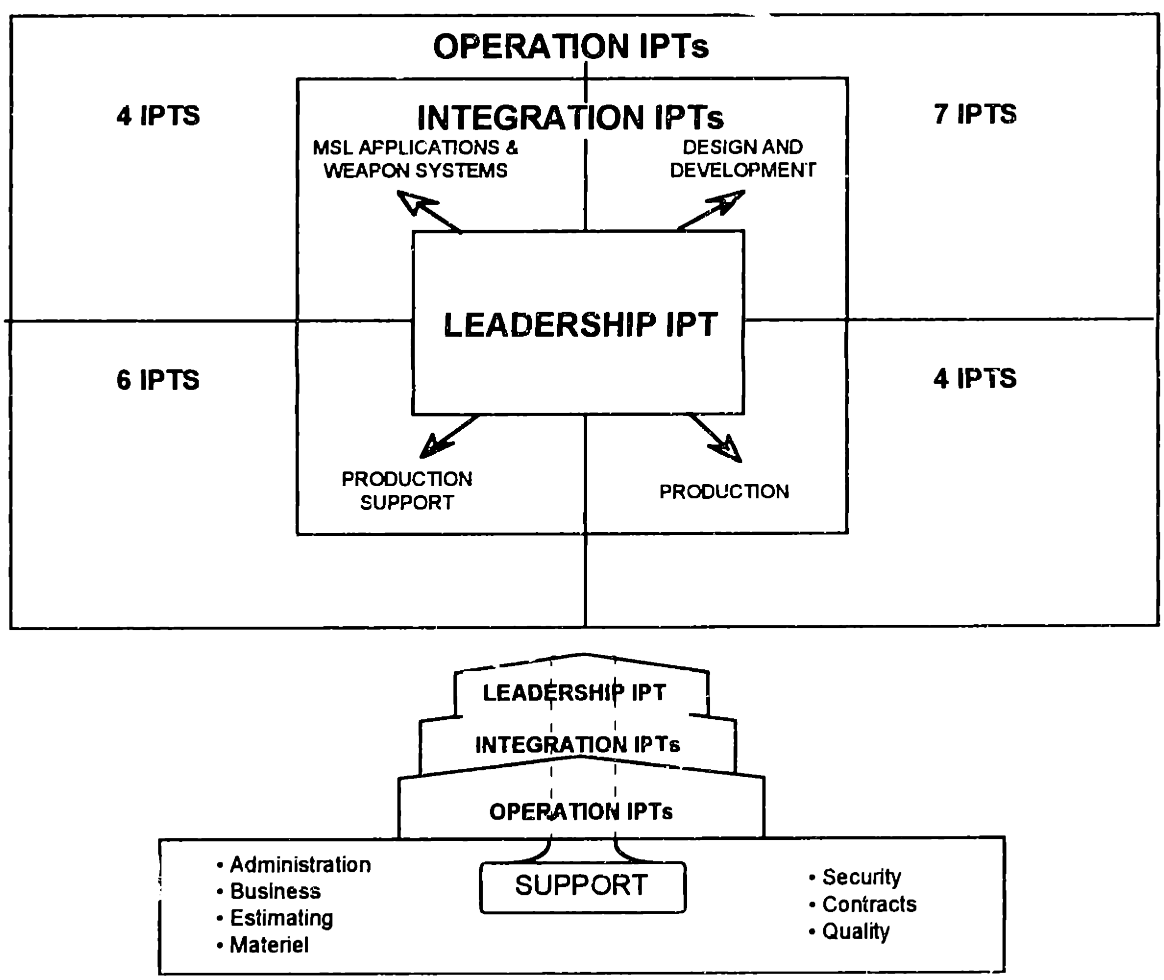
Employees may expand their skills both vertically and horizontally across the unit levels. This arrangement gives them greater flexibility and allows them to move around the company wherever their skills are needed. However, once they move to a higher level, their pay remains the same, regardless of what task they are performing. The company values worker flexibility because it enhances worker productivity. Flexible workers allow the company to optimize the variability in its operation.

6.3.3.3 Team Based Management

One of the first events in the missile program's life that resulted in significant quality improvements and cost reductions was the relocation of product development and design engineers in 1992 from Canoga Park, CA to Tucson, AZ where the product is manufactured. IPT teams were initiated later in that same year.

There are three levels of IPT. Leadership IPT is the highest level within MXL and it is comprised of the Program Manager, Integration IPT members and Finance, Marketing and other support managers. This team meets weekly to discuss strategic planning and significant program developments. Integration IPT is the next lower level and is comprised of the Operations Managers from the four major quadrants: Production; Product Support; Design and Development; MSL Applications and Weapon Systems. This team also meets weekly and is used as a medium to communicate information between the four quadrants, implement program objectives and resolve operational issues. The Operations IPT meets daily to execute program requirements and resolve day-to-day problems. The Operations IPT is comprised of the Operations Manager and each product IPT leader in that quadrant. Since the missile is divided into four natural hardware groupings, there is a product level IPT for each hardware grouping in the Production operations quadrant. The following exhibit illustrates MXL's unique organizational structure.

Figure 13. MXL Program Operating Model



During our visit, we attended an Operations IPT meeting that was held in the cafeteria during regular production hours. The team meeting was attended by ten people in this operations area. On this particular team, the team leader was the design engineer. Team leaders, in general, are multi-functional individuals and are never hourly employees due to collective bargaining restrictions. Four of the fifteen hourly employees from this department participate in all team meetings. The hourly team members are selected to participate on the team by the other hourly employees in their department. The purpose of this team meeting was to address quality and delivery problems associated with both internal and external suppliers.[24]

Failure of Self-Directed Work Teams

Hughes Missile Systems Company's first attempt at the implementation of teams was on the MXL program in 1992 in the form of Self-Directed Work Teams (SDWT). SDWT were not successful because the company attempted to implement self-managed work team concepts while ignoring the "soft side" or human element. The objective of SDWT was to empower hourly employees.

Although the implementation process was the same for all self-directed work teams, only a few of them were successful while most were not. Production management then conducted 150 random personal interviews with a cross section of employees in order to determine what was happening. The conclusion drawn from these interviews was that success and failure were based on the personality make-up of each team. It was observed that successful teams were largely composed of people who embraced self-directed work teams and were driven by its precepts. Dysfunctional teams were characterized as a group of individuals that did not trust one another and lacked an ability to work together. The first group was described as high initiative. This group supported self-directed work teams because they

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[24] The company is minimizing the distinction between salary and hourly workers. A clear example of this strategy is evident in the MXL program's dress code. Salaried employees are not supposed to wear ties when they are not interfacing with external audiences.

enjoyed the ambiguity that accompanied it. The second group was described as highly compliant. This group could not handle the ambiguity associated with SDWT and strongly preferred to be told what to do.

Development of Integrated Product Teams

Consequently, major drivers that supported the implementation of integrated product teams (IPT) at MXL were cost competition and the failure of self-directed work teams. The first step the company took was to hire a leading consultant in the area of team development and benchmarking. With this consultant, the MXL operations group conducted exploratory trips to organizations outside of their industry in order to benchmark their organizational structure and to rethink the implementation of teams in their company.

The second step management took was to develop an understanding of the worker's operating environment and functional work silos. They accomplished these objectives by conducting an employee survey called Worker Style Patterns (WSP). These surveys were conducted in a series of workshops used to define: as-is and should-be strawman, core membership of teams, roles of teams and team leaders. The team structure began operating in 1994.

The WSP survey is designed similar to a Myers-Briggs self-awareness survey where the survey presents the individual with multiple choice answers of which the individual selects the response that best describes his/her personal response. The summary of survey results provided management with an employee description of the functional responsibilities of workers, supervisors and management as well as an indication of individual preferences.

The work culture study results indicated that employees desired: more responsibility, authority along with empowerment, budget responsibility, involvement in the decision process, extensive training, rewards based on team performance, the break down of barriers between hourly and salary employees and an increased level of trust among all employees.

For example, in 1994, the Assembly Engineering WSP survey was administered to assembly engineers, their customers and their suppliers in order to understand how this group preferred to work and to define the specific tasks required to fulfill their responsibilities.

After the individual surveys were summarized, MXL management attempted to align individual preferences with optimal work styles and job requirements in order to maximize employee satisfaction. Poor job/person alignment meant that people had to either change jobs or their jobs had to be changed.

In essence, the program provided a self-selection opportunity for individuals so that they could be placed in positions that best suited their personal nature thereby enabling them to excel. Product designers who enjoyed interfacing with operations personnel could function as IPT members or if they preferred working by themselves, they could continue to do so on advanced technology development projects. The next phase of this program is to create an environment that supports the rotation of designers through production in order to transfer manufacturing learning to the product development phase.

The process of selecting team leaders for IPT is exhaustive. The first step the company used to select team leaders was to construct the optimal team leader profile by surveying all employees for their preferences in leadership characteristics. This process was implemented as part of the program-wide Work Style Patterns survey. Management then solicited applications from candidates who would like to be team leaders. The second step was to select and interview 30 candidates. From this first round interview process, management selects 10 individuals based on leadership and team skills. Management then interviews these 10 individuals and selects 5 of them for additional interviews.

6.3.3.4 Manufacturing Verification Program (MVP)

The MXL program has begun to transfer quality assurance responsibilities to production via its Manufacturing Verification Program (MVP). MVP is an employee certification program that authorizes operators to pass work on to the next operation without receiving approval from a quality control inspector. MVP requires operators to receive the same inspection training as inspectors. Inspectors audit certified employee output approximately once every five units. If the output fails an audit, then the employee's certification is removed and the employee must be recertified.

6.3.3.5 Incentives/Recognition

Hughes Missile Systems Company has initiated a comprehensive award program that recognizes and rewards contributions that have enhanced the company's values and goals. In this program, there are three levels of cash and non-cash awards for both teams and individuals. The variety of awards is designed to provide maximum flexibility in recognizing achievement.

In addition, there is an annual competition among teams to be recognized by executive management as the high performance team of the year. This type of competitive environment has created numerous benefits to the company including increased employee pride and ownership over their areas. High performance is defined by a labor index that measures labor performance relative to costs.

The award system was another key element that supported the implementation of teams and IPT. It has undergone major changes since IPT was initiated in order to support the changes implemented by the company. This system was developed largely by the efforts of Operations with support of Human Resources. The types of changes that were made required Operations leadership and initiative and could not have been driven solely by the Human Resources department.

7. Steps within Process improvements

7.1 Introduction

The last major lean transition phase in the hypothesized LAI Factory Operations Model focuses on optimizing or improving individual processes within the manufacturing system. Some companies may implement this phase before some of the other phases due to lower required capital investments but the potential benefits that they will receive may be limited to the successful implementation of previous lean transition phases. An analogy in this case would be to consider the previous transition phases as part of a process that optimizes the entire system and this phase as a process that generates local maximums but does not necessarily produce a system maximum.

In this section, the implementation sequence proposed in the hypothesized model to accomplish the Process Improvement transition phase is described. Then a comparison is made between the proposed transition phase and the case study operations.

7.2 Implementation

7.2.1.1 Improve Process Predictability

The first step within this phase is to stabilize the process. Independent of output quality, it is important to understand the system and to be able to predict its performance. Even if the process produces 30% defective parts, the focus of process improvement should be on reducing its operating variance before focusing on improving its capability, flexibility or speed. The application of common work standards and variability reduction tools are often used to improve process stability.

Many companies focus on new technologies in their efforts to improve their processes. When yields are low or process problems cause poor throughput and delivery performance, the first response is often to consider a major process upgrade, either through investment, new technology or both. Turning too quickly to investment or new technology can cause the company to neglect inexpensive, yet possibly significant, improvement leverage that can come from better process discipline.[25]

Process discipline means that process inputs must be controlled. Not only does this include physical inputs to the process (i.e., ensuring that raw materials are within specifications), but it also includes process documentation, training of employees, process audits, calibration procedures and gages, maintenance management, change control, and investment in a comprehensive production report. The focus of this step is to use formal systems to improve the consistency of inputs to the process, thereby reducing process variability. Without consistent inputs, there is no hope of achieving consistent outputs.[26]

The inconsistencies arising from the lack of discipline will make many processes appear to be out of control, or not capable. In a high-variability environment, it is difficult to identify the cause-and-effect of problems. It is even more difficult to test a hypothesis and get a result with high confidence, and to be sure the proposed corrective action really works. Identification, testing and fixing are all much easier with the consistency that results from good process discipline.[27]

7.2.1.2 Improve Process Quality

After the process has become stable and predictable, the organization can begin to focus its efforts on improving the quality of its output. The objective should be to get the process under statistical control by use of experimentation, statistical process control (SPC) and other methods in order to identify and correct assignable cause-type problems. Improved process capability (measured by Cpk) is the result of the application of statistical process control methods, operator certification, and error-proofing systems like poka-yoke.

Japanese poka-yoke systems ensure that certain, previously identified defects cannot occur.

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25 Treville, Suzanne de; Edelson, Norman M.;); Industrial Engineering Sept., 1994: "Process discipline: rethinking technology investment." Copyright 1994 Institute of Industrial Engineers Inc. (IIE)

26 Ibid.

27 Ibid.

For example, assume that a defect occurs each time material is fed into a process upside down. A poka-yoke device would detect the upside down condition and prevent the defect by stopping the machine. Poka-yoke devices provide 100% inspection for abnormalities at a fraction of the cost of traditional inspection methods, while eliminating defects at their source before they have a chance to occur.

7.2.1.3 Improve Process Flexibility

Once the process is capable, then the company can begin to focus on expanding or increasing the flexibility of its bottleneck operations. This includes the application of flexible tooling, computer numerical control (CNC) machine tools and set-up time reduction programs.

Obviously, a high level of process discipline is critical to determining where the firm should invest its capital. Poor process discipline leads to low capital efficiency. The achievement of process discipline in the first step leads to a higher probability of success with new technologies or investments. In both this step and in the following step, the organization may begin to consider capital investment or technological breakthrough as a mechanism to improve their process capability.

7.2.1.4 Improve Process Speed

The very last step within this lean transition phase is to increase process speed.[28] This is the last step proposed by the hypothesized model because in most organizations the successful achievement of the previous three steps provides significantly greater benefits than could be provided by increasing equipment speed. Methods of increasing process speed include the application of high speed machining equipment and ergonomic studies focused on the man-machine interface.

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[28] Some incremental process throughput benefits will also accrue to the system by improving process flexibility in the previous step.

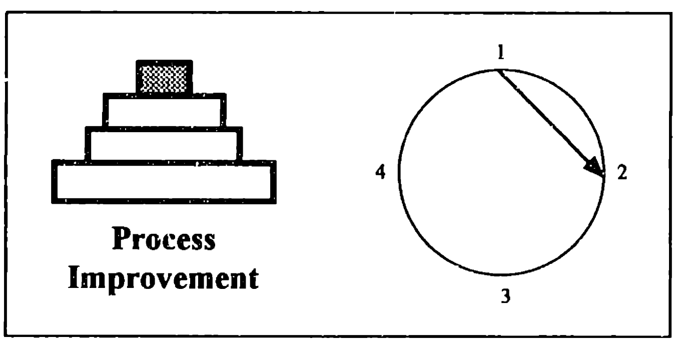
7.3 Case Studies

The first two sets of practices proposed in the model were observed at all of the case study companies. The last two steps, which involved increasing flexibility and speed, were less apparent. This supports the model's hypothesis that there is a preferred sequence in the Process Improvement phase.

7.3.1 Northrop Grumman Corporation

Northrop Grumman Corporation has invested heavily in process improvement. Their MPVR program, which is strongly supported by top management, is the basis for their operating culture. The practices implemented on the F/A-18 E/F program clearly support the first two steps proposed by the model as illustrated in the following figure. First, documentation and communication through explicit work instructions have enforced process discipline thereby improving process predictability. Second, SPC is currently being implemented to bring hole processing operations under control. However, these two steps are being implemented somewhat simultaneously. This is probably due to the simultaneous allocation of different functional groups to support those activities. QA is leading the implementation of SPC and Manufacturing Engineering is leading the implementation of work standards.

Figure 14. Process Improvement at Northrop Grumman



7.3.1.1 Improve Process Predictability

In airframe assembly, the splice operation tends to be the operation most vulnerable to process and/or product variation. Northrop Grumman Corporation tracks 8 key characteristics at the splice interface between the forward and center/aft fuselages but have not experienced any problems on the E/F program. The splice operation at McDonnell Douglas Aircraft has been reduced significantly from four days on C/D shipset #1 to one-half day on E/F shipset #1 due to reduced product variability, increased coordination with McDonnell Douglas Aircraft and an improved design incorporating lessons learned from the F/A-18 C/D program.

Another example of the effects of reduced product variability is the assembly of the vertical tails to the aft fuselage. On the F/A-18 C/D, the vertical tail was hand-crafted to match each unique fuselage. On the E/F, variability between the vertical tail and aft fuselage has subsequently been eliminated by better positioning the pieces within tolerances and the simultaneous drilling of both the tail and aft fuselage. Northrop Grumman has experienced only 0.02% defects in this operation on the E/F line and has gained considerable service benefits as the tails are now completely interchangeable with other fuselages.

Effect of Variation in Composites Fabrication

All product deliveries on the assembly line are driven by MRP II except Standard Parts which are driven by usage. Unfortunately, variability in composite part thickness has driven the need for standard parts with varying grip lengths. Currently, Standard Parts represent 20% of total inventory at Northrop Grumman. If the variability in composite part thickness can be reduced, the program could potentially reduce a significant portion of their Standard Parts inventory.[29]

7.3.1.2 <u>Geometric Dimensioning and Tolerancing (GD&T)</u>

Throughout the F/A-18 E/F program, McDonnell Douglas has attempted to make sure that everyone utilized the same language by introducing a concept called "geometric dimensioning and tolerancing" (GD&T). GD&T requires designers to define a part based on functional datums or the part's functional surfaces. It is a standardized language that helps

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[29] Standard Parts include bolts, screws, studs, etc.

assembly mechanics and inspectors interpret engineering notes in the same way. With a common language, engineers can use GD&T to explain how pieces fit together, where holes should go, and what the important features of the part are. Consequently, assemblers were less likely to misunderstand the designers' intentions.[30,31]

McDonnell Douglas also helped lay the groundwork in minimizing tolerance build-ups, which can prevent the smooth assembly and fit of some pieces. McDonnell Douglas started a variability reduction program that identified mating surfaces key to fitting up the airplane. Product centers were instructed to machine those surfaces to nominal tolerances so that there would be no step increment between the two pieces.

7.3.1.3 Manufacturing Process Variability Reduction (MPVR)

As mentioned earlier, the Manufacturing Process Variability Reduction (MPVR) program is the cornerstone of Northrop Grumman Corporation's lean transition. Top company leadership is directly involved in the executive steering group which meets quarterly to review the implementation. The objective of the MPVR program is to reduce process variability throughout the organization. This program is coordinated across Process Improvement, Definition and Documentation (e.g., product IPTs), Support Activities (e.g., process IPTs, SPC specialists, computer systems), the TIV Initiative and External Supplier ISMT. This coordinated effort has clearly defined the responsibilities for the various parties involved. The MPVR master plan was developed in 1992 and piloted in 1993. Full-scale implementation of this program began in 1994.

Northrop Grumman Corporation has embraced the philosophy that successful MPVR/SPC requires the following elements; 1) executive management leadership and support, 2) team approach, 3) education of employees at all levels, 4) emphasis on continuous improvement, 5) and a mechanism for recognizing success.

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[30] Aerospace Daily, September 27, 1994: "F/A-18E/F production showcases MDC's new manufacturing philosophy." Copyright 1994 McGraw-Hill Inc.

[31] Aviation Week & Space Technology, September 25, 1995: "F/A-18 (E/F) Design Techniques Maintain Affordability" by Stanley W. Kandebo.

Assembly Process Work Instructions (APWI) and Composites Work Instructions (CWI)

Through the MPVR program, the organization has also initiated the development and implementation of Assembly Process Work Instructions (APWI) for its mechanics. APWI describe the task required to be completed at each operation in both literal and pictorial format. APWI assist mechanics in fulfilling their responsibilities by identifying the following: reference documents, certification requirements, control parameters (e.g., tools, speeds, feeds, lube, etc.), key characteristics, "how to" process instructions, acceptance criteria, work order originator, approval signature, pictorial representation of process and gauging requirements. Explicit documentation of assembly methods and requirements supports Northrop Grumman's efforts in implementing best common work practices, thereby reducing assembly process variation and improving product quality. These work instructions were standardized by a team of mechanics selected from four different cost centers. Northrop Grumman has completed 40 out of 250 planned APWIs.

7.3.1.4 Improve Process Quality

Northrop Grumman Corporation has developed a process outlined in their pocket guide "PA/MPOC Process Flow" which describes the process, defines process capability and gage R&R and presents the Quantum SPC user interface. It has also implemented variable SPC data collection on approximately 3,500 out of a planned 18,000 close tolerance holes and approximately 5,000 out of a planned 7,500 countersinks on the assembly line with Quantum SPC software, DataMyte data acquisition and Federated gage equipment.[32] This data is analyzed by both manufacturing and quality personnel to provide mechanics with feedback and to track the process capability (Cpk) of various operations. The company uses pareto analysis techniques to help focus the Cpk improvement efforts. 80% of the close tolerance holes have Cpk values greater than 1.0 and 75% of the close tolerance holes have Cpk values greater than 1.33. 32% of the countersink operations have Cpk values greater

[32] Variable SPC data refers to the analog measurement of specific dimensions used to generate control charts as opposed to some SPC systems that utilize only attribute SPC data (i.e., pass/fail) to generate control charts. Variable SPC data provides significantly more information than attribute data does.

than 1.0 and 11% have Cpk values greater than 1.33.

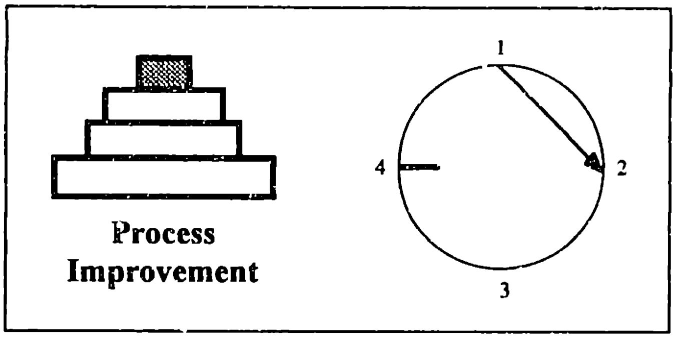
In an assembly operation, a mechanic's work standards includes some preprocessing measurement before completing the operation. In other words, the mechanic will typically pre-drill three holes and gage them in order to ensure that process is within specification before attempting to complete all of the hole-drilling requirements for that operation. Holes are gauged throughout the operation to a predetermined sampling plan based on the quantity of holes being drilled and historical Cpk data. When a mechanic observes a deviation, he is responsible for identifying and classifying the cause of the deviation on a comprehensive checklist used by manufacturing to investigate process variation. The checklist is included in Appendix A.

The company has also developed flexible tooling through an ICAT technology project whose objective was to reduce operator variability in difficult drilling operations. The tooling was not only successful in reducing process variability but it also increased process throughput speed.

7.3.2 Raytheon Aircraft

The steps being implemented by Raytheon Aircraft also support the Process Improvement transition practices proposed in the hypothesized model as illustrated in the following figure. Raytheon Aircraft, similar to Northrop Grumman, has focused considerable efforts on its variability reduction program. The basis for this program is both supplier control and statistical process control. Through the use of process capability studies based on SPC data collection, QA has assisted industrial engineering both simulate and improve manufacturing cell designs. Furthermore, as the company's shop floor employees become more involved, they are also developing methods of reprocessing products more efficiently. This step, not only reduces set-up variation, but it also improves overall throughput.

Figure 15. Process Improvement at Raytheon Aircraft



The application of work standards in the Process Improvement phase of the model is not as clearly supported at Raytheon Aircraft. One possible reason for this deviation from the model is that most of the machining equipment in that facility is automatic and utilizes DNC programming. Consequently, the impact of operator variability may be lower and therefore the need to improve process predictability may also be lower.

Through its modernization program, the company has also purchased new high speed milling machines in order to satisfy JPATS production requirements. This equipment will increase process speed and will require less floor space than the equivalent processing capability of traditional milling machines. Even though this step appears out of sequence from the hypothesized model, it illustrates how the timing of Raytheon Aircraft's plant-wide Factory Flow Redesign phase has impacted the decision to implement activities in other phases of the model.

7.3.2.1 Variability Reduction / Statistical Process Control (VR/SPC)

The Quality Assurance department at Raytheon Aircraft administers most product and process quality functions. QA has initiated the VR/SPC program plan which includes the following three phases.

First, a Material Field Quality Engineer (MFQE) has been assigned to each supplier in order to ensure that the supplier has a quality system in place and that the supplier provides statistical quality data with each lot. This process helps control process inputs.

Second, the organization is currently undergoing an internal transition from a product-focus orientation to a process-focus orientation based on their 15 step approach. QA has 300 process capability studies underway in this area. These studies are based on individual asset numbers. Each work order docket (that travels with the lot of materials) includes a machine capability study sheet that the operator is required to fill-in. These study sheets form the database for QA's machine capability studies. 230 out of 656 process capability studies have been completed in Plant #1 so far.[33]

Third, responsibility for the identification of key characteristics will be delegated to cross-functional assembly teams in the future. Key characteristics have been and are presently determined by product engineering during the product design phase. The delegation of this responsibility to shop floor assembly teams is expected to assist assembly mechanics in consistently performing high-quality assembly functions.

At the anticipated completion of the VR/SPC program in 1998, there will be 92 teams operating at Raytheon Aircraft. Of which, 70 will be active VR/SPC teams, 12 teams will be special process teams and 10 will be MFQE teams facilitating supplier component improvements and JIT deliveries. The success of the VR/SPC program has allowed Raytheon Aircraft to claim that it is the only FAA-approved airframe manufacturer to utilize statistical sampling inspection methods. They statistically control processes in the machine shop areas with the goal of achieving Cpk values greater than 1.33.

7.3.2.2 Simulation Analysis

The company is also utilizing Variation Simulation Analysis (VSA) to perform Monte Carlo simulations on tolerance stack-ups. VSA is a software package that accepts a variety of tooling, process and assembly information , and then simulates the assembly operation. The output provides the user with statistical information on the specific assembly characteristics of the part. Any areas identified by VSA as difficult assembly areas were then defined by manufacturing as "key characteristics". This activity, along with machine capability studies, assists both product engineers improve their designs and manufacturing engineers determine process routings and cell design.

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[33] In some instances, QA is also using first pass yield data as a surrogate for Cpk data when statistical variable data is not available.

7.3.2.3 Improve Process Flexibility

Operating requirements within the recently awarded JPATs contract has driven the implementation of process improvement teams for various parts. The process improvement teams are comprised of a Quality Assurance engineer (facilitator), shop foreman, manufacturing engineer and operator. The team leader is elected democratically and is usually an operator. These teams meet on a weekly basis.

Some of the results of these teams have been quite significant. For example, the number of operations required to manufacture the Beechjet Carry-Thru[34] has been reduced from nine different machine set-ups to two. The reengineering of this product's process routing by shop floor operators has significantly reduced both its manufacturing lead-times and costs while improving product quality. This accomplishment has reinforced employee enthusiasm and pride in that particular machining area because the original designs and process routings for this product were purchased directly from a leading Japanese manufacturer.

The organization is just beginning to focus on reducing lot sizes via set-up reduction teams. These teams are not formalized and are at the initial stages of development.

7.3.3 Hughes Missile Systems Company

The process discipline and variability reduction efforts being implemented on the MXL program support the hypothesized model's proposed sequence as illustrated in Figure 16. The MXL program has focused considerable attention on implementing SPC programs both internally and externally. Since most of fabrication has been outsourced, gaining control of the program's process inputs at its suppliers has played an important role in implementing SPC. Internally, the program has successfully used SPC to monitor and control its testing equipment. Further, as the program's confidence in SPC analysis tools has increased, it has also begun to apply statistical methods to indirect production activities as well.

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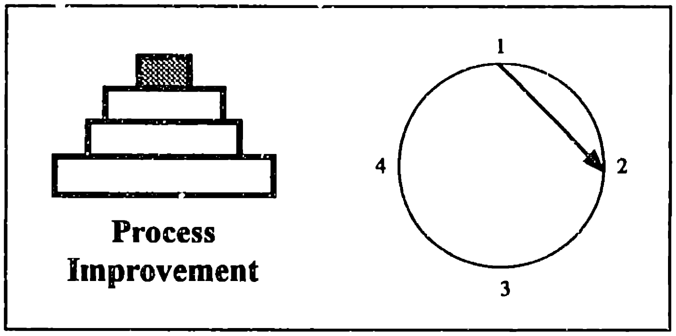
[34] The Carry-Thru is the center section of the jet that connects the wings to the fuselage.

Figure 16. Process Improvement at HMSC MXL Program



7.3.3.1 Implementation of SPC

MXL was the first program at the Hughes Missile Systems Company to embrace SPC. The customer's specification outlining the implementation of SPC was one of the main reasons the program incorporated SPC into its internal processes midway through the program's life. Even though MXL was not contractually obligated to implement SPC at its suppliers until later in the program, it did so because management recognized the importance of sharing the SPC methodologies and practices with their suppliers.

The suppliers were responsible for identifying critical material (CM) and critical processes (CP) that required measuring and reducing process variability. These steps are monitored by Hughes Missile Systems Company and the government in periodic visits.

During this time, the company also drafted a critical suppliers list which identified 30 of its suppliers. A critical supplier is a single-sourced supplier that requires more than six months to replace and provides high cost products. This list also included internal suppliers. The competitive nature of the MXL program and its greater dependence on suppliers has required the company to monitor its process inputs very closely.

Products that flow through MXL's assembly processes are verified by certified operators at each operation and subsystems and final systems are tested inline. The company uses SPC to monitor and control those processes. Over 70% of the test operations have a Cpk value greater than 1.33.

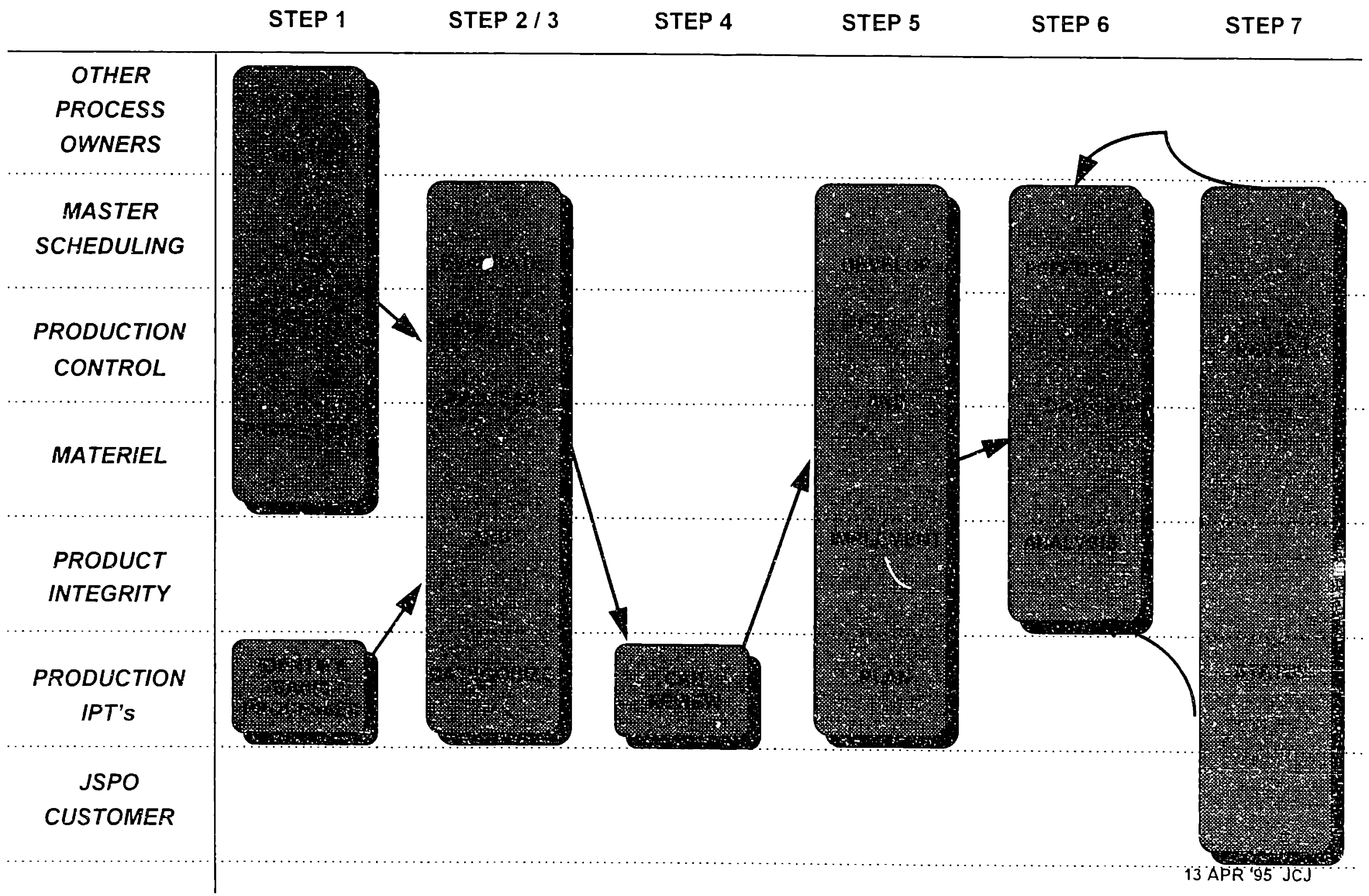
7.3.3.2 MXL Acquisition Process

The MXL program office has also applied SPC techniques to its acquisition process in order to measure and improve its performance in this area. The goal of this team is to provide all customers with material and product in a timely manner by identifying, monitoring and improving the key aspects of the MXL acquisition process. This project was initiated in June 1995. This team utilized the Hughes Missile Systems Company seven step approach to problem solving as illustrated in the following exhibit.

The team reports process capability, root cause analysis results and pareto analysis at the quarterly Corrective Action Board meeting. The reports illustrate key process errors by source and helps keep the team focused on solving the major problems. One of the long-term objectives of this program is to utilize continuous measurable improvement teams to permanently fix problems in the material acquisition process. This process has reduced procurement delinquencies from 6% to less than 1%.

APPLYING SPC TO THE MATERIAL FLOW PROCESS

"Phase 1 & 2"



8. Appendix A - Northrop Grumman Corporation

Assembly Mechanic Checklist

CODE	CAUSES	Check-box	Recommendation
A	**Workmanship**		
1	Inadequate On-the -job training		
2	Inadequate Datamyte training		
3	Hectic Schedule Driven job		
4	Inconsistent operation		
B	**Machine**		
1	Improper selection of drill motor		
2	Improper selection of drill cutter		
3	Improper selection of countersink cutter		
4	Abnormal failures of drill motor/drill cutter/countersink		
5	Inadequate Parts/Equipment in tool crib		
6	Inadequate drill supply		
C	**Method**		
1	Improper tool usage instruction		
2	No specific problem solving guidelines		
3	Improvisation of the process because of lack of supplies		
4	No specific document defining toolkit for the job		
5	Area difficult to access		
6	APWI method not utilized		
7	APWI method not available		
8	APWI instructions needs change		
D	**Material**		
1	Compound contour		
2	Thin/Thick parts		
3	Hole with Arc-spray (EMI) coating		
4	Multiple material stackup drilling		
5	Improperly trimmed parts		
6	Inconsistent standard parts		
7	Bad parts from previous cost center		

Northrop Grumman Assembly Mechanic Checklist Cont'd.

E	**Measurement**		
1	Inadequate gage		
2	Inexperienced using the gage		
3	Tight Engineering specification		
4	Surface have multiple targets for head flushness		
5	Target dimensions mentioned in APWI needs to be modified		
6	Difficult to hold the gage steady		
7	Differences in measurement accuracy of different gauging systems		
8	No proper measurement tools to verify/check the process variation on-line		
9	Improper measurement technique. Measuring after the job is done		
10	Tight control limits		
11	Poor Gage R&R		
F	**Tooling**		
1	Tools drifting while drilling		
2	Tools improperly checked		
3	Error in Tool Design		
4	Errors in Tool Fabrication		
5	Tools not properly coordinated		
G	**Environment**		
1	Difficult working posture		
2	Space light not adequate		
H	**People**		
1	High Turnover		
2	Lack of participation in NWT team		
3	Day/Night shift		
4	Lack of management participation		
5	Pressure of job affecting the NWT schedule		
6	Poor information flow to the shop floor level		
7	Lack of communication		
J	**Others**		
1	Attitude		
2	Work habit		
3	Discipline		

9. Appendix B - Raytheon Aircraft Cell Descriptions

Listing of Machine Shop Cells and Description

Cell Name	Number of Machines	Description
CNC Vertical Machining	18	Vertical 3-axis Mills, Conventional Mills, Multi-spindle Drills
CNC High Speed Horizontal Machining	1	New Leblond Makino high speed 4-axis Mill
CNC High Speed Vertical Machining	1	New Modig high speed 4-axis Extrusion Mill
Conventional Machining	11	Standard Mills, Conventional Profilers and Multi-Spindle Drills
CNC Horizontal Machining	10	Horizontal Machining Centers, Standard Mill, Multi-Spindle Drills
Large CNC Vertical Machining	14	Large Vertical 5-axis and 3-axis Profilers, Standard Mill, Conventional Profiler, Multi-spindle Drills, Radial Arm Drill
Large CNC Horizontal Machining	4	Large Horizontal Machining Centers, Gun Drill
Hinge Machining	4	Hinge Mill, Hinge Drills, Conventional Profiler
General Machining I	19	CNC and Conventional Lathes, Grinders, Standard Mills, Conventional Mills, Multi-spindle Drills, Hone, Bore
General Machining II	12	CNC and Conventional Lathes, Grinders, Standard Mill, Multi-spindle Drill
Turning and Grinding	14	CNC and Conventional Lathes, Grinders, Hones, Straightening Press
Specialty Machining	35	Standard Mills, Conventional Profilers, Vertical 3-axis Mills, Gun Drills, Broaches, Multi-spindle Drills, Bore, Grinders, CNC and Conventional Lathes

Listing of Sheet Metal Cells and Description

Cell Name	Description
Punch Press	New NC turret punch, existing punch presses, trimatic, AEM, and hand debur, countersink, press brakes, tool storage, inspection and cell support
Saws and Raw Stock	Existing SRS equipment, brake for piercing, brake for joggling, Dispatch oven, vibratory debur, misc. drills and debur equipment, tool storage, inspection, and cell support
Hydro Form	NC routers, punch presses, trim tabs, new AEM debur, Lake Erie, Versons, ice boxes, gun form, hand form, brake, TK router, misc. drills, hand rout, debur, tool storage, inspection, and cell support
Heat Treat Hub 1	New drop bottom air furnace with glycol quench, ice box, and align
Extrusion Stretch	30T Cyril Bathy, 15T Cyril Bath, ice box, band saw, hand rout, debur, angle form, drill, parts cleaner, tool storage, inspection, and cell support
Draw Form	Cincinnatis, 1000 ton, 400 ton, C150, 350 ton, ice box, band saw, shaper, hand rout and drill, trim tabs, debur, tool storage, inspection, and cell support
Skin Stretch Press	Cyril Bath 400T, Versa, Pacific, ice box, parts cleaner, hand rout, drill, trim tabs, debur, tool storage, inspection, and cell support
Brakes, Rolls, Misc.	Gantry router, 3X12 router, master router and radial drill, pin routers, brakes, rolls, trim tabs, debur, tool storage, inspection, and cell support
Chemical Milling	Chem mill, hand rout, drill, trim tabs, debur, tool storage, inspection, and cell support
Drop Hammer	Drop hammers, Baldwin, bulgers, ice box, rout, drill, band saw, trim tabs, debur, speed hammer, tool storage, inspection, and cell support
Heat Treat Hub 2	Existing heat treat, ice box, and align
Laser	Lasers, band saw, drill press, hand drill, trim tabs, debur, tool storage, inspection, and cell support
Spinning	Spin lathes, ice box, band saw, hand rout, drill, debur, and tool storage
Mini Fab	Existing Mini Fab equipment, 2X8 NC router, new AEM debur, tool storage, inspection and cell support
Special Parts Group	Existing SPC equipment and conventional brake
Plastics	May be moved in whole or part?
Degrease Hub	New parts cleaning system
Age Harden Hub	Existing ovens

10. Appendix C - Hughes Missile Systems Company

Hughes Missile Systems Company - MXL Program

Commitment To Our People

MXL leadership is committed to changing the workplace culture by building an environment of trust, enthusiasm and teamwork. We will accomplish this by creating a communications process that is characterized by a free flow of information in all directions. This will enable us to develop an informed workforce with access to all the information affecting their work.

Utilizing the IPD team culture, we will recognize and empower the diverse talents of our work force. By teaming our people in situations where they interact to achieve common objectives, we will help remove the barriers that tend to separate our people and create the synergy necessary to achieve our common goal of being competitive. We will work with the rest of the Tucson plantsite where our work force is assigned from a homeroom to MXL to expand the MXL value that flexible employees are more valuable employees.

In addition, IPT's will allow us to involve the people who are closest to the task to suggest and implement ideas for improvement.

The ultimate results will be twofold. Together we create a more pleasant, rewarding and interesting place to work while maximizing our productivity.

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