Creating A Rapid Response Design, Assembly, Integration, And Test Facility In A Non-Repetitive Environment

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Abstract

This thesis is based on the author's seven-month internship with the Boeing Company, Space and Communications Group in Houston, TX. The Houston site has been going through tremendous change. With cost constraints on NASA Boeing is working hard to improve its level of service while simultaneously reducing cost. Boeing is transforming the Houston Product Support Center, within the Houston site, into a "Rapid Response Design, Assembly, Integration and Test Facility." Creating such a facility in a manufacturing environment of non-repetitive one-of-a-kind flight hardware presents interesting challenges.

This thesis provides a cursory overview of select manufacturing strategies and facility evaluation tools in use across industry, which may aid in the creation of said facility. These tools were then used to evaluate the Houston facility to identify key ingredients to the creation of a rapid response facility.

The work of this project resulted in enhanced communication across the Houston site, a signed project charter, as well as a go forward plan for site transition. In addition, the project provided for the author invaluable lessons that were both technical and organizationally related.

Thesis Supervisors:
Professor Roy E. Welsch, Sloan School of Management
Associate Professor David S. Cochran, Department of Mechanical Engineering

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1. INTRODUCTION

1.1. Background

1.1.1. Boeing Corporation [10]

The Boeing Company is the leading aerospace company in the world, as measured by total revenues. The holder of more than 6,300 patents, Boeing is the world's largest manufacturer of commercial jetliners and military aircraft, and provides related services worldwide. Boeing is also NASA's largest contractor. The company's capabilities and related services include helicopters, electronic and defense systems, missiles, rocket engines, launch systems, satellites, advanced information and communication systems, and financial services. It is the world's premier large-scale system integrator, with plans to develop a space-based air traffic management system to solve the world air congestion problem, as well as a global-mobile communications system that will allow passengers on any moving platform to be connected to high-bandwidth data. At year-end 2000, Boeing employed a diverse and skilled workforce of 198,000 people. Along with hundreds of thousands more people employed at approximately 28,800 suppliers worldwide, they provide Boeing products and services to customers in 145 countries.

Consisting of four primary operating groups: Commercial Aircraft, Military Aircraft and Missile Systems, Space and Communications, and Boeing Capital Corporation, Boeing generates $50+ Billion a year in revenue.

1.1.1.1. Space and Communications Group [25]

Backed by a 50-year heritage of space-related high-technology achievements, Boeing Space and Communications is a diverse $10 billion enterprise whose more than 43,000 employees are involved in operating the Space Shuttle, building the International

Space Station, overseeing our nation's missile defense and reconnaissance systems, and creating new satellite-based information and communications services.

With a suite of healthy core businesses, the Seal Beach, Calif.-based organization today also is pushing into new frontiers of aerospace high technology. Anchored by a stable commercial and civil space launch business that includes the reliable Delta family of rockets and unique Sea Launch program, Boeing S&C is also NASA's largest contractor for all U.S. human space flight efforts. In the defense realm, the group that designed the first Global Positioning System satellites today is prime contractor for the Ground-based Midcourse Defense Segment Program and primary architect for the National Reconnaissance Office's Future Imagery Architecture.

Leveraging its expertise in core civil, military and commercial space programs, S&C increasingly is moving into new information and communications service markets that broaden traditional conventions of the aerospace industry. Following the acquisition of the Hughes Space & Communications Company and related operations, S&C is now also the world's leading builder of commercial satellites. The company is becoming a major participant in the burgeoning space-based communications and services marketplace with offerings like digital cinema and satellite-based air-traffic and battle space management initiatives.

Boeing Space and Communications serves markets in launch services, information and communications, human space flight and exploration, and missile defense and space control. The group also provides subsystems and support in the areas of electronics and propulsion.

1.1.2. Houston Site [24]

The Boeing-Houston Operation is an operating unit of Boeing Space and Communications Group, a leader in the aerospace industry. Boeing conducts operations at five NASA centers - Lyndon B. Johnson Space Center; Goddard Space Flight Center; George C. Marshall Space Flight Center; John F. Kennedy Space Center, John C. Stennis Space Center - as well as Boeing divisions at St. Louis, Missouri, Huntington Beach, Seal Beach, and Canoga Park, California, Seattle, Washington, and other U.S. and international sites.

Houston Operations has supported the Johnson Space Center (JSC) since the mid-1960's. Originally, Boeing engineers provided technical support to NASA flight crews and controllers in the development of simulators and trainers, flight plans and procedures and real-time support for the Mercury and Gemini programs. Later these efforts were expanded to include crew procedures development and flight crew training for the Apollo, Skylab, and Apollo/Soyuz missions.

Since 1974 Boeing has provided Space Shuttle engineering and operations support at JSC. Initially, this work was part of the Space Shuttle development program. Boeing performed management and technical integration for the program by analyzing and verifying the design of Shuttle systems. Later, as the development phase was completed, the program and its work evolved into the detailed mission planning and operations support necessary for the mature, high flight rate operations environment of the Space Transportation System.

In 1985 Boeing began supporting the development of concepts and requirements for the Space Station program. In 1993 Boeing was selected as prime contractor for the design, development, test and evaluation, and delivery of hardware and software packages critical to the operation of the International Space Station. Boeing's light manufacturing capability in Houston blends engineering design support with the understanding of the realities of hardware capabilities to produce space-rated hardware and mockups for the International Space Station, Space Shuttle, Crew Return Vehicle and other space related hardware. Boeing engineers and designers are also responsible for the design of the interstage for the Boeing Delta IV, the next generation of advanced expendable launch vehicles.

In 1995, Boeing expanded its market base into the commercial telecommunications space sector. Boeing is currently developing ground control center software applications and providing engineering and operations support for programs such as Motorola Iridium®.

In Houston, Boeing offers the following support services:

System Engineering and Integration/Project Management

Mission needs and conceptual studies; design and development; fabrication, integration, test and evaluation; procurement; operations and sustaining engineering; risk management; cost and performance management.

Engineering

Thermal, structural, guidance, navigation and control, flight mechanics, mechanical CAD, automation and robotics; onboard and ground control center software; decision support tools; high fidelity simulations; advanced planning and scheduling systems.

Information Systems/Software Development

Requirements definition; design and implementation; requirements testing and analysis; configuration control; user training; data base management systems; graphical user interfaces.

Mission Planning and Analysis

Ascent, ascent-abort, on-orbit, rendezvous, proximity operations, descent, entry, interplanetary, payload flight design and integration; flight planning and profile design; performance analysis; dispersion analysis.

Mission Operations

Operations planning; human space flight operations; satellite operations; flight techniques and procedures.

Light Manufacturing

Space-rated hardware design and fabrication; training mockups; light weight composites

1.1.3. Boeing Acquisitions and Cultural Effects

Boeing has continued to increase its size and offerings through acquisitions. Although acquisitions provide increased breadth of offerings and, in ideal conditions, efficiencies as well, there can be some negative aspects.

Business systems, business processes, and business culture is carried with each of these acquisitions. In many of the historically rich businesses, like Rockwell and McDonnell Douglas, this is particularly true. The Strategic, Political and Cultural effects of this strategy are addressed in Section 2.9 of this thesis: Organizational Processes Investigation and Change Initiation.

1.1.4. Internship Project Overview

This internship has provided the opportunity to evaluate the development of a rapid response design assembly integration and test facility.

1.1.4.1. Drivers for Internship Focus

The Boeing Company is the prime contractor for the International Space Station and the developer of the Space Shuttle. Through acquisitions they now own the majority of contractors who provide components and devices for the Space Shuttle and the International Space Station as well as many other peripherals required by NASA engineers and astronauts. As such NASA inundates Boeing with requests to design and manufacture many different items. For the Space Shuttle program, Boeing has a full time task force called the CREW Equipment Team.

Boeing currently has five facilities used exclusively for supporting these special request demands for the International Space Station alone. Boeing feels that although producing these types of devices is not overly profitable to the organization, percentage-wise, it is a crucial strategic capability required to stay in the driver's seat for business with NASA and is key to customer relationships. With the increased cost reduction pressures placed on the International Space Station, Boeing has been looking for ways to reduce the cost associated with providing this quality of responsive service, without reducing quality or increasing lead times.

To address this issue, Boeing has decided to consolidate their support operations. They have selected the three optimal sites to provide this service, one of which is the Houston site. A new facility has been built in Houston to further consolidate the two existing facilities used for support of the Shuttle Operations and the International Space Station. The new facilities will house these operations and focus on two primary tasks: design development and fast track manufacturing. In essence, what Boeing is creating is a high quality Job-Shop tasked with fast track manufacturing of products with "perfect quality, right quantity, right mix, and the ability to identify problems immediately."

1.2. Objectives

My internship with Boeing was very dynamic. There was tremendous change occurring within Boeing simultaneously to the project. Consolidation efforts for the "Five to Three" were consuming significant focus and executive attention. As site focus and site needs continued to evolve and change, the internship project was redirected toward the identification and implementation of an appropriate ERP system for the Houston site. With the multitude of systems in use across Boeing as well as within the Houston Site, internship research turned toward identification of the critical capabilities of such a system for the Houston Site.

In this Thesis I am focusing research on these objectives:

Identify Key Characteristics of a Rapid Response Facility: The internship project established a Boeing project structure and charter with tasks for identifying critical capabilities of a "Business System" for the proposed rapid response design, assembly, integration and test facility. This thesis is used as a means to further investigate the structure of a rapid response facility and what key characteristic must exist to make such a facility successful and is not limited to just the "Business System" aspect.

Business Systems Review: Some time will be spent reviewing aspects of business systems available to aid in the creation and operation of a rapid response manufacturing facility.

Organizational Processes: With the recent acquisitions, organizational processes significantly impact Boeing's operations and functional interactions. This is evident in the extensive business systems they have as well as the processes and steps associated with cross-functional and cross project interaction. Some time will be spent investigating Boeing's existing structure as well as providing organizational structure elements required to attain a rapid response design assembly integration and test facility.

1.3. Approach

The analysis of creating a rapid response design, assembly, integration, and test facility was divided into two primary steps: the internship and the thesis.

The internship was a time to submerge myself in the Boeing culture and work hand in hand with Boeing employees on various tasks. This allowed me to experience strategies that worked well and strategies that needed adjustment to create the desired atmosphere. The experience also provided the opportunity to focus on cross-functional team organization for preliminary analysis of the existing business systems and to establish a project team charter that empowered the group to continue business system analysis and implementation.

This thesis is used as a means to document the processes of the internship and to further investigate what is required to create the proposed rapid response facility.

1.4. Methodology

1.4.1. Internship

Initially a substantial amount of time was spent visiting, exploring and observing other Boeing Space and Communications manufacturing facilities. Although manufacturing had been performed at the Houston site, much of the manufacturing was light manufacturing and the processes in use at the site had not been developed to the extent that the processes had been developed at other sites. Visiting the other Boeing facilities provided an opportunity to learn more about Boeing policies and procedures.

Because of the dynamic environment of the Houston site and the consolidation efforts of the International Space Station program and the Shuttle program, my internship focused on business systems required at the Houston site. By traveling to Boeing facilities across the country, I was able to identify common systems and to begin what I saw as the most appropriate system for implementation.

I then formed a Houston based implementation team and steering committee to continue business system investigation and establish an implementation team. Through the process of forming this team and motivating key contributors the varied culture of the Houston site and recent investment in existing business systems presented challenges for the team. To push through those challenges we gained executive support for the project and created a team charter. Executive representatives signed this charter and assets were set aside to continue business system evaluation.

To perform system evaluation, we began process and value stream mapping. This was done to provide a picture of the existing state of the system and how Boeing Houston delivers value to the customer.

1.4.2. Thesis

I am using this thesis as an opportunity to investigate theories and methods used to generate similar "rapid response" facilities in industry. Additionally, the thesis provides the opportunity to perform investigation into tools and methods for looking at an organization and evaluating structures that promote a rapid response environment.

2. INVESTIGATION AND LITERATURE REVIEW

2.1. Rapid Response

Boeing is attempting to create a rapid response facility. But what does rapid response really mean?

According to www.dictionary.com rapid and response are defined as follows:
Rapid: 1: done or occurring in a brief period of time; 2: characterized by speed; moving with or capable of moving with high speed
Response: 1: The act of responding, where responding is defined as: 1: To act in return or in answer.

In essence what Boeing would like to do is to "act in return or in answer" in a "brief period of time" to a customer request. But what should the "act in return" consist of? Through working with the customer, four key customer deliverable requirements can be identified: 1) perfect quality, 2) correct quantity, 3) on time, and 4) within budget.

2.2. Lean Theories

Lean manufacturing is another term for Just In Time manufacturing and is adopted from the Toyota Production System. Even within Toyota, Lean Theories center around the manufacturing environment and are not pervasive throughout all functions of the organization. It is important to keep this in mind as we discuss "Lean".

All activities associated with lean philosophy center around three key concepts: the elimination of waste or "muda", the concept of "Flow", and the implementation of "Pull".

In essence, lean manufacturing is exactly that: lean - consisting of little or no fat! Much like the requirements for a lean human physique, the three concepts above (elimination of muda; flow; and pull) can be equated to cutting junk food from a diet, exercising regularly, and eating only when the body requires food.

Waste in a manufacturing environment can be defined as anything that is not "value adding" to the product for the customer. The Toyota Production System (TPS) has identified seven specific categories of waste: overproduction, inventory or work in process (WIP), transportation, processing, motion, waiting, and defects. By eliminating waste of this type, a company can be more agile. It keeps finances from being tied up in inventory and WIP, is able to adjust to market demands quicker, and prevents margin erosion to maintain profitability.

"Flow" represents the ability of the manufacturing system to maintain a steady "leveled" production in which all operations make the quantity and mix of products demanded by the final customer within a given demand interval. This demand interval is often referred to as the takt time, which is calculated as operation time divided by the product demand for that time. The idea is to balance the flow so that all operations or cells produce at the same cycle time, which is something less than takt time. An analogy often used to describe lean manufacturing is to picture the manufacturing system as a river. Parts and work in process flow through the manufacturing system much like water does through a river. The ideal that lean conceptualizes is the delivery of product (water) to all customers, as smoothly as possible, at the right time and in the right quantity as is required: no more, no less. If too much is in the system the WIP (water) can become a hindrance to operations. To keep costs at a minimum and to ensure that the processes are as efficient as possible the inventory level (water level) is reduced. This reveals process obstacles (rocks), which must be removed to keep flow smooth and predictable. This promotes the idea of continuous improvement, "kaizen".

The end customer ideally performs regulation of manufacturing flow. This is done through the application of a "pull" system. The idea is that information flows in the opposite direction as the manufacturing process so that only what is needed is produced. The goal of this method is to provide the ability to produce exactly to demand and to eliminate speculative production. Often a "Kanban" is used as the means to signal the next pull function in the system. The Kanban system provides a means to allow one process to make only what is required by the next process when it needs it, and thus minimize waste. In essence the Kanban links all manufacturing processes from the final customer back to the raw material.

The idea of smooth flow is very important in lean manufacturing. Many techniques are used to aid in matching production to customer demand. Often work-in-process inventory (WIP) is placed between stations to uncouple the variation of time and motion between two operations. Summing all such WIP in the manufacturing system establishes the standard work in process (SWIP). Lean manufacturing also enlists the use of Hijunka Box's to help level scheduling of the production system to control pace of demand. To provide some flexibility to the system, ranges of demand variation (that a supplier should be able to provide on short notice) are built into the system through the use of flex fences. Flex fences are inventory buffers to accommodate this variation. These techniques enable lean manufacturing to handle some sources of internal and external variation.

In order to attain manufacturing system functional requirements, of high quality and easily identify problem conditions, design parameters such as synchronized production, standard work methods, and Poka-Yoke are put in place. If work is always performed in the same sequence with Poka-Yoke for mistake-proofing, then any variance from the norm is easily identified and can be corrected immediately. Through the use of small lot sizes, waste is kept to a minimum by minimizing rework or scrap if a quality issue is encountered. Small lot sizes also allow for changing customer product mix and demand.

Lean Manufacturing practices suggest there are six functional requirements for efficient facilities: Perfect Quality, Guarantee the Right mix to the customer, Guarantee the Right Quantity to the customer, be able to handle sources of internal and external variation, be able to identify problem conditions immediately and resolve problems in a timely manner, and lastly perform the first five with the least amount of resources.

2.3. Theory of Constraints

Theory of Constraints (TOC) is a method of system improvement through the identification and elimination of bottlenecks. The Theory of constraints was developed by Dr. Eliyahu M. Goldratt and first expressed in his book The Goal. Application of TOC additionally provides a method to deal with uncertainty in project management by emphasizing what needs to be focused on in order to keep a project on track.

The general view that TOC expresses is the importance of looking at the organization as a system instead of independent processes. TOC maintains that the success of the system is contingent on how well the various processes interact. TOC does however recognize "flow" through an organization and the role that processes do play. TOC views a system much like a chain where the processes are linked together to create the system. Like the chain, the organization (system) is only as strong as its weakest link. TOC contends that to improve and grow an organization it must improve as a system. Since a system is like a chain its weakest link or process must be strengthened and improved. This weakest link is known as the "constraint".

In the TOC world there is much discussion about throughput, investment (inventory) and operational expenses. The belief is maintained that the profitability and thus success of an organization is driven by these three constraints. TOC contends that reduction of investment (inventory) and operational expense is bounded by a lower limit of zero. Instead TOC turns its attention to throughput. TOC believes that throughput can be increased infinitely and therefore will have a larger impact on the profitability of an organization.

H. William Dettmer of the University of Southern California summarizes five steps of Theory of Constraints [21]:

> STEP #1: IDENTIFY THE CONSTRAINT. Find the one element of your system which, like the weakest link in a chain, limits the system's ability to perform its function in pursuit of its goal. The Pareto principle says its an 80-20 relationship. But it's probably more like 99-1. There's a variety of ways to find the constraint, whether it's a physical object or a policy. Some very effective methods have been proposed by Dr. Goldratt, but there are others unrelated to TOC that can be used, too.
>
> STEP #2: DECIDE HOW TO EXPLOIT THE CONSTRAINT. Once you've identified the element of the system-- physical or policy-- that's constraining the system's performance, you "exploit" it by deciding how best to wring the maximum performance out of the constraining element as it currently exists (i.e., without major system changes or capital improvements). This is more of a "thinking" step than a "doing" step.
>
> STEP #3: SUBORDINATE EVERYTHING ELSE TO THE DECISION IN STEP #2. Take whatever steps are necessary to synchronize, or align, the performance of all other elements of the system with the "exploited" constraining element. This may mean slowing down "faster" parts and speeding up "slower" ones. This is the "action" step. Step-2 was a "thinking" step. If you're constraint is broken at this point, you go back to Step-1 and start looking for the next constraint (next weakest link in the chain). If not, go on to Step-4.
>
> STEP #4: ELEVATE THE CONSTRAINT. If the constraining element still remains the reason why the system's performance "tops out" AFTER you've completed Step-3, you have to do more. "Elevate" usually meansdoing something to increase the capacity of the constraining element. Obviously, if your constraining element is chugging along at maximum efficiency (which it should be after Steps-2 & 3), the only way to improve overall system performance is to obtain more of the constraining element. In a manufacturing environment, this may mean a capital investment in more equipment, or hiring more people, or perhaps subcontracting out some of your backlog. This step will invariably break the constraint, because it isn't considered completed until the capacity problem of the constraining element is finally eliminated--i.e., the constraint is broken.
>
> STEP #5: GO BACK TO STEP-1, BUT AVOID "INERTIA". This is the "repeat Steps 1-4" step. But the warning about "inertia" is important. It's designed to discourage

complacency, which comes in two flavors: 1) "We've solved THAT problem already; we don't need to re-visit it again", and 2) "The environment doesn't ever change much."

The first of these is related to the interactive nature of systems and how changes to one part inevitably affect some other part. When you go back to work on the second constraint (i.e., the second pass through the five steps), any system change you might make at Steps 3 and 4 are likely to affect your constraint-breaking solution from the first pass. You may have to either adjust the first solution, or-- worst case-- re-visit the first solution entirely.

The second complacency caution relates to the fact that the environment DOES change, and, in so doing, perfectly good solutions can obsolesce naturally. So even if subsequent constraint-breaking efforts don't affect earlier solutions, those solutions will inevitably die of old age anyway-- and need to be re-visited eventually to keep the improvement process ongoing.

By H. William Dettmer
University of Southern California

"A basic principle of the theory of constraints is that the undesirable effects we experience in a field such as project management are usually the result of a manageable number of core problems. If they can be identified they can be directly addressed rather than treating the symptoms." Newbold [6]

Application of TOC to project management is able to identify the core problems by changing the common "critical path" to "critical chain". Critical chain takes into account not only task duration but also incorporates resource management. Briefly critical chain takes the "average" task duration and then uses three different types of buffers to account for any uncertainty: feeding buffers, resource buffers and a project buffer. This use of buffers instead of slack allowance in each task helps to compress the schedule. Also tasks are scheduled as late as possible to still allow for successful completion of the project. Successful application of critical chain allows for management of not just a single project but also multiple projects and Newbold [6] suggests it provides the following benefits to traditional project management:

- Project Lead times are cut significantly, by pooling the "slack" into strategically placed buffers.
- Investment and work–in-process are minimized.
- Project completion dates are secure.

- The need for rescheduling is minimized.
- Task priorities are clear.

2.4. Unique Challenges To Job-Shop Type Operation Procedures

In practice, Job-Shops are typically small manufacturing enterprises (SME's). They are often characterized by manufacturing facilities with fewer than 100 employees, sales revenue under $5 million per year and typically a small customer base. Although this Boeing operation exceeds 100 employees and has better than $5 million in sales revenue through its support functions, they have only one customer. As such Boeing experiences many of the same challenges associated with implementing lean manufacturing principles as small manufacturing facilities (SME) do. Niko H. Prajogo and Robert B. Johnston summarize key JIT components and barriers SME's have in implementing the JIT components in their paper "Barriers to Just-in-Time Implementation in Small Manufacturing Enterprises" (SME). The barriers to implementing the JIT components at the Boeing facility have been incorporated with their work in Table 1.

Table 1: JIT Components and barriers to implementing them

JIT Components	Definition	Barriers to SMEs	Boeing Case
Production Leveling	To produce the same quantity and mix of items every day	Lack of bargaining power with customers	Unknown demand, for unknown product
Pull System	Materials are drawn by the users from the "downstream" stage as needed	Difficulties in implementing cellular manufacturing	No barriers
Good Housekeeping	Workers are encouraged to keep their own work spaces tidy	No barriers	No barriers
Small Lot Production	To produce in small batches and to reduce buffer	Depends on implementation of other components	May require many cellular designs

JIT Components	Definition	Barriers to SMEs	Boeing Case
Setup Time Reduction	To eliminate external setup times and to reduce internal setup times	Limited funds to afford new technology	Possible budget constraints, or space constraints
Total Preventive Maintenance (TPM)	To avoid any breakdown from the outset by maintaining the machinery	Limited resources and funds in conducting training	No barriers
Total Quality Control (TQC)	To make the output right the first time by employing quality at source, line stop and foolproof devices	No barriers except limited funds to develop foolproof devices	No barriers, except limited attention to line/cell since not core business
JIT Purchasing	Comprises of JIT deliveries, information sharing, quality at the suppliers and long-term partnerships	Lack of bargaining power with suppliers	Strong bargaining power with suppliers. Possible issue with quantity of suppliers. How many?
Line Balancing	To adjust the output of a series of cells to the same rate	Depends on whether flexible manufacturing is achieved	Unknown quantity and mix of product / unknown product
Flexible Manufacturing	Facilities and workforce can be rearranged according to customer demand. It comprises Standard Operations, Group Technology and Flexible Workforce	Lack of expertise in simplifying design and lack of resources to form cells	Crucial to accomplish this. Training of resources to new way of thinking
Small Group Improvement Activities (SGIA)	To empower employees to improve the operations.	It is a normal occurrence in SMEs as communication is freely exercised	Differences in existing unit cultures

The primary obstacle in implementation of the above components at Job-Shops centers around scheduling of production. This is an issue that has had significant attention over the past 40 years and has been the topic of many operations research papers. The large product base, low production quantities, variable demand for each product, and limited resources create many challenges for finding an optimal scheduling practice for Job-Shops.

2.4.1. Job-Shop Scheduling

Scheduling is the allocation of shared resources over time to competing activities [1]. In a Job-Shop this is particularly applicable to machine scheduling. Purchasing a separate machine for every process step of every product line is expensive, a waste of factory space, and creates situations where machines stand idle. Although in a quality lean production facility, idle machines may not necessarily be "a bad thing". As long as production is matched to customer demand, it does not make sense to have a separate line for each product. Resource limitations such as limited space and limited budget necessitate the development of alternative solutions.

To date, much Job-Shop scheduling research has centered around optimization programs. The scheduling is optimized around machine utilization time, makespan. Makespan is defined as the time required to complete all the jobs. The optimization programs seek to optimize primarily by minimizing makespan and secondarily by minimizing manufacturing costs. This optimization is performed iteratively and typically goes through two passes for each iteration. One pass is geared toward a global optimization and a second on a local level looking for any immediate improvements in the optimization. For a detailed explanation of these processes see A.M.S. Zalzala and P.J. Fleming, **Genetic Algorithms in Engineering Systems** [1] and S. Binato, W.J. Hery, D.M. Loewenstern, and M.G.C. Resende, **A Grasp for Job-Shop Scheduling** [19].

Anant Singh Jain & Sheik Meeran, **A State of the Art Review of Job-Shop Scheduling Techniques** [9], provides an excellent overview of existing methods for scheduling Job-Shops. The report describes in detail optimization procedures, approximation methods, and a few other miscellaneous methods. Optimization procedures include efficient algorithms, mathematical formulations, as well as branch and bond techniques. Approximation methods encompass Priority Dispatch Rules, Bottleneck Based Heuristics, and Artificial Intelligence (AI). AI is particularly interesting because it is one of the methods that has been strongly influenced by industries outside of manufacturing, to include biology and computer science. This extension into other, seemingly unrelated industries, exemplifies the magnitude and extensive reach of this type of scheduling problem. The two AI methodologies found to be most successful at solving this type of problem are constraint satisfaction approaches and neural network methods. Some of the promising AI methodologies incorporate the ability to perform Local Search Methods and Meta-Heuristics. Problem Space Based Methods such as Search in Problem Space and in Heuristic Space, Greedy Randomized Adaptive Search Procedure, and Comparative Analysis as well as Threshold Algorithms such as Iterative Improvement, Threshold Accepting, Large Step Optimization, Comparative Analysis, Simulated Annealing, and Comparative Analysis top the list of successful methodologies used most frequently in scheduling analysis performed today.

Anant Singh Jain & Sheik Meeran summarize by suggesting that the best results are obtained through the use of Hybrid solutions, in particular ones which incorporate the local search approach. They suggest that future work will include determination of application guidelines, instillation of a more scientific framework for analyzing the hybrids, and that groups working on completely divergent approaches to a problem can and should have cross input; "Thereby constructing an environment that encourages the congregation of diverse ideas and the creation of new concepts."

2.4.2. Job-Shop Scheduling and Lean Manufacturing

From a manufacturing system perspective, the methods for solving the scheduling problem become very interesting. "Current market trends such as consumer demand for variety, shorter product life cycles and competitive pressure to reduce costs have resulted in the need for zero inventory systems. However, to maintain market share, the system must be fast responding which implies that more stock has to be maintained. These conflicting requirements demand efficient, effective and accurate scheduling which is complex in all but the simplest production environments. As a result there is a great need for good scheduling algorithms and heuristics. Scheduling is essentially concerned with solving a Constraint Optimization Problem (COP) and in the context of manufacturing it involves finding a sequential allocation of competing resources that optimizes a particular objective function" [8].

The question which must be asked when viewing the scheduling problem from a lean manufacturing perspective is: Are we optimizing for the correct aspect? All of the methods discussed base their decision on makespan with some emphasis on cost. Finding this optimum point may in fact provide the lowest cost solution or the optimal use of resources, but does it meet the criteria for a Lean Manufacturing system? To analyze this lets look at the following six functional requirements: Perfect Quality, Guarantee the Right Mix to the customer, Guarantee the Right Quantity to the customer, Be able to handle sources of internal and external variation, Be able to identify problem conditions immediately and resolve problems in a timely manner, and lastly Perform the first five with the least amount of resources.

2.4.3. Perfect Quality

Perfect quality would be difficult to attain using many of the scheduling techniques discussed above. In particular, since the scheduling systems above optimize makespan, the parts could be sitting in a queue or waiting long periods of time before they are processed. If a quality issue is detected it may be difficult to track when and on what machine that error occurred. This would eliminate the ability to apply Kaizen to the machine or process that is generating poor quality.

2.4.4. Guarantee the Right Mix and Quantity to the Customer

By scheduling jobs so that operations are squeezed into timeslots so as to minimize makespan, there is no guarantee that at the end of the day the correct quantity has been produced. In order to attempt to meet the right quantity, an optimization would have to be run each and every morning based on the daily requirement. These optimizations are time consuming and tedious to perform, often requiring much manipulation for specific tasks.

There is no good way to identify if the correct quantity is being produced. With these methods of scheduling, quantity and mix attainment can only be determined at the end of the demand period that was optimized. For example, if the Job-Shop needed to manufacture 20 green Lego systems, 15 red Lego systems, and 5 blue Lego systems in one day, they would not see complete systems gradually accumulating in shipping or unfilled kanbans, but rather a bunch of partially completed Lego systems throughout the facility, with blind faith that, if the optimization was performed correctly, and if there was no internal or external variation, then at the end of the day they would be successful in meeting mix and quantity. To have a better understanding of where they stand in meeting demand, Job-Shops could further reduce the optimized demand period, but at some point this becomes futile because it will eventually break down to individual operating times, the very metric used in the scheduling optimization.

2.4.5. Handle Sources of Internal and External Variation

Internal and external variation would be devastating to this perfectly constructed method of scheduling. Although problem conditions would be forced to be corrected, in order to maintain the schedule, there is no buffer planned into the scheduling process to accommodate such variation. To do so would require processing time modifications for each operation. By adjusting every operating time, the results obtained from scheduling optimizations would be biased and may not truly reflect the best schedule. Once the schedule has been set there is no flexibility in the system. The manufacturing system must follow the settings and is unable to adjust quickly, in terms of range and time, to external and internal changes.

2.4.6. Easily Identify Problem Conditions

Although problem conditions will be identified, they certainly will not be easy to identify. There are so many parts in so many different stages of the manufacturing process it is impossible to look at the floor and see where the daily manufacturing stands. It is not easy to identify if the correct quantity or mix of product is being created and this will not be known until the end of the makespan period maximized. Without a detailed schedule and a method for tracking each part, identifying correct quantity and mix is impossible to do in this type of scheduling scenario. Implementing a complex computer system would just intensify the challenges, intimidate workers and waste monitory resources. The system should be able to operate smoothly, on its own, without the implementation of complex computer simulations and tracking systems. It is however important to note that for geographically disperse manufacturing facilities, where the "entire" manufacturing floor can not be observed at once, a "Business System" may add significant value.

2.4.7. Perform First Five Functional Requirements with the Least Amount of Resources

This is the one functional requirement that the current methodologies come closest to fulfilling. By minimizing makespan these scheduling techniques are minimizing the resources used. However, they do not meet the requirement that this practice be done while still meeting the first five functional requirements. As such the current scheduling methodologies fail to meet this functional requirement as well.

2.4.8. Summary

The existing methods of Job-Shop scheduling do not meet lean principles. The mere method of moving parts around and having them wait at machines creates tremendous waste in the forms of inventory waste, transportation waste, and motion waste. In addition there is no way to guarantee that parts are manufactured only when they are needed and in the quantities they are needed.

With the creation of their new manufacturing facility, Boeing must face these issues. Boeing has added complexity from two sources: First, they may also have to perform R&D on a product before attempting to add it to the manufacturing system; and Second, many of the products are one of a kind. Only one will ever be produced and many of the operation times are guesses at best. Developing a lean scheduling methodology and integrating its implementation with manufacturing system design will tremendously improve Boeing's service level while reducing its operation costs.

2.5. Facility Evaluation Methods

2.5.1. Manufacturing System Design Decomposition

Manufacturing System Design Decomposition (MSDD) is a unique combination of Axiomatic Design and Lean Manufacturing Theory fused together to provide a means to clearly define objectives or Functional Requirements (FR) and the corresponding physical implementation or Design Parameters (DP) of manufacturing systems [12]. The MSDD is particularly suitable for medium to high volume repetitive manufacturing and specifically useful for [13]:

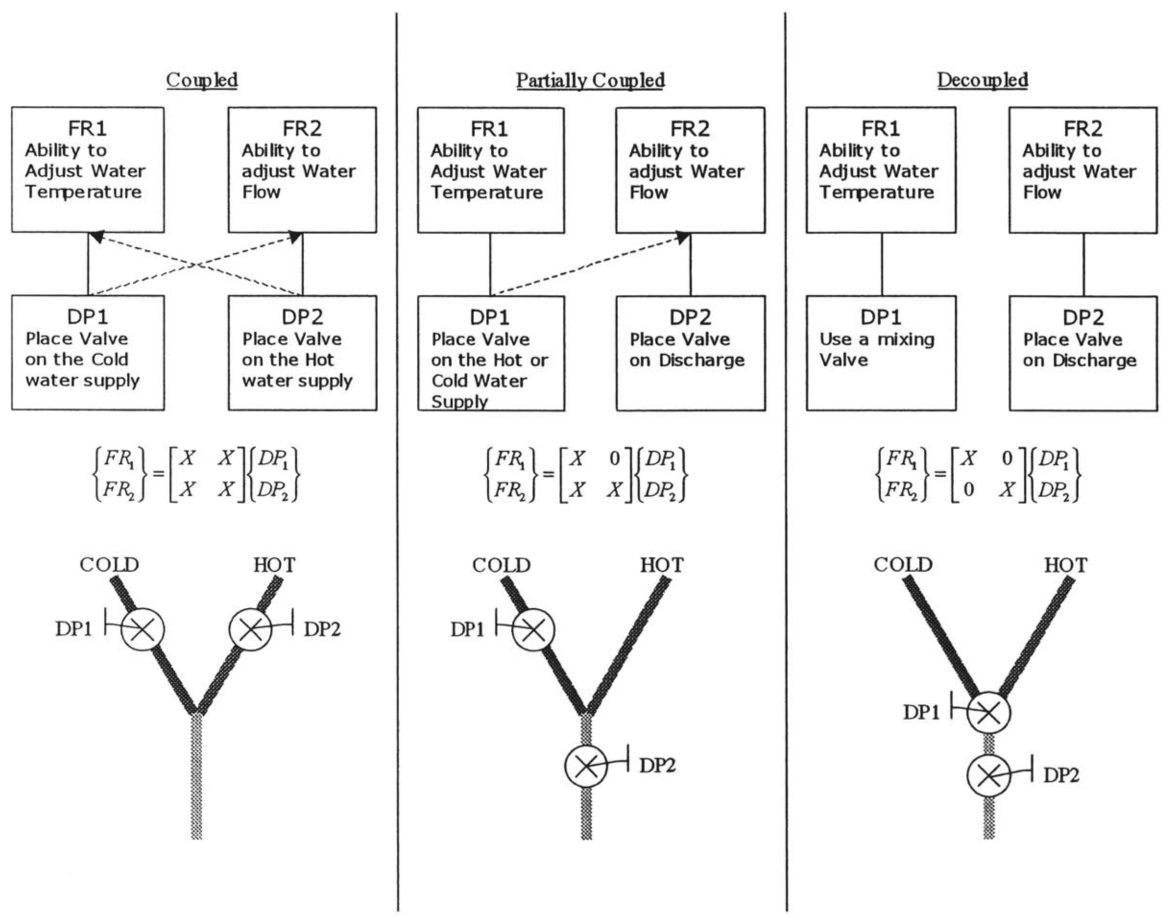
1. Understanding the relationships between high level system objectives (increasing customer satisfaction, reducing system throughput time, etc.) and lower-level design decisions (equipment design and selection, system layout, etc.)

2. Understanding the interrelations, precedence, and dependencies among various elements of system design that determine its ability to meet high-level requirements and objectives.

The axiomatic design approach calls for independence of the solution (DP) to only its related objective (FR). The importance and benefit of the "Independence Axiom" is not immediately obvious. To aid in understanding lets look at an example.

Suppose a plumber is tasked with the job of installing a valve assembly that will be used in a thermal process where water temperature (FR1) and water flow (FR2) are critical to the process. What should the system design look like? Figure 1 depicts three plausible solutions: a coupled solution, a partially coupled solution and a decoupled solution.

Figure 1: Independence Axiom Example



The "Coupled" solution suggests placing a valve on the cold water (DP1) and a valve on the hot water (DP2). Clearly this solution will allow for accomplishment of the objectives (FR1 and FR2). The problem is that as either valve is adjusted it affects both water temperature and water flow. Adjusting to attain the temperature and flow required for the process would be a tedious iteration of multiple adjustments. Clearly this is not the best solution.

The "Partially Coupled" solution takes one step closer to independence. The solution suggests placing a valve on either the hot or cold water supply (DP1), and a valve on the discharge (DP2). In this case DP1 is still capable of adjusting for both temperature and flow. DP2 on the other hand is only capable of adjusting flow. Thus one dependency has been removed. In order to adjust temperature and flow of the system a logical order is defined by the decomposition. A partially coupled solution is also said to be "path dependent". That is that the solutions must be implemented in a given order. In this case DP1 and then DP2. The design matrix of Equation 1 presents the path dependence.

Equation 1: Design Matrix for Valve System 2

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ X & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix}$$

If there are off diagonal entries and they can be arranged into a triangle, the design is partially coupled. By looking at the matrix the path dependence is easily identifiable. The matrix is arranged such that the DP that influences the most FR's is on the left hand side of the matrix. The first solution to implement, the DP that influences the most FR's, is the one at the top left of the triangle and then work down the triangle. In this case DP1 and then DP2. Thinking about the valve system, this sequence makes sense. As DP1 is adjusted the temperature (FR1) and the flow (FR2) are adjusted. Then to fine-tune the flow DP2 is adjusted. If DP2 were done first then once DP1 was adjusted DP2 would need to be tweaked again. The process flow is thus determined. In addition to arranging the design matrix in this manner the FR-DP pairs are arranged from left to right in the same manner. This makes the implementation flow of the decomposition easily identifiable.

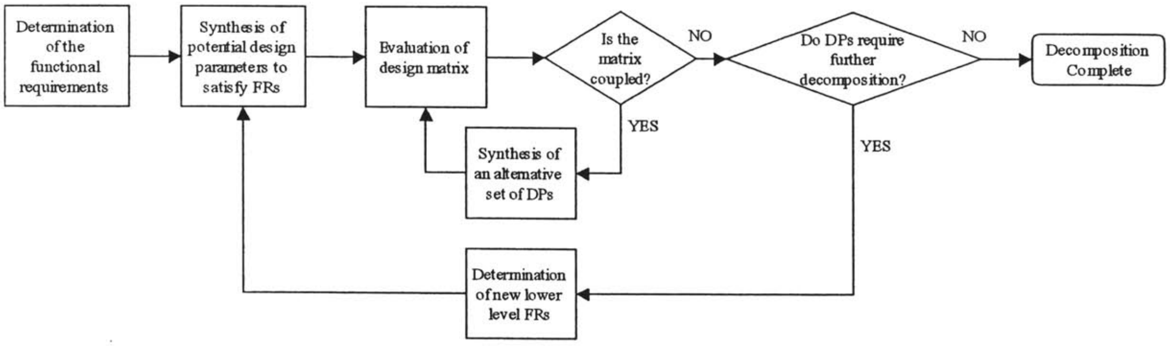
The "Decoupled" solution suggests keeping the valve on the discharge (DP2) for flow control (FR2) and utilizing a mixing valve (DP1) to control temperature (FR2). With a decoupled arrangement of this type, achievement of the FR's is easily attained. Any DR can be implemented in any order. The solution is not path dependent. If temperature needs to be adjusted DP1 can be adjusted. Similarly if flow needs to be adjusted DP2 can be implemented.

The above example emphasizes the importance of the "Independence Axiom". The solution can be more easily implemented by decoupling the solutions and having just one DP influence just one FR. It minimizes system complexity, and solutions (DPs) can now be tracked with performance measures. Without this independence, measuring an FR and determining why it was not met would be extremely difficult if not impossible.

Implementing all of the fully decomposed FR-DP pairs may have cost benefit tradeoffs. Since the FR-DP pairs have been decoupled a choice can be made on which ones to implement and when. By decupling the solutions the implementation of one does not necessitate the implementation of another.

To attain the final solution, FR-DP pairs are decomposed to the maximum extent possible without limiting the usefulness or range of applicability. This is done by following the Axiomatic Design Process for Decomposition, Figure 2.

Figure 2: Overall Axiomatic Design Decomposition Process [13]



The Manufacturing System Design Decomposition is a novel way of looking at manufacturing system design. Cochran [12] proposes seven benefits to using the MSDD:

- Ability to concretely describe and distinguish between various production system design concepts

- Adaptability to different products and manufacturing environments

- Ability to design or create new system designs to meet new requirements (e.g. to determine a new design when the FRs or DPs change)

- Portability of a production System Design Methodology across industries (e.g. auto to aircraft to food)

- Indicates the impact of lower-level design decisions on total system performance

- Provides the foundation for developing a new set of manufacturing performance measures from a system-design perspective

- Makes the connection between machine design requirements and system objectives

To begin the decomposition, Cochran chose a Functional Requirement that would be portable across industries and yet still provide a logical starting point for the decomposition. Cochran begins his decomposition from the point of view of the owners and shareholders of the company. He presumes that manufacturing facilities are in business to make money and chooses ROI as his high level FR. As he continues through the decomposition, the views of other stakeholders are incorporated.

The decomposition results in a matrix of sorts that identifies six key categories of interest: Quality, Identification and Resolution of Problems, Predictable Output, Delay Reduction, Operational Costs, and Investment. A complete decomposition can be found in Section 7.1 on page 132 of this document. For a detailed description of the each FR DP pair please see Cochran 2000, "**A Decomposition Approach for Manufacturing System Design**" [13].

2.5.2. Lean Aerospace Initiative and the Lean Enterprise Self Assessment Tool

The Massachusetts Institute of Technology (MIT) and the Warwick Manufacturing Group of the University of Warwick, under the guidance of the U.K. and U.S. Lean Aerospace Initiatives, created the Lean Enterprise Self Assessment Tool (LESAT). The goal of the LESAT is to create a method to evaluate the current state of an aerospace enterprise and provide a roadmap for transitioning to a future system state of lean aerospace as defined by the Lean Aerospace Initiative (LAI). LAI recognized that LEAN was not a tool that could only be applied to the manufacturing floor, but was also a strategy that an enterprise could use to run its business. The LESAT is geared at the enterprise level and has identified the following evaluation structure [16]:

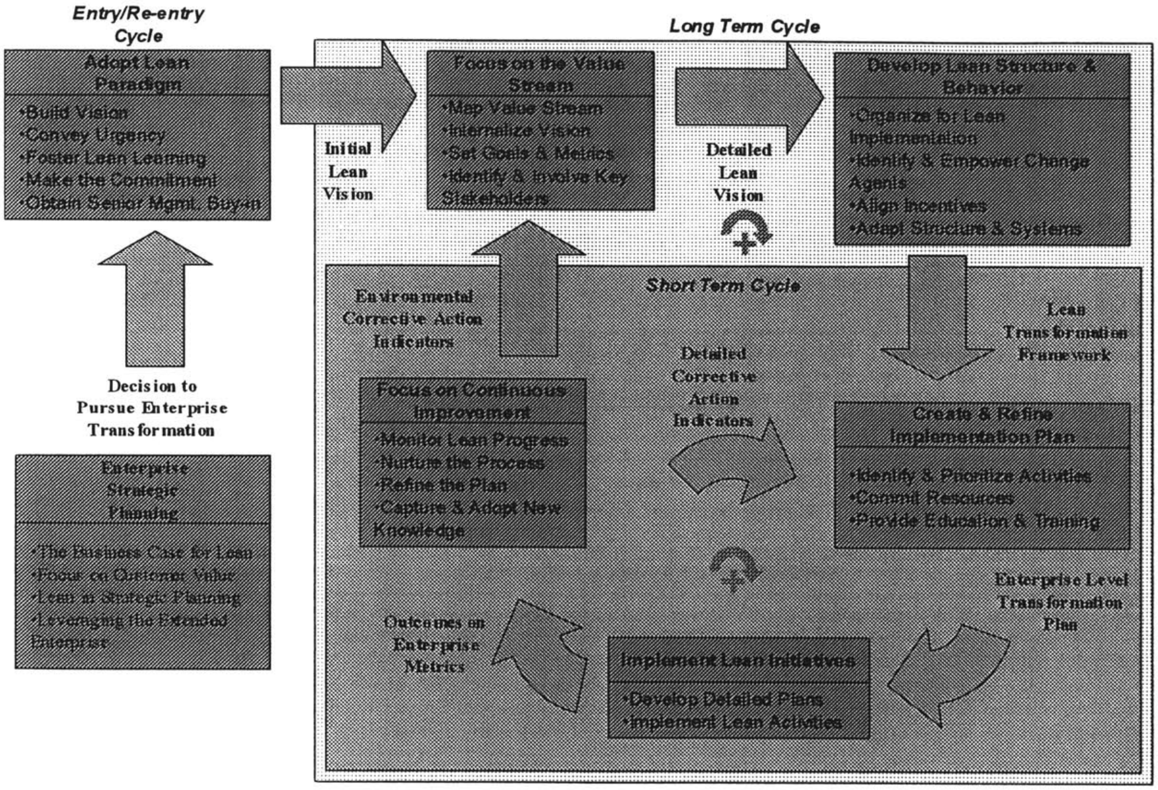
<u>Section I – Lean Transformation/Leadership</u>
I.A Enterprise Strategic Planning (3 Lean practices)
I.B Adopt Lean Paradigm (4 Lean practices)
I.C Focus on the Value Stream (4 Lean practices)
I.D Develop Lean Structure and Behavior (7 Lean practices)
I.E Create and Refine Transformation Plan (3 Lean practices)
I.F Implement Lean Initiatives (2 Lean practices)
I.G Focus on Continuous Improvement (5 Lean practices)

<u>Section II – Life-Cycle Processes</u>
II.A Business Acquisition and Program Management (4 Lean practices)
II.B Requirements Definition (2 Lean practices)
II.C Develop Product and Process (3 Lean practices)
II.D Manage Supply Chain (3 Lean practices)
II.E Produce Product (2 Lean practice)
II.F Distribute and Service Product (4 Lean practices)

<u>Section III – Enabling Infrastructure</u>
III.A Lean Organizational Enablers (5 Lean Practices)
III.B Lean Process Enablers (3 Lean Practices)

The LESAT structure guides company lean evaluators through pointed questions that help them to assess the current and desired state of their organization. By doing so the evaluator is provided some guidance on what things in the organization need to be adjusted in order to become lean. Unlike the MSDD discussed in Section 2.5.1, the LESAT does not directly provide the physical implementation or Design Parameters to attain lean. The LAI team created a roadmap (Figure 3) to guide an enterprises transition to lean (TTL).

Figure 3: The Lean Aerospace Initiative's Transition to Lean Roadmap © 2001 Massachusetts Institute of Technology



As suggested in the TTL Roadmap (Figure 3), support of enterprise executives is critical. Lean is not a set of tools or procedures that can just be implemented and success guaranteed. A conscious decision must be made at a corporate level that Lean implementation is going to be a strategic direction.

The LESAT does an excellent job of presenting observed functional requirements of a complete lean enterprise. As with all lean activities the LESAT is a work in progress. The Roadmap allows for iteration through its three cycles: entry, long term and short term. These cycles have been designed into the roadmap to allow for revision of not just corporate implementation but also to further develop the roadmap as more aerospace companies become successful at implementing lean across their organization.

2.5.3. Process Mapping

Process mapping is the method of defining inputs and outputs of a task and how multiple tasks chain together to meet a specific need. It provides the "big picture" of the organization, explaining how processes are organized and fit together. Documenting a process provides an initial baseline toward standardization and incremental improvement of that process and the processes that are required to create value or tasks which are necessary to support the creation of value. Each process definition should have a clearly defined objective stating the overall purpose of the process, what is being done, where it is being done, and how it is being done.

Process mapping creates a visual cue that an inexperienced worker can reference to support their activities. It also ensures standardization and consistency of the processes. This will aid in quality assurance and identification of problem situations. As the process is consistently used, problems will be highlighted and incremental improvement in the processes can be made. Additionally process mapping allows for mapping of processes that may cross-functional barriers. None of these benefits can be reaped until a process map has been created.

There is no industry standard for what a process map looks like. There are many commercially available software programs to aid in the creation of a map. Standard word processing or graphical programs readily available on most computers work well. A visual layout approach is typically the best way to display a process and is the easiest to understand. The idea is to just get the processes documented.

The structure of a process map first entails the identification of major processes, which should be kept at a fairly high level. Sub-processes can than be drilled down deeper to identify activities associated with these processes. Much iteration may be required to map the processes and activities into the most efficient model.

A process map should be identified for the current state as well as a future state map. Comparing the current and future state maps will highlight processes that need improvement or elimination. While performing the process mapping and comparison, many questions should be asked about specific processes, including:

- Is the process necessary?
- Why is it done this way?
- Who does it? Who should do it?
- Is there a better way?
- When is it done? Should it be done at a different time? Using another space?

2.5.4. Value Stream Mapping

Much like process mapping, Value Stream Mapping is a method of tracking how an organization creates value. Unlike process mapping, Value Stream Mapping focuses its efforts on two main processes: (1) the production flow from raw material into the arms of the customer and (2) the design flow from concept to launch [4]. This mapping provides a view of value creation and a means to identify potential points of waste. Process mapping focuses its efforts on the entire enterprise and all functions to include accounting.

A Value Stream Map shows both information and material flow. It also shows all of the operations to include their cycle times, change over times, uptime, available processing time, number of workers and other pertinent processing information.

Standard symbols are used to represent various processes. One benefit of value stream mapping is that it allows a person educated in value stream mapping to immediately understand the system.

Rother and Shook (1999) "Learning to See" [4] identifies several reasons why value stream mapping is so valuable:

- It helps you visualize more than just the single-process level in production. You can see the flow.
- It helps you see more than waste. Mapping helps you see the sources of waste in your value stream.
- It provides a common language for talking about manufacturing processes.
- It makes decisions about the flow apparent, so you can discuss them. Otherwise, many details and decisions on your shop floor just happen by default.
- It ties together lean concepts and techniques, which help you avoid "cherry picking."
- It forms the basis of an implementation plan. By helping you design how the whole door-to-door flow should operate – a missing piece in so many lean efforts – value stream maps become a blueprint for lean implementation. Imagine trying to build a house without a blueprint!
- It shows the linkage between the information flow and the material flow. No other tool does this.
- It is much more useful than quantitative tools and layout diagrams that produce a tally of non-value-added steps, lead time, distance traveled, the amount of inventory, and so on. Value stream mapping is a qualitative tool by which you describe in detail how your facility should operate in order to create flow. Numbers are good for creating a sense of urgency or as before/after measures. Value stream mapping is good for describing what you are actually going to do to affect those numbers.

2.6. Business Systems

In today's fast paced competitive world every advantage that a company can gain must be taken. The technology age has brought with it new tools for management. One of the most notable has been the amazing computing power of the desktop computer. As computers and servers have become more powerful and less expensive, software management tools have been evolved and implemented. In this section, I will discuss the history and major components of these business systems.

2.6.1. History

In the 1960's manufacturing systems were beginning to use computers for inventory control. These software packages, run on mainframe computers, used traditional inventory control calculations. As computing power became less expensive and more refined, so did the software tools. Joseph Orlicky from IBM performed substantial research on this subject and publicized a collection of his notes in the 1970's. As a result he is generally credited for the development of MRP systems. MRP stands for Material Requirements Planning and was the next step improvement over order point quantity methods such as the base stock method or the economic order quantity. Its application was geared to make materials management easier through electronic control of bill of material data, inventory data, and master production schedule information. MRP took this information and built time-phased net requirements for the sub-assemblies, components, and raw materials planning for the end product. Table 2 [20] shows typical inputs required of an MRP system and the resultant information obtained from those inputs.

Table 2: Inputs and Outputs of MRP

Information Needed for MRP	Information Obtained from MRP
• Demand for all products.	• Planned orders: replenishment orders to be released at a future time.
• Lead times for all finished goods, components, parts and raw materials.	• Order release notice: notices to release planned orders.
• Lot sizing policies for all parts.	• Action notices: notices to expedite, de-expedite, or cancel orders, or to change order quantities or due dates.
• Opening inventory levels.	• Priority reports: information regarding which orders should be given priority.
• Safety stock requirements.	• Inventory status information Performance reports such as inactive items, actual lead times, late orders, etc.
• Any orders previously placed but which haven't arrived yet.	

The MRP system was a good improvement over the old methods but it still had two major flaws: 1) it assumed infinite capacity, and 2) it assumed fixed lead times. Material Resource Planning (MRPII) evolved in the 1980's and clamed to fix the infinite capacity problem by providing interpolation to adjust for capacity. This feedback mechanism became know as Capacity Requirements Planning (CRP). To make the capacity calculations CRP needs additional information such as setup time, resource requirements, and labor requirements. In addition to this feedback loop in the 1990's MRPII extended capabilities to other areas like shop floor control, engineering, marketing, purchasing, finance, human resources, and project management. In essence MRP is designed to determine what is required to meet the projected demand as provided by the master production schedule. For this reason MRP is often looked at as a push system. A push flow is the process of material and product being forced through the manufacturing system. This is opposite from the "pull" flow discussed in Section 2.2.

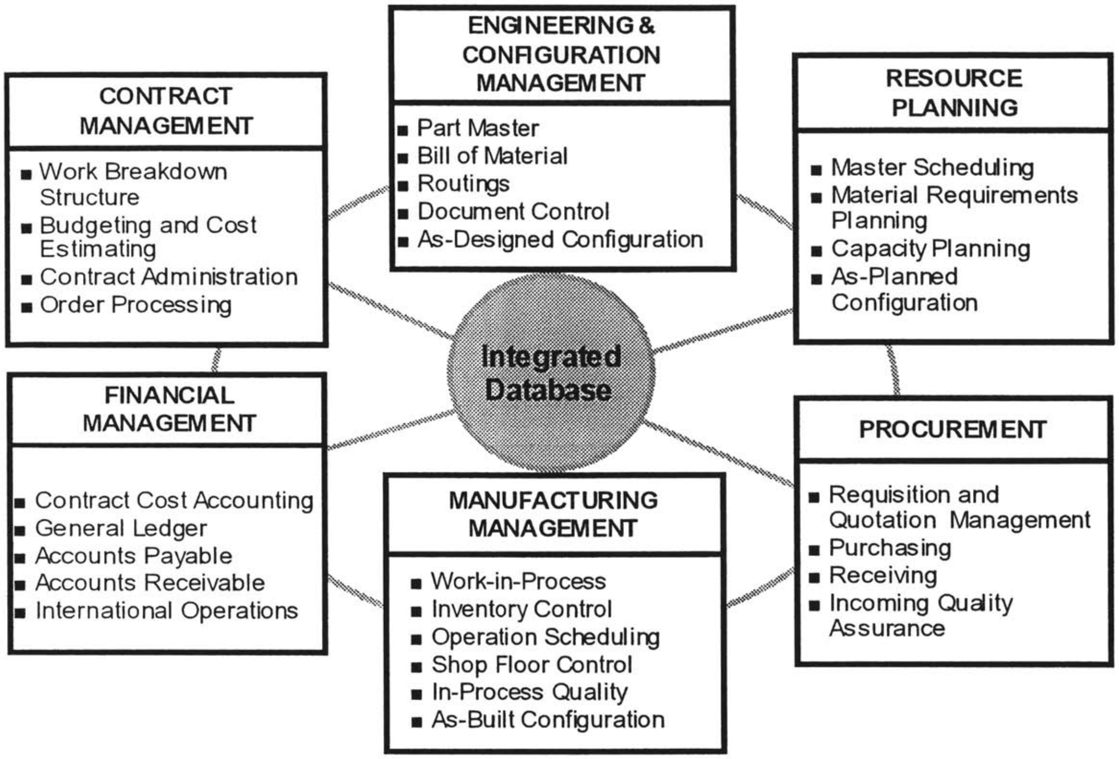
As the MRPII continued to incorporate functional capabilities it became known as Enterprise Resource Planning (ERP). ERP has also been given the unique challenge of combining and managing the principals of global supply chain management.

2.6.2. Enterprise Resource Planning

In growing companies and in large corporations three of the greatest difficulties are in the acquiring of accurate data, timely information and the communication barriers between functional organizations. Enterprise Resource Planning (ERP), a derivative of MRP and MRPII, is touted as the solution to these challenges. It is intended to aid in the management of the enterprise by providing a common informational database for the distribution and sharing of information for critical management decisions. Figure 4 graphically depicts many of the components of an ERP system[1].

[1] Figure 4 was extracted from a WDS *Compass*CONTRACT® presentation and slightly modified. Western Data Systems (WDS) is a major provider of ERP Systems. http://www.westdata.com/

Figure 4: ERP Components



2.6.3. Manufacturing Execution Systems

The Manufacturing Execution System (MES) is an extension of MRP and ERP systems. At times the standard shop floor control provided by ERP and MRP does not get as detailed as some organizations would like. MRP was developed primarily for scheduling but not necessarily for detailed work instructions. As John Buell and Janet Gould put it "... an ERP system is good for some things, getting a bird's-eye view into the shop floor wasn't one of them" [15]. The problem was that ERP did not provide real time information from the shop floor. It was really only good for recording information.

An MES is designed to get into the details on the shop floor. It takes work orders generated by the MRP system and creates detailed work instructions. It includes shop floor specifics such as labor and machine tracking, routing, and quality. MES systems often have the capability to generate paperless work instructions to operators and provide them the ability to link directly to detailed drawings, specifications, images, assembly videos, tool descriptions, and the ability for data collection as the job is executed. MES systems were created for one additional task, to help transition the MRP system from that of a "push" design to more of a "pull" design. MES's added flexibility and instantaneous information from the shop floor almost make it a must for make-to-order manufacturing facilities.

One such software package is created by SOLUMINA®. SOLUMINA® supports three major manufacturing requirements [23]:

> **Process Engineering and Planning:** Enables the creation and maintenance of detailed on-line work instructions for building a product. Work instructions can contain text, tool lists, part lists, buyoffs, data collections, and links to objects such as CAD drawings, images, and videos. Inspection points and manufacturing buyoffs can be authored into work instructions at critical points in the manufacturing process. The real-time update of these work instructions reduces errors and controls the configuration of products, even with the changing engineering requirements.
>
> **Process Execution:** Provides graphical assignment of resources, material and part data, collection of data, and paperless work instructions for shop floor personnel.
>
> **Process Quality:** Provides a mechanism for quality assurance and manufacturing personnel to control and monitor the quality of products produced. Discrepancies can be initiated, evaluated and dispositioned when non-conforming products are identified. Corrective action can also identify and eliminate the causes of non-conforming product in support of ISO9000 standards.

2.6.4. Project Data Management

Project Data Management (PDM) is a software tool that is used to manage the design and development of products through the management of master part items. PDM's are capable of creating part items and managing the relationships between them and the product structure. This software is particularly useful in concurrent engineering environments. Designers with access to the PDM are able to share the latest revised drawings since they and their associated detailed information reside on the same database. The revised drawing is maintained along with the original data so that modifications can be tracked and dated. Through the use of a relational database the PDM is capable of managing attribute and product data such as size, weight, where used, etc. and the relationship between them. In essence PDM systems perform three main functions [22]:

1. They manage what happens to the data when someone works on it. ('Work Management'.)
2. They manage the flow of data between people. ('Workflow Management'.)
3. They keep track of all the events and movements that happen in functions 1 and 2 during the history of a project. ('Work History Management'.)

As an engineer works through the design of a product, they need to access many forms of information and literature. The PDM provides a medium through which this information can be stored, managed and shared with the development team.

The **PDM Information Center** [22] suggests that Project Data Management software provides the following benefits:

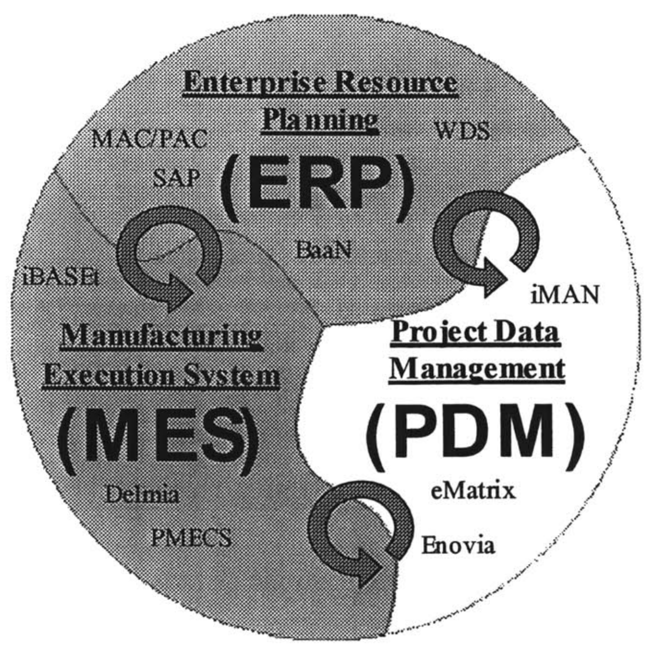
- **Reduced Time-to-Market of Products:** Speed tasks, concurrent task management, and less time spent searching for information.
- **Improved Design Productivity of Engineers:** Access ability of design tools, ease of part design reuse, and information in one location.
- **Improved Design and Manufacturing Accuracy:** All team members use the same data which is always up to date.
- **Better Use of Creative Team Skills:** Provides media for data sharing and collaboration.
- **Data Integrity Safeguarded**: Single central storage location.

- **Better Control of Projects** through tools such as: defined product structure, change management, configuration control, traceability, automatic data release and electronic sign-off procedures.
- **Better Management of Engineering Change:** ability to create and maintain multiple designs and revisions with time & date stamped signoffs.

2.6.5. Prevalent Architecture

I have provided a brief overview of the three major components of today's manufacturing companies' business systems. Each system provides very specific tasks and interestingly each system overlaps into the other systems domain. Each system provides some but not all of the capabilities of the others so they must be linked together. Figure 5 depicts a representation of how this might be conceived along with just a few of the developers of each package.

Figure 5: Prevalent Business System Architecture



2.6.6. Virtual Manufacturing Systems

As computing power continues to improve and relational databases become stronger the ability to virtually manufacture products is becoming a reality. Rather than designing an impossible to manufacture part or an exceedingly difficult to assemble product, the assembly process can be stepped through virtually. Additionally, in a Job-Shop environment like Houston where floor space is limited, hardware positioning and movement within the factory can be performed virtually to prove the validity of lift procedures and hardware positioning. The use of Virtual Manufacturing provides the following benefits:

- Validates Design Before Commitment (Producibility)
- Validates & Assures Safe Manufacturing Practices
- Avoids Costly Reworks/Identifies Potential Assembly Anomalies
- Validates Manufacturing Sequences & Tooling Concepts
- Validates Serviceability & Operation (Ergonomics)
- Provides Illustrative & Simulation Enhanced Work Instructions
- Enables Optimization of Factory Resources
- Reduces Prototypes & Physical Training Aids
- Reduces Cycle Time/Avoids Redundant Analysis (Mfg-Eng, Planner, Technician)

For lower cost repetitive product manufacturing, the benefits of virtual manufacturing may not be as significant over the entire product life cycle. However, in one-of-a-kind manufacturing or made-to-order it becomes invaluable. Having the ability to run through all the possible configurations and assembly procedures virtually and then being able to correct the design or process saves resources.

2.7. Five Major Organizational Archetypes

In the old business world there were limited organizational structures. Structure was modeled from the military and a bureaucratic structure was ramped. In today's world structures need to adjust to be more effective, but what works? A partial answer to this question can be found by looking at new ventures to see what structures succeed and which fail. A study of 172 Silicon Valley high technology start-ups, conducted by M. Diane Burton, Michael T. Hannan and James N. Baron (Stanford Graduate School of Business) as part of the ***Stanford Project on Emerging Companies***, generated results suggested that a major contributor to continued success was the appropriate structure of the organization.

The organization model is a construct for thinking about how the functions of people, organizational culture and the formal organizational structure and procedures interact and support the firm's critical tasks necessary to accomplish their strategy and align with the strategy going forward.

The study found that there are five major models that describe the organization. The five different organizational models are provided below:

- The Star model;
- The Engineering model;
- The High Commitment model;
- The Bureaucratic model; and
- The Autocratic model;

One way of thinking about each of these organizational models is to look at their differences along various dimensions. The models differ by the basis of employee attachment and retention, the criteria for selecting employees, and the means of managerial control and coordination. Each of these dimensions can be described further by providing additional attributes in the form of questions, such as:

Employee Attachment and Retention

- To what degree does compensation (money) attract and retain employees in each of these models?
- To what degree does the quality and type of work (work) attract and retain employees?
- Does the work group as a community (love) influence how employees are attracted and retained?

Employee Selection

- To what degree are the skills (skill) of an employee requisite for a hiring decision?
- How much does employee talent and potential (potential) enter into a hiring decision?
- How much is an employee evaluated on their fit (fit) with the team or organization?

Control and Coordination

- How much direct monitoring (direct) is conducted?
- How much peer or cultural/social control (culture) exists in the organization?
- To what degree does the organization rely upon professional standards (professional)?
- Do formal processes and procedures (formal) act as a control and coordination mechanism, if so to what extent?

The following table summarizes the findings of a study conducted of hundreds of high-technology firms in and around the Silicon Valley area. The research effort concentrated on much more than we highlight here; however, a good summary of the differences in organizational dimensions for the five organizational models is presented.

Table 3: SPEC Research Analysis Findings

	Organizational Dimensions		
Model Type	**Attachment**	**Selection**	**Control**
Star model	Work	Potential	Professional
Engineering model	Work	Skill	Cultural
Commitment model	Love	Fit	Cultural
Bureaucratic model	Work	Skill	Formal
Autocratic model	Money	Skill	Fit

2.7.1. The Star Model

In the Star organizational model employees are attracted to the challenging work. The firms select "stars" from elite sources and exhibit professional control through standards of behavior, almost always through socially informal means. Star organizations can be quoted as saying:

We recruit only top talent, pay them top wages, and give them the resources and autonomy they need to do their job.

Scientists like autonomy and independence. I value it myself and it's important to make sure that they have that. They feel the environment is exciting and that the leadership is there to provide the kind of place where their career is constantly renewing and growing. This essentially is most of my work-- to see that they reach their maximum potential to grow.

Some examples of Star organizations include:

- Apple Computer Corporation
- Microsoft

2.7.2. The Commitment Model

In the Commitment organizational model, employees are attracted to the people or culture of the organization. The firm selects employees that fit with that culture. High commitment firms accomplish control through peer and social control via the culture. Like the Star model these controls are informal. Commitment organizations can be quoted as saying:

I wanted to build the kind of company where people would only leave when they retire.

I think people should be treated as human beings, as real people. And really care for them. We are still pretty much like family. We try to keep as much of that as possible even as the company is bigger. That's one thing I learned from HP [Hewlett-Packard]. Bill Hewlett still flipped hamburgers for us at the company picnic.

Some examples of Commitment organizations include:

- Hewlett-Packard Corporation
- IBM (in the 1970s and early 1980s)

2.7.3. The Engineering Model

In the Engineering organizational model, employees are attracted to the challenging work. The firm selects employees with specific current competencies. High commitment firms accomplish control through peer and social control via the culture. Like the Commitment model these controls are informal. Engineering model organizations can be quoted as saying:

We were very committed. It was a skunk-works mentality and the binding energy was very high.

We wanted to assemble teams of people who are turned on by difficult problems. The emphasis was to build an environment of individuals who are performance driven, achievement oriented, customer focused, feel relatively at ease to join and disband from specific teams, skilled at interdisciplinary problem solving irrespective of culture or discipline.

Some examples of Engineering organizations include:

- Sun Microsystems, Inc.
- Numerous high-technology startups in Silicon Valley

2.7.4. The Bureaucratic Model

In the Bureaucratic organizational model, employees are attracted to the challenging work. The firm selects employees with specific current competencies. Bureaucratic firms accomplish control and coordination through formal procedures. Bureaucratic organizations can be quoted as saying:

We're not hierarchical as much as we are procedures, methodologies, and systems. I really try to see that everybody in the company maintains procedures rather than just hand wave and do things any way. We don't want to be so hierarchical as to be startling, nor do we want to be so flat as to have everybody poking into everybody else's business.

We make sure things are documented, have job descriptions for people, project descriptions, and pretty rigorous project management techniques.

Some examples of Bureaucratic organizations include:

- Disney Corporation
- The U.S. Army

2.7.5. The Autocratic Model

In the Autocratic organizational model employees are attracted to compensation (money). The firm selects employees with specific current competencies. Autocratic firms accomplish control and coordination through direct monitoring. Autocratic organizations can be quoted as saying:

One thing we wanted to avoid was consensus management. I think it lends itself to major slow-downs in development schedules. We have good communication around a core group, but we certainly know who makes the call on things... We don't have the resources available to spend a lot of time getting everyone warm and fuzzy rather than to a decision.

You work, you get paid.

Some examples of Autocratic organizations include:

- Siebel Systems.
- Most of the major investment banks such as Morgan Stanley, Goldman Sachs, Merrill Lynch, and Lehman Brothers.

2.8. The Congruence Organizational Model

The notion of congruence – the idea that an organization should craft human resources policies that are internally consistent and that suit its strategy, technology, and context – is hardly controversial. Yet it is much harder to pull off than it sounds. Examples of misaligned and/or internally inconsistent human resources practices are not hard to find, and while imitation may provide an easy solution for your firm, it is also one of the ways in which organizations can develop human resources practices that are either misaligned with your strategy or internally inconsistent with other policies and practices already in place. One sometimes observes a frenzied and indiscriminate rush to emulate the human resources practices of highly successful companies such as compensation of elements of a firm's culture without regard for the interaction among the different elements or factors. These factors as I have stated above (with some addition) include 1) the external environment in which the firm performs, 2) the people, 3) the organization's culture, 4) the organization's strategy and 5) the technology of production and organization of work. I will explain each of these briefly below.

2.8.1. The External Environment

The boundaries among social, political, legal and economic pressures on the organization are fuzzy, so they are grouped into a single category. Here are some questions to think through the issues about how the company performs in the external environment.

The social forces impinging on human resources management begin with the local society's norms about work and employment. What in the society lends status to individuals? What sorts of behavior are frowned upon and what sorts are condoned? What are viewed as the social responsibilities of the firm? What types of organizational controls are and are not acceptable and legitimate?

In the legal environment, what are the statutory responsibilities of the organization? What rights do workers have both individually and collectively? What sorts of employment practices are sanctioned? What legally enforced distinctions must be made among workers (e.g. exempt versus nonexempt in the United States)? What distinctions are impermissible?

As for the economic environment, what conditions exist in the local labor market? How great is labor mobility? What economic pressures does the organization face in other product and factor markets?

2.8.2. The People

The key factors here are mainly demographic. How old is the workforce? How well educated? How homogeneous or heterogeneous are people socially? Social homogeneity refers to uniformity with respect to social characteristics such as sex, race, age, income, and education, and to norms of behavior derived from the society that workers come from. Another important form of workforce homogeneity is partly social, partly technical – namely the occupational mix required in the organization. For example, a law partnership that specializes in business law will be much more homogeneous than a "full-service" law firm, which is, in turn, much more homogeneous than say Proctor and Gamble.

2.8.3. The Organization's Culture

The organization's culture refers to norms of conduct, work attitudes, and the values and assumptions about relationships that govern behavior at the organization. Many variables enter here, including: Is the culture egalitarian or hierarchical? Is the culture one of cooperation or competition among co-workers? Is work itself regarded as a joy or as drudgery that provides a means to some other end? Is conformity important, or does the organization encourage diversity or even contention in thought or action? Are workers regarded as mere employees – that is, is the labor exchange largely economic in character – or are workers regarded more as team members?

2.8.4. The Organization's Strategy

By the organization's strategy, I mean the answers to the following questions. What are the organization's distinctive competencies – things that it can do better than the competition? On what basis does the organization hope to achieve a competitive advantage – for instance, technical innovation, premium customer service, superior quality, an integrated line of products or services, or low-cost production? On what basis will its competitive advantage be sustained? Is the firm relying on knowledge based barriers to entry, on legal protection, on a reputation for aggressive behavior in response to challenges? What are the long-term objectives – for instance growth, market share or niche penetration? I should also include here the firm's financial strategy, especially its financial structure, the use of debt versus equity financing and whether its equity is publicly or privately held?

2.8.5. The Organization of Work

The organization of work entails simply how labor inputs are converted to outputs. This organization involves such things as how tasks are organized and coordinated, not simply what types of machines (if any) are used. There are six broad categories found within the organization of work:

- Physical layout, worker privacy and proximity;
- Required skills;
- Monitoring of employee input;
- Task ambiguity and creativity;
- Patterns of worker interdependence and cooperation; and
- The distribution of outcomes.

2.8.6. Summary

The five categories of the congruence model are all interdependent. They must be in balance to drive the success of the business. To execute on the strategy the critical tasks must be completed. To complete the critical tasks requires the appropriate supporting organization. The people who are attracted to the culture, which is dictated by the critical tasks, influence the organization. The system must be in harmony with the other parts to be successful. The challenge that Boeing is faced with is bringing the various cultures from the acquisitions together into a common culture, transitioning through the consolidation efforts, and adjustment of its strategy to meet market shifts. Adjusting the strategy places demands on the other drivers of the system. With tremendous lags in culture, people and the establishing formal organization in the dynamic consolidation effort, it will be difficult for Boeing to dramatically change its strategy. Small gradual changes will be required to ensure the organization can change.

2.9. Organizational Processes Investigation and Change Initiation

As part of an Organizational Processes course requirement I performed an Organizational Initiative Analysis (Section 7.2). I based my evaluation upon the interactions I had with Boeing Space and Communications and their employees while on my internship. The evaluation consists of four topics: Background and Brief Description of the Internship Project, Using the Three Perspectives on Organizational Processes, Leading the Change Process, and Evaluation and Recommendations. The Background section may cover much of the same information discussed above.

Much like the Congruence Organizational Model which uses five factors to describe an organization, TOPIC #2 of this evaluation uses three lenses: Strategic, Political, and Cultural. Performing the analysis in this manor provides a little different but equally important perspective into the organization. The Organizational Initiative Analysis looks much more at my observations of Boeing and in particular the Houston site's organizational structure. Unlike the Congruence Organizational Model, it does not go into detail about the importance of congruence, nor does it evaluate how well congruence has been established in the structure.

3. RESULTS AND DISCUSSION

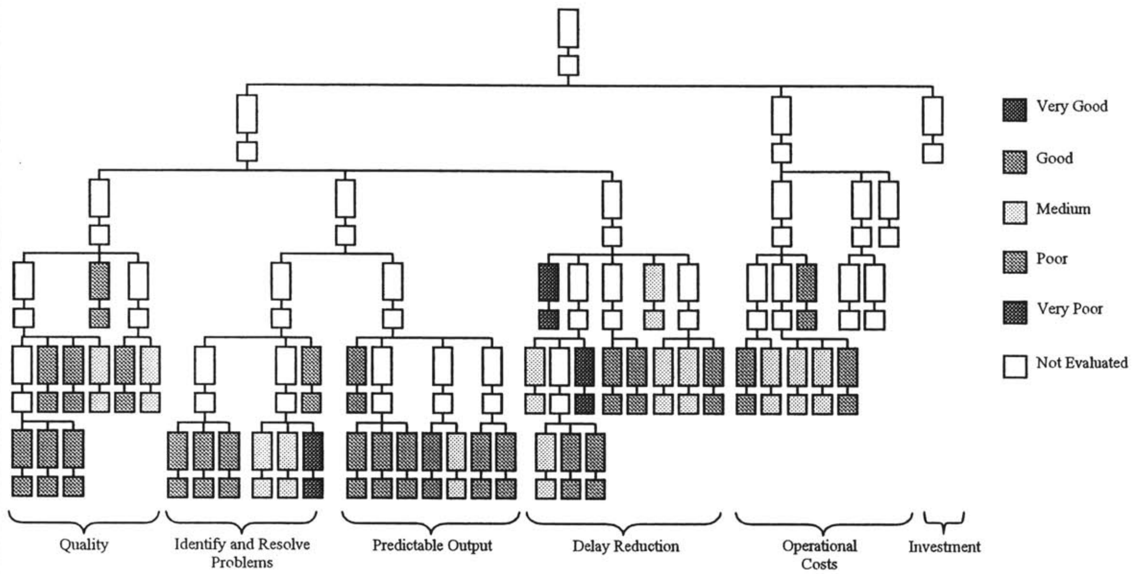
3.1. Houston Manufacturing System Evaluation with MSDD

The Manufacturing System Design Decomposition is a full package tool. Not only does the MSDD provide an approach to systems design, it provides a means to assess the current state of the existing manufacturing system design and how much it resembles the MSDD design. Through the use of a questionnaire, an evaluation of the current state is benchmarked against the currently evolved MSDD. The decomposition was originally created with the automotive industry in mind. Cochran expresses the next step in MSDD research as "to determine the applicability of the FR-DP relationships for various industries and applications and to interpret the implementation flowchart for various industries [12]." Cochran has had success with application of the MSDD in a number of industries including aerospace.

In Cochran's words the MSDD captures seven benefits, discussed in Section 2.5.1, for "repetitive, discrete-part manufacturing environments" [12]. The Houston manufacturing facility is predominantly non-repetitive, after all there is just one International Space Station. At times there are exceptions to this and there may be multiple or "similar" components that are manufactured for the International Space Station, but this is the exception and not the rule. Although the MSDD was not specifically designed for non-repetitive manufacturing, using the MSDD to analyze operations at the Houston facility will undoubtedly provide insight into Houston's operational efficiencies. Using the MSDD in this way may also prove its flexibility and applicability in a non-repetitive Job-Shop environment.

To begin I asked for a number of operations representatives to perform the MSDD evaluation. I asked them to focus their evaluation on the manufacturing floor operations and processes used there. The results are represented graphically in the shape of the MSDD as well as in tabular form (Table 4).

Table 4: MSDD Evaluation of Manufacturing Facility



MSDD Branch	Very Poor	Poor	Medium	Good	Very Good	Not Answered
Quality	0	7	2	0	0	0
Identifying and Resolving Problems	1	4	2	0	0	0
Predictable Output	0	5	2	1	0	0
Delay Reduction	2	5	5	0	0	0
Operational Costs	0	3	3	0	0	0
Total	**3**	**24**	**14**	**1**	**0**	**0**

On first glance the results do not look good. Most of the evaluation settled in the Poor region. It is important to note that this does not necessarily mean that the manufacturing facility is operating poorly. It simply means that the current operation of the manufacturing facility is not in line with the standard established by the MSDD. Since the MSDD was designed for repetitive discrete manufacturing, there could be some inherent and necessary differences between the way operations have been established at the Houston facility and those recommended by the MSDD.

The MSDD facility evaluation tool asks questions to determine how well the DP's have been meet. The purpose of the decomposition was to identify the DP's that were required of the system. The MSDD evaluation tool therefore assumes that if these are not met than the functional requirements are not met as well.

The nature of the Decomposition was to continue decomposition to a point were one independent solution could be implemented. As a result the MSDD facility evaluation tool color-codes only the FR-DP pair at the end of the decomposition chain. Let's look at each of the six key categories of interest grouped by the MSDD: Quality, Identification and Resolution of Problems, Predictable Output, Delay Reduction, Operational Costs, and Investment, along with their respective FR-DP pair questions and briefly discuss the applicability of each.

The FR-DP pair questions are scored on a 1-5 scale. 1 being strongly disagree and 5 being strongly agree. Some of the score values have an R associated with the score. This R signifies that the question is a "reverse question." In other words strongly agreeing with the question signifies poor performance and the value of 5 for strongly agree would equate to a value of 1 for the score averaging.

3.1.1. Quality

FR-DP Pair: Q111	**FR:** Ensure that operator has knowledge of required tasks		**DP:** Training Program
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We have standard training procedures for each operation.	1		Core team of high-skilled people, which can perform every task - from kitting to boxing. Low-skill jobs with easy job-training for temporary workers at end-of-quarter.
Operators know upstream and downstream processes.	4		Make all operators familiar with the whole value stream - not only the immediate adjacent processes. Core team is capable of all processes. Temporary workers can better see the whole value stream.
We continuously improve training procedures.	2		
Operators are usually trained on the job.	R 4		
How many hours does each shop floor operator spend on training per year?	NA	Unknown	
Are these hours paid?	NA	Train both off and on hours	
Average Score:	2.25	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

A training program is a requirement no mater what type of manufacturing is performed. This FR-DP pair is applicable for the Houston site just as it is for other manufacturing. Because of the non-repetitive nature of the manufacturing performed at the Houston site, there must be more interaction and planning. I believe this is why the "operators know upstream and downstream processes" received a relatively high score. Regardless of the relatively high score it is important to improve this. As pointed out in the Concept Comment it is important for operators to be familiar with the whole value stream. By definition a value stream is product dependent and since typically there is just one product manufactured for any given design, it is difficult to define the value stream, hence it is not visible to the operators.

Recommendations:

1. A generic process flow that represents the most common value streams could be designed and made visible to workers.

2. Manufacturing engineers could contribute to the design process not only for manufacturability purposes but also to create and document the value stream mapping for the product. This mapping could then be displayed at time of manufacturing.

FR-DP Pair: Q112	**FR:** Ensure that operator consistently performs tasks correctly		**DP:** Standard work methods
Question	**Score**	**Evaluator Comment**	**Concept Comment**
Operators are involved in creating the work methods.	5		Organizational decision: Do you want your operators being involved in designing work? Or is it only the supervisor? The result affects skill level!
Work methods have been defined for each operation and contain information about required quality standards.	2		Time every assembly step and create man machines charts (see also R111 and P131). For example material presentation and work sequence: which hand should be used to grasp a screw, left or right? If right hand, then place the bin of incoming material appropriately!
A written or electronic copy of operator's standardized work is available at each station.	1		
Variation in quality is reduced either by adjusting the work method or through operator training.	2		The first step is enforcement of standards so that variation can be determined. Then determine if: (1) the work method needs to adjusted (2) operator needs training (3) operator found better way to do things (4) tools and equipment must be improved. Determine the root cause for the variation first
We enforce that every operator performs the tasks according to the work method.	1		Enforce standards.

Average Score: 2.2 Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

Creating man machine charts for every operation required in the creation of the flight hardware would be nearly impossible to do for most tasks. The reason for this is because many of the operations are performed only once so obtaining an average time is impossible. At times similar operations such as those associated with joining and fastening may take place on different products. In these instances creation of man machine charts could be valuable for not only quality, but also time estimation. These common operations could be documented and modeled clearly.

With the one time operation nature of these products and with the high quality requirement, by suggesting the creation of man machine charts is impossible I do not mean to suggest that thought should not put into these operations. On the contrary, ensuring that the product can be manufactured and ensuring the procedures for lifts, assemblies, and any other required operation is critical. To cut time and possibly costly mistakes on the shop floor these types of operations can be performed virtually. Having the procedures performed virtually via an electronic tool will enable all pertinent project members to establish the plan regardless of geographic location. When the time comes to perform the operations a digital representation could be played at the operators work station along with detailed work instructions. This ability can be provided through the use of a good MES system and the use of virtual manufacturing software.

Recommendations:

1. Look for common operations across products. Standardize those operations and document them electronically and/or hard copy. Make the procedures available to the operators.

2. Look for similar procedures and track their cycle times. Although specific procedure information cannot be defined, commonalities and general operation procedures can be grouped to provide average times for use in scheduling and creation of value stream maps for future products.

FR-DP Pair: Q113	**FR:** Ensure that operator human errors do not translate to defects		**DP:** Mistake proof operations (Poka-Yoke)
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We frequently use devices that prevent errors from occurring (e.g. using positioning holes, light curtains for picking material, poka-yokes).	2		Extensive use of PTL.
We immediately detect defects and do not send them downstream.	2		Extensive use of pick-to-light (PTL) to avoid picking wrong parts. In addition, third way has all processes adjacent to each other, which provides fast feedback similar to cellular approach, where defects are detected within one work group.
Operators call for help or stop the line when they recognize a quality problem.	3	we work "around" quality problems if possible	
Average Score:	2.33	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

The "one-of-a-kind" nature associated with space flight hardware limits the use of pick-to-light[2] application. This is primarily due to the fact that there is only one part so there is typically not a large bin of parts. As for passing defects downstream this is still very relevant. During the value stream mapping phase, quality inspections could be identified and scheduled in the work sequence. Inspections in these instances are

[2] Pick-to-Light is a system that lights a light on the bin that contains like parts. For example in a computer assembly factory Pick-to-Light may be used to light a light on a bin containing 60GB hard drives so that the operator pulling parts for the parts list can identify the bin immediately and reduce the chance of grabbing a 40GB hard drive by accident.

typically focused on the assembly. Assembly procedures such as joining and fastening are common procedures. Common quality issues associated with these procedures could be documented and provided at the work cells for comparison. Note: in this text "work cell" or "work station" is defined as the location on the manufacturing floor where a particular piece of flight hardware is assembled.

Since most space flight hardware requires close geometric tolerances and because of the hardware's significant size it is often fixtured in place in the manufacturing facility. Because of this it is impossible to implement any type of a moving production line. To ensure the correct parts are on hand at the appropriate time and in the appropriate work cell, a kitting process can be and often is used. In this process a kitting contents pick list could be created with a picture of each. The night before or morning before, a runner could be tasked with filling the pick list. If an automatic inventory and storage system has been installed then the pick-to-light application would work well. The computer controlled inventory and storage system would in essence be the pick-to-light tool. It could be scheduled to pull each part based on a kit number in the computer which contains the pick list as created during the value stream map creation in the joint design sessions. Without a computer based inventory control system, a pick-to-light system would need to be hardwired, and with the inevitable changing of parts associated with the location identified by the associated light, the pick-to-light would be useless.

Recommendations:

1. Identify quality inspections during value stream mapping and include them in the schedule.

2. Provide common defect examples at each station so operators can perform

quality inspections.

3. Use kitting for minimization of part searches.

4. Investigate use of a computer based inventory control system for pick-to-light like implementation.

FR-DP Pair: Q12	**FR:** Eliminate machine assignable causes		**DP:** Failure mode and effects analysis
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We use cause and effect analysis tools to determine the source of defects caused by machines.	3		
We keep records of manufacturing defects for every machine.	2		
We have eliminated most machine assignable causes.	2		
Average Score:	2.33	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

The Houston site is predominantly an assembly integration and test facility. As a result it performs only light manufacturing. Regardless, this FR-DP pair is still very applicable to the Houston site. Actions must be taken to improve these scores.

Recommendations:

1. Implement policies and procedures to use effect analysis tools to determine the source of defects caused by machines.

2. Keep records of manufacturing defects for every machine.

FR-DP Pair: Q13	FR: Eliminate method assignable causes.		DP: Process plan design
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We encourage our operators to improve work methods.	3		Standard improvement procedure to capture operator knowledge and suggestions.
We have detailed process descriptions for all operations.	1		
Average Score:	2	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair certainly applies to the operations at the Houston site, perhaps even more so than other manufacturing environments. Because of the high precision and quality required, input from the skilled workforce is invaluable. The use of value stream mapping at time of design along with the use of virtual manufacturing will help describe operational processes.

Recommendations:

1. Implement a reward system of some sort for operator suggestions to improve work processes.

2. Document current work processes so that there is a baseline from which recommendations can be made.

3. Maintain updated process documentation.

FR-DP Pair: Q14	FR: Eliminate material assignable causes		DP: Supplier quality program
Question	**Score**	**Evaluator Comment**	**Concept Comment**
Quality is our number one criterion in selecting suppliers.	2		
We cooperate with suppliers to ensure defect free deliveries of parts.	3		
Incoming material is defect free.	4		

If you cooperate with suppliers, please describe briefly how you do it.	NA		
Average Score:	3.0	Medium	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

The quality of material, parts, components, and sub assemblies in the assembly, integration, and test operations performed at the Houston site is one of the most critical criteria! Since there is often only one part that will be used in the final assembly this part must be of top quality from the get go, there isn't another one to use if the first is bad. With the strict requirements of pedigree on parts and their often unique nature, it is not unusual for there to be long lead times associated with them. If a part is bad it could drastically impact the schedule of not only that product but also other products. Since the product is often fixtured in one location of the factory, this space could be unusable for vast periods of time just because of poor supplier quality. This is not an acceptable situation for a rapid response facility.

Recommendations:

1. Work with procurement to express important of using suppliers with high quality.

2. Initiate supplier benefits programs based on quality. Perhaps the program could focus around payment terms. If quality is good provide payment in shorter time period, if poor quality payment terms are extended.

FR-DP Pair: Q31	**FR:** Reduce noise in process inputs		**DP:** Conversion of common causes into assignable causes
Question	**Score**	**Evaluator Comment**	**Concept Comment**

We have procedures to distinguish between common and assignable causes of variation in process quality.	2		
Disturbances from outside the process are detected before they can affect the process output.	3		
We have procedures that enable operators to detect a change in the process inputs rapidly.	2		
Average Score:	2.0	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

With the variability and often uncertainty associated with product mix in the facility, noise in process inputs is inevitable. The trick is converting as many common causes as possible into assignable causes. By doing so one is able to work at controlling the variables.

FR-DP Pair: Q32	**FR:** Reduce impact of input noise on process output		**DP:** Robust process design
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We have made our processes insensitive to disturbances from outside (e.g. material or environmental influences).	4		
We apply standard procedures to eliminate root causes of quality variation.	2		
Average Score:	3.0	Medium	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair is applicable in any manufacturing environment. For space flight hardware this is particularly important. Focusing on reducing the input noise on process output can help to guarantee quality of the end product and ensure a safe product.

Recommendations:

1. Standardize processes.

2. Use product design meetings to incorporate some process evaluation as well.

FR-DP Pair: Q2	FR: Center process mean on the target		DP: Process parameter adjustment
Question	**Score**	**Evaluator Comment**	**Concept Comment**
Process mean is only set within tolerances, but not necessarily on target.	R 2		
We operate processes on target.	2		
We continuously monitor processes to check whether they are staying within tolerance specifications (e.g. through SPC).	1		
Average Score:	2.33	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This is critical and must be done, especially in this environment. I believe that one of the main contributors to this problem is the lack of process documentation and revision. Boeing seems to rely on quality inspections to catch any aspect that is out of allowance. When a parameter is found to be out of specification there is significant pressure to go through a lengthy evaluation to determine if the flaw creates a safety hazard and if it should be reworked. The significant cost associated with the evaluation and possible rework is often significantly less than would be required if new parts were ordered and the work was started again from scratch. Regardless of which alternative is ultimately chosen the process is tremendously time consuming and expensive. It is clear that to be a rapid response facility this must be improved.

Recommendations:

1. Processes must be documented.

2. Processes must be adhered to and modified as required to guarantee the desired outcome, the first time.

3.1.2. Identifying and Resolving Problems

FR-DP Pair: R111	**FR:** Identify disruptions when they occur		**DP:** Increased operator sampling rate of equipment status
Question	**Score**	**Evaluator Comment**	**Concept Comment**
Machine downtimes are immediately noticed (e.g. through information technology or process design)	2		The idea here is to have an integrated manufacturing environment, in which all processes are tightly connected. Downtimes are quickly recognized and conveyed.
We use devices such as Andon boards or radio communications to signal the occurrence of disruptions.	2		
Operators can easily see whether they are ahead or behind schedule.	2		Production counter at both ends of the cell show actual production and scheduled production. All operators can see if the cell is ahead or behind schedule at any given time.
Variation in work completion time is easily identified.	2		Detailed work instructions for every operation, for every combination of work loops. Thorough training and enforcing standards. One may work with a time clock counting down times. It may also be necessary to create a leveled schedule to ensure that on average takt time is achieved.
Average Score:	2	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

The DP associated with this FR suggests, "increased operator sampling rate of equipment status" in an effort to identify disruptions caused by machine down time or another disruption. The work station should display a visual cue in the event of a disruption. Operators should also be able to effortlessly confirm their adherence to schedule and allotted time for an operation.

In a Job-Shop type of environment this can be very difficult to establish. Operations are not always the same for each product, and given that a process step is often only executed one time, takt time calculation is virtually impossible to calculate. So what should the allotted process time be? Should it just continue until it is done?

One way to tackle this challenge is to use process mapping as discussed above to created a baseline from which a benchmark can be established. The Value Stream mapping created during the design cycle can then incorporate this time. Additionally, with an average process time available, scheduling techniques can be used along with virtual manufacturing, if available, to generate work instructions with estimated processing times. If the work station has electronic capabilities for operator input, processing times can be recorded and used to add to the database of processing time for similar processes. The use of a scheduling tool based on Theory of Constraints (TOC) works well in this situation. TOC scheduling uses the "average" processing time to generate its schedule, and through the use of critical chain, inherent to TOC, one easily identifies what the bottleneck of the system is. The TOC schedule could be used in place of a Kanban as a pull signal.

Recommendations:

1. Place andon light at each work station or work cell

2. Display value stream map for project, with processing time information, at each work station.

3. Display TOC schedule at each work station for visual cue of scheduled

processing time and amount of buffer capacity consumed. Note: each process will most likely not have its own buffer, particularly if it is on the critical chain. The buffer consumption will also most likely be updated only daily. So this will not provide the specific information for the process at hand but rather the overall project.

4. With electronic work instructions at each work station, a time bar signifying the scheduled time could be displayed. As the process is executed the bar could fill with a green bar. Once time reached the last 10% of scheduled time the bar could turn red. Once it reached the end of the scheduled time it could automatically activate the andon light to alert the floor that there may be an impact to the schedule and the team needs to determine the most appropriate course of action.

FR-DP Pair: R112	**FR:** Identify disruptions where they occur		**DP:** Simplified material flow paths
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We can always determine which upstream machine is responsible for a defect.	3		
Process layout allows immediate detection of disruptions (e.g. downstream operations are quickly starved).	1		All operations integrated in one cell. Disruptions can easily communicated from last to first operation and vice versa. Counter at beginning and end of cell.
Downtimes can be unnoticed by downstream processes because processes are separated from each other either physically or through large buffers.	R 5		Since all operations are tightly integrated in one manufacturing cell, disruptions at any points are more visible and quickly noticed.
Average Score:	1.66	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

As seen in the results of these questions, downtimes can go unnoticed. This is not necessarily because processes are physically separated from each other or that there is a large buffer between them, after all most hardware is fixtured in one location and all processes for that product occur there, but rather there is no set process flow or schedule for production. Most shop floor level scheduling is done via word-of-mouth.

Recommendations:

1. Display and adhere to Value Stream Map.

2. Display and adhere to TOC Schedule.

3. Make efficient use of kitting.

FR-DP Pair: R113	**FR:** Identify what the disruption is		**DP:** Feedback of sub-system state
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We apply standard procedures for determining the root cause of disruptions.	2		
Our system exposes disruptions and makes them easy to recognize (e.g. accumulating material shows that a production unit is falling behind).	2		This is layout in the small scale: defined buffers between sub-systems (e.g. decouplers between operator work loops). Accumulating material is visible and triggers an alert.
Breakdowns in equipment are easy to diagnose.	3		
Average Score:	2.33	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

Identification of disruptions is equally as important in this manufacturing environment as it is in others, but the methods may not be the same. The Concept Comment talks about the use of decouplers. When the decoupler starts to accumulate WIP the location of the disruption is clearly identified. It is the process just after the decoupler. Unfortunately decouplers cannot be used in this environment since this manufacturing facility is predominantly one-of-a-kind products. The important thing to do here however still remains the same: A feedback method must still be in place.

Recommendations:

1. Installation of andon light at work station.
2. When andon is illuminated a team forms to determine root cause of disruption. Once determined, some form of documentation should be generated for future problem elimination.

FR-DP Pair: R121	**FR:** Identify correct support resources		**DP:** Specified support resources for each failure mode
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We have standard communication paths to contact support staff.	3		
Average Score:	3	Medium	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

Certainly this is required for any manufacturing facility. It is integral to a number of the recommendations already provided. Teams must be established for each product. In the event that temporary workers are working the process when a corrective measure is required, the appropriate contact personnel should be available at the work station in the form of either an electronic or hard copy list of names and contact information.

FR-DP Pair: R122	**FR:** Minimize delay in contacting correct support resources		**DP:** Rapid support contact procedure
Question	**Score**	**Evaluator Comment**	**Concept Comment**
Our communication devices allow rapid correspondence (e.g. walkie talkies, andon boards).	3		

Disruptions are quickly conveyed (e.g. by starting an alarm, information technology).			Andon lights throughout the cell, quick recognition of deviations from standards; balanced work loops between operators allow for quick detection, if an operator falls behind.
Average Score:		Medium	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair is applicable to the Houston site.

Recommendations:

1. Installation of andon lights at work stations.
2. If electronic work instructions available at work station computer then potentially an alphanumeric pager could be sent to pre-assigned personnel.

FR-DP Pair: R123	**FR:** Minimize time for support resource to understand disruption		**DP:** System that conveys what the disruption is
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We have information devices (e.g. a display at the machine panel), which show the cause of a disruption.	2		
We document disruptions and create a knowledge base to understand recurring problems.	1		Define how to document decisions and problem solving. Create a knowledge database, which can also feed back experiences from manufacturing to product design.
Average Score:	1.5	Very Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair is applicable to the Houston site.

Recommendations:

1. Documentation of disruption.

2. If paging system used it could provide code or detailed explanation.

3. Multi colored andon light.

FR-DP Pair: R13	FR: Solve problems immediately		DP: Standard method to identify and eliminate root cause
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We follow standard procedures for resolving problems.	2		
To keep production moving, we usually solve problems only temporarily. Reoccurrence of the disruption is likely, since the root cause is not eliminated.	R 5		
Operators on the shop floor have the authority to take necessary steps for resolving disruptions.	3		General consideration. Operators should be seen as core element of the manufacturing system.
We have a formal suggestion program for all employees.	4		
How would you characterize your problem solving process? (team based, Kaizen sessions, management driven etc.)	NA	Management Driven	
Average Score:	2.5	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair is extremely applicable to the Houston site. Although there are many different operations and a large quantity of them are once-only type of processes, the root cause still needs to be investigated and identified. The reason for this is simple, the root cause could be tied to a more common process and it will likely affect other processes and operations.

Recommendations:

1. Follow standard procedures for resolving problems.

2. Have shop floor teams work to solve the problem and provide incentive for them to make future recommendations.

3.1.3. Predictable Output

FR-DP Pair: P11	**FR:** Ensure availability of relevant production information		**DP:** Capable and reliable information system
Question	**Score**	**Evaluator Comment**	**Concept Comment**
Our operators have access to all information regarding their tasks.	4		
The operators always understand what to produce, when to produce, and how to produce.	4		
Operators have easy access to process information.	4		
We often have production disruptions due to missing information.	R 4		
What information regarding production is most important to you? How do you communicate the information and make it accessible?	NA	Schedule info is communicated mostly verbally	
How do operators know what, when, and how much they are supposed to convey, maintain, produce, repair? Please list the main ways to transfer that information.	NA	Verbally, there are too many MWO's to choose from	
Average Score:	3.5	Good	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

A capable reliable information system is critical to any manufacturing facility. Houston is no exception. My internship was spent investigating ERP systems and building support and involvement from functional groups within the Houston site the evaluation and eventual implementation of a system. Having accurate, reliable, and timely information to make good business decisions is a necessity in today's competitive landscape.

Boeing rated Good in this department. The evaluator also expressed that most of this information was available through word-of-mouth. Because of the high cycle times typically associated with space flight hardware for a given process, this method of information communication has worked well. A concern one might have is that as the site begins to respond quicker to the customer and begins processing more work, will these methods still be acceptable? Another concern focuses on the comment that the evaluator made: operators know what, when, and how much they are supposed to convey, maintain, produce, repair "Verbally, there are too many Manufacturing Work Orders to choose from." It sounds as though there may be some significant time delay here. What is the root case? As observed from earlier questions, time is not often taken to evaluate root cause. One contributing factor could indeed be that instructions of this type are conveyed verbally. What if the person who starts the information chain is absent?

Recommendations:

1. Display TOC schedule for product at their respective work station.

2. Each shift should come to their work station and find a kit and associated work instructions with it. If available, electronic work instructions on a computer would also help. They would provide access to all drawings and simulations available for that product, which could eliminate wait time for information relayed via word-of-mouth.

FR-DP Pair: P121	FR: Reduce variability of task completion time		DP: Standard work methods to provide repeatable processing time
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We time each operating step in detail and include the information in the work instructions.	1		
Variation in work completion time is being solved either by adjusting the work method or through operator training.	2		Enforcement of standards. Update of standards and training.
Work completion time of the same task often varies between operators.	R 4		Enforcement of standards.
There is high variation of work completion time between cycles of the same operator.	R 4		
Average Score:	1.75	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair is applicable to Houston. As discussed earlier many of the processes in the facility are non-repetitive but there are some that are repetitive processes.

Recommendations:

1. Processes that are repetitive need to be documented and timed.
2. Processes that are non-repetitive need to be categorized with other similar non-repetitive processes, generally documented and time averages generated.
3. Training on documented process procedures.
4. Encourage improvements and updates to the processes, but insist adherence to the documented process. If improvement is made, update the documented process.

FR-DP Pair: P122	FR: Ensure availability of workers		DP: Perfect Attendance Program
Question	**Score**	**Evaluator Comment**	**Concept Comment**
Our operators are at their work station, when they are supposed to be there.	3		Play music 5 minutes before break ends, 1 minutes etc.
Operators can work ahead of schedule and take an unplanned break.	R 4		Counter at each end of cell. No sub-subsystem is able to work ahead or take unplanned break - only complete cell.
Unplanned absenteeism often affects our ability to produce to schedule.	R 4		
What is your average percentage of absenteeism per year? (only unplanned absenteeism such as sickness, not showing up at work place)	NA	Unknown	
Average Score:	2.33	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

The Houston manufacturing facility is relatively small. The workers are highly skilled and many of them have specialty skills. If one is absent it can cause challenges to complete the work. Additionally the root cause for schedule slippage when an individual is absent could stem from the fact that work to be done is currently identified and communicated via word-of-mouth. If there is no specific means to indicate how far the absent employee progressed on the last pile of MWO's, then the workers in attendance may not be able to determine where to pick up the last task. This problem could stem back to elements discussed earlier.

The other two questions used to evaluate adherence to this FR-DP pair relate to operators being able to work ahead to take an unscheduled break, and whether or not a worker was at their work station when they were expected to be. These may be misleading in the results of this answer. Since the operations are not in a moving line then taking a break does not result in the downfall of the cell. This may not be as critical. The teaming environment of the shop floor consisting of so many skilled workers may also necessitate a little less rigidity than is suggested by the MSDD. The point however is still valid and well taken.

Recommendations:

1. Implement a perfect attendance program.

FR-DP Pair: P123	FR: Do not interrupt production for worker allowances		DP: Mutual Relief System with cross-trained workers
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We have standard procedures in place for mutual relief.	2		
Operator allowances (e.g. for personal hygiene) usually lead to production disruptions.	R 3		
What do you think is important to the operators in helping them produce high quality products? (please circle) Being on a team - being well trained - taking part in designing their workplace - having suggestions accepted - monetary incentives - other_	NA	Having suggestions accepted, and monetary incentives	
What of those circled in the previous question is in place? (please circle) Being on a team - being well trained - taking part in designing their workplace - having suggestions accepted - monetary incentives	NA	None	
Average Score:	2.5	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair is applicable to the Houston site as well.

Recommendations:

1. Cross train workers.

2. Implement an improvement suggestion program and include a reward mechanism. When a suggestion is implemented provide a "kaizen architect" certificate. After an individual receives a set number of certificates give them a $50 bill. – This is just an example.

FR-DP Pair: P131	**FR:** Ensure that equipment is easily serviceable		**DP:** Machines designed for serviceability
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We are able to perform standard service checks without interrupting production (e.g. from the back of a machine).	4		
The ability to easily service equipment determines requirements for its design (e.g. accessibility, controllability, ability to monitor the process, exchangeability of components).	3		
Repair: equipment is usually repaired by outside contractors or the equipment vendor.	R 4		
Maintenance: our own employees maintain our equipment.	4		
Average Score:	3.25	Medium	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair applies to the Houston site.

Recommendations:

1. Keep this in mind when acquiring new equipment.

2. Depending on relative importance of any one machine, may consider training

an in-house person for serviceability.

FR-DP Pair: P132	FR: Service equipment regularly		DP: Regular preventative maintenance program
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We dedicate a portion of every day solely to preventive maintenance and follow the preventive maintenance schedule.	2		Define and follow preventive maintenance schedules. Must be considered in original capacity planning phase.
We are usually behind production schedule and have no time for preventive maintenance. Repair is our maintenance.	R 3		
We emphasize proper maintenance as a strategy for achieving schedule compliance.	3		
Our equipment and tools are in a high state of readiness at all times.	4		
What percentage of time do you dedicate for preventive maintenance? (time for preventive maintenance / available production time)	NA		
What percentage of time is lost due to unscheduled maintenance? (unscheduled maintenance / available production time)	NA		
Average Score:	3.0	Medium	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair is applicable to the Houston facility. It is important to document and adhere to a preventative maintenance program for all equipment.

Recommendations:

1. Document a maintenance program.

2. Document and record maintenance activities.

FR-DP Pair: P141	FR: Ensure that parts are available to the material handlers		DP: Standard work in process between sub-systems
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We have standard levels of inventory between sub-systems for each part.	3		
Operations are frequently starved due to unavailability of incoming parts.	R 4		
There is unpredictable fluctuation in our inventory levels.	R 4		
Average Score:	2.33	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

The FR of this FR-DP is critical to all manufacturing facilities. The DP of this FR-DP pair on the other hand is only applicable to repetitive manufacturing. The Houston manufacturing facility is a non-repetitive manufacturing environment, which creates one-of-a-kind flight hardware. It is the norm to create just one of each part. For this reason it is critical to work with suppliers and have good scheduling of part orders to ensure no scheduled process is starved of parts.

Recommendations:

1. Use of kitting.

2. Improved supplier relations and accurate lead time approximations.

FR-DP Pair: P142	FR: Ensure proper timing of part arrivals		DP: Parts moved to downstream operations according to pace of customer demand
Question	**Score**	**Evaluator Comment**	**Concept Comment**

The frequency of material delivery is based on consumption from the customer process.	1		
We use Material Requirements Planning (MRP) to schedule production resources.	R 2		
Average Score:	2.5	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

The FR of this FR-DP is critical to the Houston facility. The DP of this FR-DP pair on the other hand is not as applicable here as for repetitive manufacturing. The reason for this is because the customer demand is only for one, and the customer is always the same entity. In repetitive manufacturing, customer demand signifies the mean aggregate demand of all customers. Projects managed at the Houston site are of a design build nature and therefore the products created are really "made-to-order." As such a schedule is created. That schedule in essence then becomes the customer demand.

So although the FR is applicable the evaluation questions may not be. Since there really is no customer consumption it is impossible to schedule material delivery "frequency" based on "consumption", only one will be consumed. And the use of an MRP system to determine the schedule of production resources may not be a bad thing. With the number of independent products (or sub-systems of the main product: ISS) being manufactured at any given time, a method used to identify when material is required needs to be implemented. We have already determined that the use of customer demand alone cannot fill this role. Earlier in this paper we discussed a kanban, and for the same reason this cannot be used to identify production resource requirements. We are left little alternative but to use some sort of an MRP system. Perhaps this system could be driven by a TOC schedule. As discussed earlier the TOC schedule could take the place of a kanban.

Recommendations:

1. Use TOC schedule to aid in material arrival timing.

3.1.4. Delay Reduction

It is important to note that much of the evaluation in this section is based on adherence to takt time. The notion that flow through the facility should be based on takt time and ultimately upon customer demand is a key component of Lean Manufacturing. As discussed throughout this paper, takt time calculation for a non-repetitive Job-Shop, like the Houston facility, is nearly impossible. JIT and Lean Manufacturing principles were designed for industries with relatively stable demand. Even with JIT and Lean Manufacturing the manufacturing system design must be reworked if there is a change in demand. This is to account for the resultant change in takt time. Since the MSDD was designed for original application in a repetitive manufacturing environment where takt time can be calculated, much of the MSDD Facility evaluation is based on takt time adherence and standard work procedures. Regardless of this fact there are still strong lessons that can be taken from the MSDD.

FR-DP Pair: T1	**FR:** Reduce lot delay		**DP:** Reduction of transfer batch size (single-piece flow)
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We are transporting standard quantities between operations – (i.e. each trip transports the same number or parts).	0		
We tend to have large transfer batch sizes between operations relative to demand between operations.	R 5		
Average Score:	0.5	Very Poor	1=strongly disagree 5=strongly agree R=reverse question
Discussion:			

This FR-DP pair does not fit the type of manufacturing performed at the Houston site as it relates to "hardware". Since the manufacturing is one-of-a-kind, it is impossible to have a hardware transfer size greater than one.

This FR-DP pair may however still be applicable when it comes to paperwork, quality inspections, and other processes of that type required of the manufacturing facility. As a result these paperwork delays could affect the completion of the hardware.

FR-DP Pair: T21	**FR:** Define the desired production pace(s) (or takt time).		**DP:** Definition or grouping of customers to achieve desired production pace (or takt time) within an ideal range
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We determine the desired production pace of the manufacturing system at an early stage of a manufacturing system design project.	3		
We have clear customer - supplier relations throughout the value stream.	3		One cell including all operations. No physical separation of kitting, assembly, boxing. Everything close together to enable fast feedback.
How do you determine the number of machines for a value stream?	NA	Assume they can all be available if high enough priority	
How do you determine the cycle times for each operation in the value stream?	NA	Ask the operator or lead	
Average Score:	3.0	Medium	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

As discussed above, the production pace cannot be based on aggregate customer demand. The cycle times are based on average times for the same or similar processes for products previously created. Nevertheless this FR-DP pair is still very relevant to operations within the Houston facility. Because the facility is intended to be rapid response it is critical that the manufacturing facility be designed to enable fast feedback.

Customer and supplier relations are critical in the event of a last minute design change, or worse, cancellation of project. Through the use of value stream mapping and a TOC schedule, the production pace can be identified and set. Based on the scheduling iterations required to schedule all of the projects, grouping of customers and or products may be required.

Recommendations:

1. Use of Value Stream Mapping.
2. Use of TOC Scheduling.

FR-DP Pair: T221	**FR:** Ensure that automatic cycle time <= minimum desired production pace (or takt time)	**DP:** Design of appropriate automatic work content at each station

Question	**Score**	**Evaluator Comment**	**Concept Comment**
We design our manufacturing processes so that the cycle time closely matches the desired production pace (or takt time).	2		What is the customer demand? What is the range of output you want to achieve between lowest volume at beginning of quarter to highest volume end of quarter? Then also consider "ideal range" of assembly cycle time - not too boring, not too complex.
When automatic/machine cycle times are longer than desired production pace (or takt time), we try to divide the operation into two or more operations to achieve takt time with each operation (rather than two equivalent machines operating in parallel).	2		
We usually try to minimize the number of machines by decreasing the cycle time per machine regardless of the desired production pace (or takt time).	R 2		Equipment design not an issue in the assembly environment.

We are well balanced across the process flow.	2		All process cycle times interact in one cell. Balanced work loops from kitting to boxing to accommodate desired output rate of the cell.
Average Score:	2.5	Medium	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair is difficult to apply in a non-repetitive environment. Takt times cannot be calculated and as discussed earlier, customer demand is for one product that is scheduled explicitly as opposed to having an average demand quantity over a given period of time. On the other hand this can be viewed more generally. Looking at the Houston site some expectation of capacity must be established. It does not make sense for any section of the manufacturing facility to sit idle. To make maximum efficient use of the manufacturing facility the process flow should be balanced as best as possible. The common processes and common tools should be scheduled accordingly. This can be done to some extent through the use of value stream mapping for process and tool identification and through the application of TOC to balance the machine, tool and human resources.

Recommendation:

1. Use of value stream mapping and process mapping.

2. Use of TOC for scheduling.

FR-DP Pair: T222	**FR:** Ensure that manual cycle time <= desired production pace (or takt time)		**DP:** Design of appropriate operator work content/loops
Question	**Score**	**Evaluator Comment**	**Concept Comment**

We design each operator's work loop to run as close to the desired production pace (or takt time) as possible.	2		Must consider the range of possible operating points of the cell. For example, during low demand periods, an assembly operator may work on 5 work stations with a work loop of 5 minutes. During high demand periods the operator works on 2 stations with a work loop of 2 minutes. For each desired output rate of the cell, it is necessary to define work loops for all operators and balance the work loops.
When manual cycle times are longer than the desired production pace (or takt time), we try to divide the operation into two or more operations (rather than having two operators performing the same operation in parallel).	2		
Average Score:	2	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

Although the application of this FR-DP pair is difficult in a non-repetitive manufacturing environment for reasons previously discussed, it provides valuable food for thought. During the product design phase involvement of manufacturing engineers is required for manufacturability analysis. During the design phase the design team should also spend time contributing to the identification of work content and the creation of process sequences. This will help to ensure on time product delivery.

Recommendations:

1. Use value stream mapping to aid in visualization of work process sequences required for the assembly of a given product. This will aid in the design of the most efficient process flow for the given product.

FR-DP Pair: T223	**FR:** Ensure level cycle time mix		**DP:** Stagger production of parts with different cycle times
Question	**Score**	**Evaluator Comment**	**Concept Comment**

If a manufacturing unit produces several parts and the parts have different cycle times, we stagger the parts to produce on average to the desired production pace (or takt time).	2		Create a level schedule, which produces on average according to takt time. This requires to know all assembly times for each unit upfront. It may be sufficient to distinguish between short, medium, and long cycle time units and level those out to reach on average medium cycle time units. That is, avoid releasing 20 long cycle time unites in a row.
Our run sizes (quantities between machine changeovers) depend on consumption from the customer not only on the optimal run lot size per machine.	2		Combine kitting with having all parts at the assembly station. The goal is to produce a wide variety of products without the need to change over, I.e. deflashing the incoming parts. It may be required to have several stations within the cell dedicated to particular families. The stations hold some key parts of the family.
The team leader or line supervisor is capable of creating a leveled schedule.	2		
Average Score:	2.0	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP influences the variability of a production facility. By leveling cycle time across the facility, a level stream of product can flow through the facility. This is like taking the potholes out of a road. The less variability the smoother and more manageable the ride. But with the inherent instability associated with a Job-Shop, can and should this be done?

As discussed in Section 2.4, one of the largest challenges for a Job-Shop is scheduling. It is desirable to level production and the use of the equipment because it helps to ensure that the maximum throughput is being generated by the facility and thereby positively affecting ROI, but how can it be done? Rajan Suri has established a unique approach of a modified kanban system and use of MRP called *Paired-cell Overlapping Loops of Cards with Authorization (POLCA)* to level production [5]. This method works well in a Job-Shop environment where equipment is stationary and parts flow, but does not seem as applicable when the product is stationary and the machines are mobile, as is the case in Houston.

Recommendation:

1. It seems that the application of TOC is the most appropriate method to level production in this type of an environment.

FR-DP Pair: T23	**FR:** Ensure that part arrival rate is equal to service rate		**DP:** Arrival of parts at downstream operations according to the pace of customer demand
Question	**Score**	**Evaluator Comment**	**Concept Comment**
Part deliveries are independent of actual downstream consumption.	R 4		
We communicate the pace of customer demand to the value stream (for example, using electronic or manual information and withdrawal kanban cards).	1		
We design our delivery cycle time to be a multiple of the desired production pace (or takt time) across the value stream.	1		
Average Score:	1.33	Very Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP has limited application as viewed from a single value stream for a given product. However, combining part requirements for all concurrent product assembly the arrival rate becomes critical. Taking the view that the product work station or work cell serves as the customer in demand of the parts emphasizes the importance of a smooth arrival rate to meet the schedule.

Recommendations:

1. Maintain excellent supplier relations to ensure parts are on hand when required.

2. Implement kitting and kit delivery processes.

3. Use TOC for scheduling.

FR-DP Pair: T31	**FR:** Provide knowledge of demanded product mix (part types and quantities)		**DP:** Information flow from downstream customer
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We schedule only one operation in the value stream.	2		
We use a pull system for production control.	4		
We usually meet the production schedule every day.	2		
We frequently produce more (or less) than scheduled.	R 4		
We frequently produce more (or less) of a particular part type per day than the downstream customer consumes per day.	R 4		
Our operators have easy access to the production schedule.	2		
Average Score:	2.33	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

Products on the manufacturing floor already have contracts associated with them and hence demand is known. The question however is whether or not the product mix and schedule information has made it to the production floor? It is important to communicate the production schedule to the floor. Currently schedule information is communicated via word-of-mouth. As discussed earlier this communication method has drawbacks associated with it. Production schedule access must therefore be increased.

Recommendations:

1. Display schedule at each manufacturing work station.

FR-DP Pair: T32	**FR:** Produce in sufficiently small run sizes		**DP:** Design quick changeover for material handling and equipment
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We are working aggressively to reduce setup times.	2		
We have converted most of the setup time to external time while the machine is running.	2		
We have low setup times for equipment in the evaluated value stream.	2		
We tend to have large run sizes in our master schedule.	R 4		Goal is to produce in single-unit increments with no changeover (material or otherwise) between any family the cell is capable to produce. This requires material management and equipment management to accommodate different product sizes and weights.
What is your policy in determining run sizes for the different operations?	NA	Efficiency of Machines - Reduce setup	
Average Score:	2.0	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR is associated with delay reduction and is to produce sufficiently small run sizes. Since we are making non-repetitive products at the facility this is already achieved. The associated DP, to have quick changeover, on the other hand is not currently met. In a rapid response facility, having the capability to perform quick changeovers is invaluable. Doing so will allow a product to be completed as quickly as possible, the ultimate goal of a rapid response facility.

Recommendations:

1. Work aggressively on reduction of setup times.

2. Work to convert most of the setup time to external time while the machine is

running.

FR-DP Pair: T4	FR: Reduce transportation delay		DP: Material flow oriented layout design
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We have laid out the shop floor so that our machines and processes are in close proximity to each other.	3		One large cell has all processes integrated eliminating the need for conveyors.
We group machines of the same process together.	R 4		All processes are integrated in one manufacturing processes.
We have eliminated transportation by having processes adjacent to each other.	3		
Average Score:	2.66	Good	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

Reduction of transportation delay is important to the Houston facility. Because of the necessity to fixture products in certain locations, most machines and tools must be mobile. Movement of equipment can be minimized by efficient shop floor work station layout.

Recommendations:

1. Utilize value stream map of new products to identify common machine and tool requirements with products in production on the floor. Lay out the new work station in such a way that it is as close as possible to other work stations that use similar tools and equipment.

2. Virtual manufacturing could also assist with floor layout and lift procedure scenario analysis.

FR-DP Pair: T51	FR: Ensure that support activities do not interfere with production activities	DP: Subsystems and equipment configured to separate support and production access req'ts

Question	Score	Evaluator Comment	Concept Comment
Delivery of material does not interrupt production.	2		Feed material from back to the assembly station.
Picking up outgoing material interrupts production (e.g. due to the need for fork lifts to move large bins).	R 4		
Material handling and transportation equipment does not limit the pace of the production.	3		No complex and long conveyors, which can cause congestion. Sliding tables can make it easy to move products between assembly stations. The transportation of units to the software download racks can be done similar to concept P or with the help of racks as they are used in concept C.
Operators have to leave their work station to pick up new material.	R 3		Feed material from back to the assembly station.
Operators frequently perform activities, which disrupt the standardized work.	R 3		Detailed design of material presentation, re-entry points of repaired products or re-routed products (if that happens at all).
Average Score:	2.6	Medium	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair is applicable to the Houston facility. At times disruptions to other work stations is inevitable. If a "critical lift" is to be performed, there are safety procedures that need to be meet. Depending on the location of other hardware in the facility, multiple lifts may be required. An example of this would be in order to remove one product another may need to be repositioned.

Recommendations:

1. Arrange manufacturing work stations in a manner that provides independent material delivery paths.

2. In hindsight design the manufacturing floor to be symmetric with access doors at each quadrant. For example if it is expected that the manufacturing floor

capacity is going to be designed to allow for four different flight hardware structures to be assembled at the same time, then the expected average size could be determined and the floor sectioned off into four quadrants of appropriate size. An access door should be provided for each quadrant. Two track mounted lifts, operating on the same tracks, could be provided for the floor. Each lift should have capability to be positioned directly over any point in the facility. This will eliminate the need for complicated lift procedures incorporating rental cranes and the sort.

3. Use of virtual manufacturing for visualization and scenario analysis.

FR-DP Pair: T52	**FR:** Ensure that production activities don't interfere with one another		**DP:** Ensure coordination and separation of production work patterns
Question	**Score**	**Evaluator Comment**	**Concept Comment**
Operators work loops are laid out so that one operator does not interfere with another.	4		
The coordination and separation of production work patterns is considered during the design phase - it does not just evolve during operation.	2		
Average Score:	3.0	Medium	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

Same as for FR-DP pair T51.

FR-DP Pair: T53	**FR:** Ensure that support activities people/automation) don't interfere with one another		**DP:** Ensure coordination and separation of support work patterns
Question	**Score**	**Evaluator Comment**	**Concept Comment**

The process design ensures that support resources do not interfere with each other.	2		Defined material supply routes and times.
The coordination and separation of support work patterns is considered during the design phase - it does not just evolve during operation.	2		
Average Score:	2.0	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

Same as for FR-DP pair T51.

3.1.5. Operational Cost

FR-DP Pair: D11	**FR:** Reduce time operators spend on non-value added tasks at each station		**DP:** Machines & stations designed to run autonomously
Question	**Score**	**Evaluator Comment**	**Concept Comment**
Eliminating non-value added time spent at each station is a priority of station design.	2		
Operators usually wait at a machine until the machine cycle is finished.	R 4		
Machines are designed to eliminate the need for operators to watch the machine cycle (in order to prevent defective parts).	2		
Average Score:	2.0	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair is applicable to the Houston facility. With limited resources available, reducing non-value-added tasks is a must.

Recommendations:

1. Design machine to eliminate need for operators to watch the machine cycle.

FR-DP Pair: D12	**FR:** Enable worker to operate more than one machine / station		**DP:** Train the workers to operate multiple stations
Question	**Score**	**Evaluator Comment**	**Concept Comment**
The operators are capable of performing more than one task.	5		Core team of high-skilled people, which can perform every task - from kitting to boxing. Frequent rotation during low-demand periods to avoid work becoming boring. Temporary workers should also be rotated to gradually improve their capabilities.
Plant employees are rewarded for learning new skills.	2		
We rotate operators to other jobs within their subsystem.	2		
Average Score:	3.0	Medium	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair is applicable to the Houston site. From the evaluation it is clear that operators are capable of performing more than one task. For this reason providing a reward for learning new skills may not be as important at this time. Rotation of operators among machines will maintain their existing skills.

FR-DP Pair: D21	**FR:** Minimize wasted motion of operators between stations		**DP:** Configure machines / stations to reduce walking distance
Question	**Score**	**Evaluator Comment**	**Concept Comment**
When the shop floor layout is designed, equipment and material are placed so as to minimize walking distances.	3		Operators walk between assembly stations. Stations should be in close proximity.
We usually arrange equipment first and then consider the work loop of the operator.	R 3		Integrated cell applies concurrent engineering for the human-machine interface.
We design equipment to minimize walking of the operator.	3		

Most of our operators are bound to one station and do not have to walk at all.	R 1		Operators should move between stations. Even the assembly operators should move from one station to another to perform specific assembly steps. The assembly task is divided into several stations and several operators assembly the complete unit. As volume goes down, fewer operators work on more station, but do not perform more tasks at one station. As volume goes up, more operators work on fewer stations. But the work content per work station should keep constant as the stations is designed to accommodate particular tasks including the necessary raw material.
Average Score:	3.5	Medium	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair is applicable to the Houston facility.

Recommendation:

1. Perform facility layout analysis along with each value stream map for new products added to the floor.

FR-DP Pair: D22	**FR:** Minimize wasted motion in operators' work preparation		**DP:** Standard tools / equipment located at each station (5S)
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We have defined locations for all tools.	2		
Tools to perform a task are frequently missing.	R 3		
We enforce keeping work stations in clean and orderly condition.	3		
Average Score:	2.66	Medium	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair is applicable to the Houston facility.

Recommendation:

1. Define locations for tools.

2. Implement 5S program.

FR-DP Pair: D23	FR: Minimize wasted motion in operators' work tasks		DP: Ergonomic interface between the worker, machine and fixture
Question	**Score**	**Evaluator Comment**	**Concept Comment**
We continuously improve workplace ergonomics by rearranging equipment, tools, material presentation etc.	3		The physical structure of the cell should be flexible enough to realize improvement suggestions.
We use time studies to update standard work sheets.	2		
Ergonomic interfaces among worker, machine, and fixture are an important consideration during initial layout design.	2		
Average Score:	2.33	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

This FR-DP pair is applicable to the Houston facility.

Recommendation:

1. Perform process mapping and documentation of common processes.

2. Use of virtual manufacturing to analyze ergonomics.

FR-DP Pair: D3	FR: Eliminate operators' waiting on other operators		DP: Balanced work-loops
Question	**Score**	**Evaluator Comment**	**Concept Comment**

Balancing work loops of operators is an important system design objective.	2		Must consider the range of possible operating points of the cell. For example, during low demand periods, an assembly operator may work on 5 work stations with a work loop of 5 minutes. During high demand periods the operator works on 2 stations with a work loop of 2 minutes. For each desired output rate of the cell, it is necessary to define work loops for all operators and balance the work loops.
It is often the case that within a team of operators some are idle for part of the cycle, while others are busy for the entire cycle.	R 4		
Average Score:	2.0	Poor	1=strongly disagree 5=strongly agree R=reverse question

Discussion:

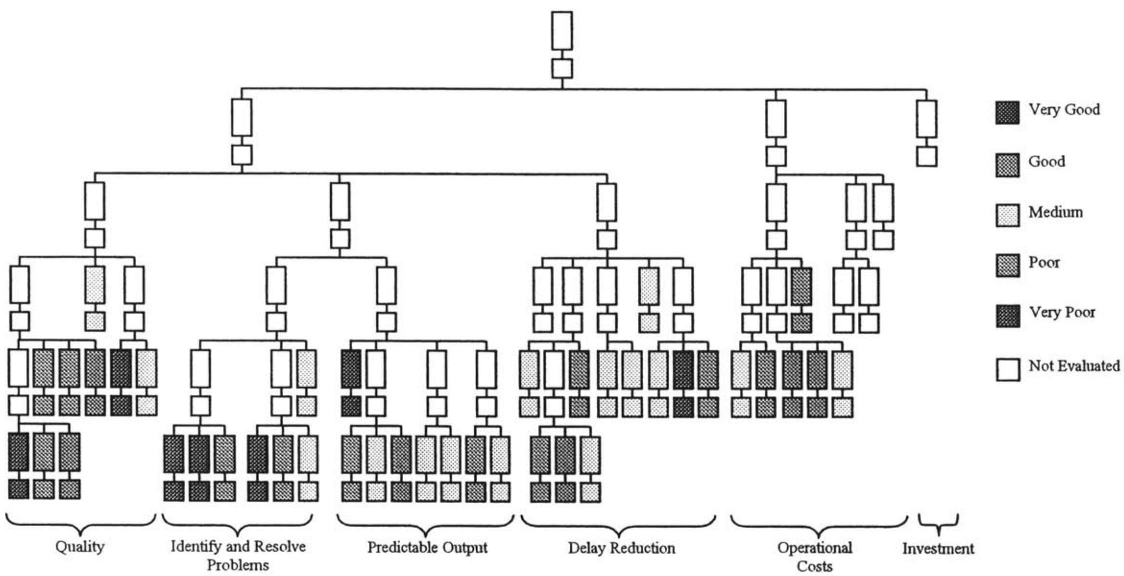
The balancing of work loops was discussed above. This is critical to successfully create a rapid response facility. To improve resource availability of operators, TOC can be used to perform shop floor scheduling.

3.2. Houston Site Functional Interaction Evaluation using MSDD

When we discuss a "Rapid Response" facility we must take into account not only the operations of the manufacturing facility, but also the interactions of all functions. The ability to respond quickly by any functional group could be severely hampered by a slow response in one of the other functions.

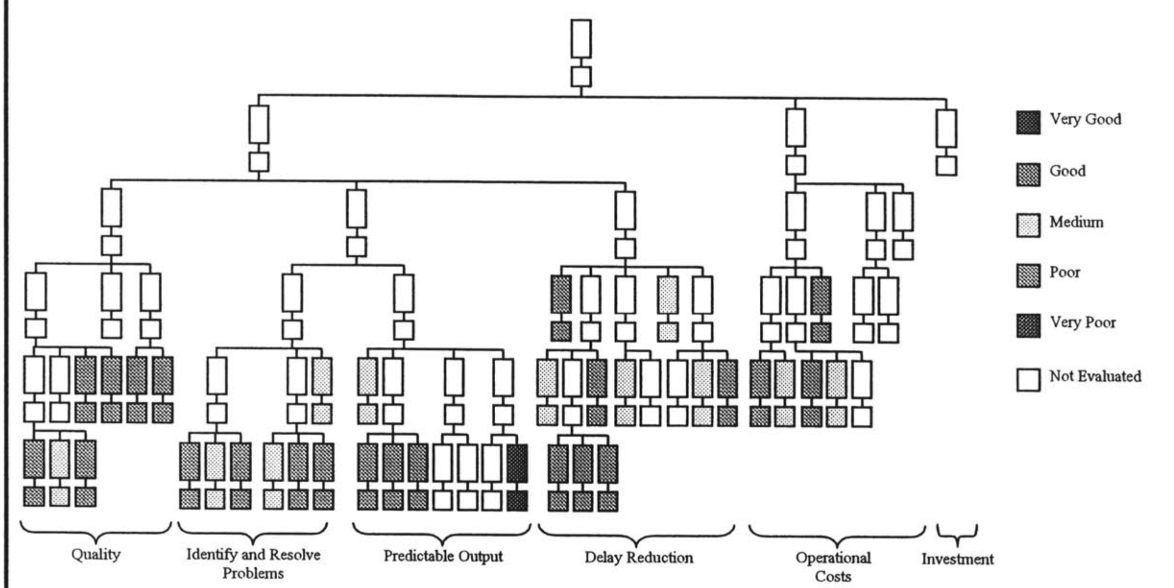
The MSDD provided insight into the manufacturing floor operations and seemed to be portable even with some of the distinct differences of product mix. In an attempt to evaluate how well the Houston site operates as a system I decided to once again apply the MSDD evaluation tool. Understanding that the questions were very much posed in a manufacturing framework, I asked evaluators to read the question and then look at the Houston site functional groups process flows and interactions as if each were a manufacturing station. They were instructed to use their best judgment in question interpretation and association with their function. I asked them to perform the evaluation again from this new perspective. Results are shown in Table 5 and Table 6.

Table 5: MSDD Evaluation of Houston Site General Process Flow – by Eric Schmidlin



MSDD Branch	Very Poor	Poor	Medium	Good	Very Good	Not Answered
Quality	2	4	1	2	0	0
Identifying and Resolving Problems	3	2	2	0	0	0
Predictable Output	1	2	4	1	0	0
Delay Reduction	1	3	6	1	0	1
Operational Costs	0	2	2	2	0	0
Total	**7**	**13**	**15**	**6**	**0**	**1**

Table 6: MSDD Evaluation of Houston Site General Process Flow – by Boeing Representation



MSDD Branch	Very Poor	Poor	Medium	Good	Very Good	Not Answered
Quality	0	6	1	0	0	2
Identifying and Resolving Problems	0	4	3	0	0	0
Predictable Output	0	3	1	0	1	3
Delay Reduction	0	6	4	0	0	2
Operational Costs	0	3	2	0	0	1
Total	**0**	**22**	**11**	**0**	**1**	**8**

One of the biggest challenges in performing this evaluation was in the question interpretation and association of the manufacturing task with a corresponding functional process task. I split the results that I obtained in my evaluation from that of the Boeing representative because of the difference in quantity of questions left unanswered in the Boeing representative's response. I believe this to be a result of the difficultly in forming a connection between the questions posed in manufacturing terminology with formulation of corresponding questions in a functional interactions sense. This difficulty seems to have taken place in the predictable output section of the MSDD, where one might expect this difficulty to be. The predictable output section talks extensively about equipment. For my evaluation I tried to answer the questions with the association of manufacturing equipment to be correlated with office equipment, like computers, copy machines and such. I looked at parts and operations often in the sense of drawings and creation of the drawings, respectively.

In any event the results point to the same conclusion: They tend to accrue around the poor ranking. This is particularly true for the "Identification and Resolution of Problems" portion of the MSDD. This signifies a tremendous lack of communication, a lack of process visibility, or both.

By forming a cross-functional team to perform process mapping and value stream mapping, communication will begin to improve, and the resultant product will be a fully connected, well-documented process flow. With this in hand the site can begin to work at eliminating non-value-adding steps from the processes. The mapping team can use the map to identify the critical touch points between the functions and identify ways to improve communication and information flow.

An additional way to improve could be with implementation of appropriate business systems, such as an ERP system. With process and value stream maps in hand critical capabilities of a business system can be identified. A gap analysis can be performed against existing business systems. At this point the team will have sufficient information to identify what systems may be available to fill the gaps either through a full installation or through separate components, depending on other requirements identified and costs.

3.3. Requirements of a Rapid Response Facility

3.3.1. Requirements Identified with use of the MSDD Evaluation Tool

Looking at each of the FR-DP pairs associated with the MSDD evaluation tool provides substantial insight into criteria important to not just repetitive manufacturing facilities, but also non-repetitive manufacturing facilities. Although the MSDD FR-DP pairs themselves were not derived specifically for the manufacturing environment found at the Houston site, all except one had valuable lessons and suggestions for operational improvement at the facility. It seems that the MSDD is partially portable to this type of environment. Some of the FR-DP pairs of the MSDD may need to be revised for extensive use in this environment.

It is interesting to note that one of the goals of the MSDD is to decouple the FR-DP pairs. And yet as the review of the MSDD facility evaluation unfolded, it became evident that the implementation of just a few recommendations could significantly improve the effectiveness of the facility.

Key Recommendations:

1. Perform Processes Mapping:

Processes need to be documented and made available to operators. Because of the one-off type nature of the products created at the facility it is difficult to map processes.

Look for common operations across products. Standardize those operations and document them electronically and/or by hard copy. For the remaining operations that are not common across products, look for "similar" procedures and track their cycle times. Although specific procedure information cannot be defined, commonalities and general operation procedures can be grouped to provide average times for use in scheduling, creation of value stream maps, and cost estimation for future products.

Documenting the processes establishes a baseline. For quality and other issues procedure (processes) must be adhered to. A system can then be created which seeks input and improvement recommendations from operators. The documented process becomes the baseline upon which to "Kaizen".

2. Value Stream Mapping:

As discussed in the evaluation, it is important for operators to be familiar with the whole value stream. By definition a value stream is product dependent and associated with only one product. Since most of the products at the Houston facility are non - repetitive one-of-a-kind products, each would ultimately have its own value stream. As a result it is difficult to convey the required operations both up and down the value stream for a given product. A generic process flow that represents the most common value streams could be designed and made visible to workers to provide generic factory floor information and general flow.

In the future before a new product is accepted into the facility, manufacturing engineers could contribute to the design process. Their contribution is not only for manufacturability purposes but also to create and document the value stream map for that specific product. The value stream map should include all pertinent information, like cycle times, quality inspection points, etc. This mapping could then be displayed at the work station assigned to that product.

3. Theory of Constraints:

TOC came to mind for a number of uses. Specifically TOC scheduling is based on "average" processing time. Since for many operations all we will have is a best guess of what the processing time will be based on "averages" of similar processes performed in the past TOC seems to be a good substitute to a kanban system. The use of buffers and through its inherent capability of resource leveling TOC provides some stability to the system. The TOC displayed graphically at each work station will also aid as a visual cue of scheduled processing time and amount of buffer capacity consumed.

4. Business Systems and Visual Cueing:

Business systems seemed to come up fairly regularly as well. In a dynamic environment such as the Houston facility the, use of business systems to aid in the gathering and documentation of information is invaluable. Two examples that came up were the use of virtual manufacturing and a manufacturing execution system (MES).

Ensuring that a product can be manufactured and ensuring procedures for lifts, assemblies, and any other required operation is functional, safe, and efficient is critical. To cut time and possibly costly mistakes on the shop floor, these types of operations can be performed virtually. Having the procedures performed virtually via an electronic tool will enable all pertinent product design team members to design assembly processes regardless of geographic location. When the time comes to perform the operations at the manufacturing work station, a digital representation could be played at the operator's work station accompanied with detailed work instructions. This ability can be provided through the use of a good MES system and the use of virtual manufacturing software.

Electronic work instructions at each work station, provided via a MES, could display a time bar signifying the scheduled time. As the process is executed the bar could fill with a green bar. Once time reached the last 10% of scheduled time the bar could turn red. Once it reached the end of the scheduled time it could automatically turn on an andon light signaling a support team that help is needed. Regardless of the use of an MES system manual andon lights can be placed at each work station. When the andon is illuminated a predetermined team would form to determine the root cause of the disruption.

If an automatic inventory and storage system has been installed then a pick-to-light application would work well. The computer controlled inventory and storage system would in essence be the pick-to-light tool. It could be scheduled to pull each part based on a kit number. The computer can store this information in a pick list as created during the joint design sessions. When the part is stored the computer can remember where that part is stored. This can eliminate the time spent waiting and searching.

5. Kitting

The majority of the space flight hardware assembled in Houston requires close geometric tolerances. For this reason and because of the hardware's significant size, it is often fixtured in place to the floor of the manufacturing facility. It is therefore impossible to implement any type of a moving production line. To ensure the correct parts are on hand at the appropriate time and in the appropriate work cell, a kitting process can be used. In this process a kitting contents pick list could be created with a pictorial representation of each part. At some time prior to being required, a runner could be tasked with filling the pick list.

6. Supplier Relations

Creating a rapid response facility requires that parts are available when they are required. Since there is only one product being produced it is also critical that that part is received from the supplier with perfect quality. Some time should be spent working with procurement to express the importance of using suppliers with high quality and predictable lead-time. A supplier benefits programs based on quality could be devise to align incentives. One possible example of this type of program may focus on payment terms. If quality is good, payment made to supplier in shorter time period; if poor quality, payment terms are extended. It is tempting to provide some incentive based on lead-time; however, using TOC as a scheduling mechanism, one might prefer that they provide a 50% estimate on lead-time. If incentive is provided for meeting their promise date then it will promote the inflation of their lead times. To operate efficiently we need accurate median lead times and can use TOC to account for variability in delivery.

3.3.2. Organizational Requirements

Sections 2.7, 2.8, and 2.9 all take a look at the Organizational aspects of companies. The organizational strategy is the backbone of an organization. If it is not correctly structured the company will fail. The result of the research conducted by Diane Burton showed five archetypes that worked for new ventures. Although Boeing is a large existing corporation, evidence shows that it must evolve to meet the demands of the new world. I have included this information to convey the structures that we know work.

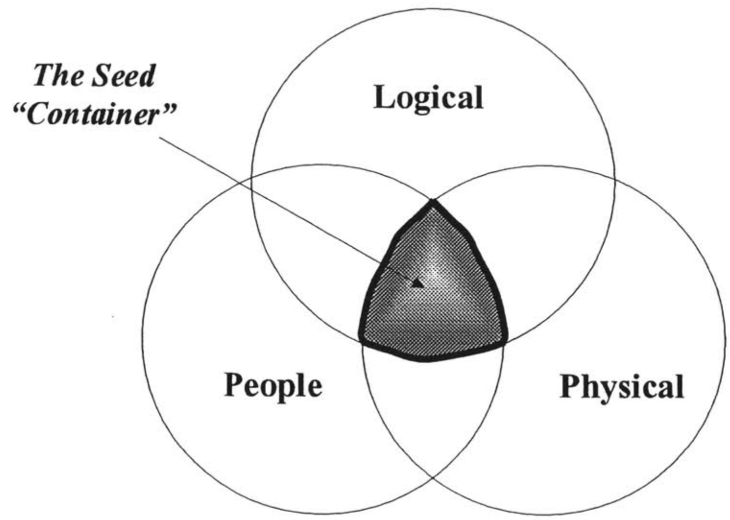
As addressed in the ORGANIZATIONAL INITIATIVE ANALYSIS (Section 7.2) the Boeing Space and Communication Houston Site is still working through challenges associated with the recent acquisitions of McDonnell Douglas and Rockwell. As the distinct cultures of the three groups meld together it is important to keep in mind corporate strategy, how this site contributes to that strategy, and how best to structure the site organizationally. The idea is to maintain congruence (Section 2.8).

The ORGANIZATIONAL INITIATIVE ANALYSIS (Section 7.2) also discussed structuring a Lean Enterprise Group directly under corporate management. This group requires support and influence across functions, being established directly under corporate will aid in attaining this necessary support. The group should have specific funding and create the environment through which real change in the organization can be catalyzed without the dilution that is often observed by large corporations trying to implement the latest craze.

Cochran and Issacs (2002) [11] clearly articulated this idea as "creating the container." Isaacs defines a container "is a pattern of relationships among people that enable them to sustain a high level of shared goals, energy, and coordinated actions" [7]. Cochran and Issacs (2002) [11] go on to discuss the container:

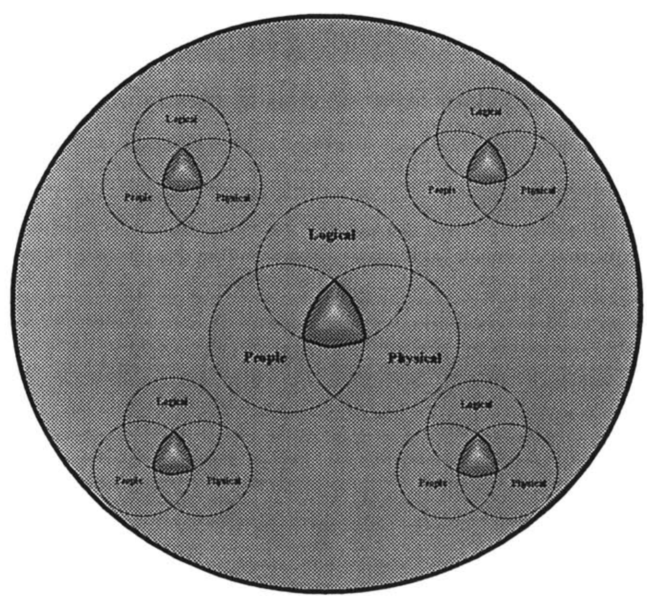
> In its simplest form a container consists of two major components—the boundary, and its contents. The boundary of the container represents the outer limits within which the functions within the environment can operate. The contents of the container can be thought of as being formed by 1) the patterns of structural relationships that guide 2) the activities that make the system run on a daily basis. Thus the 'container' can be visualized as the intersection of three patterns of relationships—with each pattern being necessary but not individually sufficient to form the fresh water, or seed, container [Figure 6].

Figure 6: Building the seed 'container'



When referring to an enterprise subsystem, the "seed" container—or fresh water environment—is just one of many instances in time and space, and is within the bounds of the enterprise container [Figure 7].

Figure 7: Multiple seed containers in an enterprise



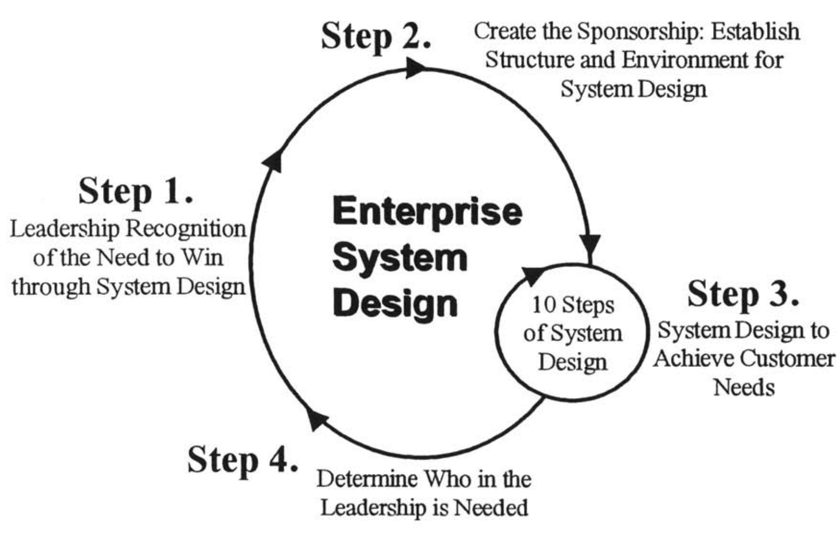
A well-developed container is one in which the people have reached a level of generative interaction that is stable, is reliable in its ability to handle pressure, respond swiftly and intelligently to problems, and can sustain itself through reflection and active learning.

> The container supports the system design cycle of designing, testing, reflecting. Containers represent the critical and missing bridge between the existing piece part or fragmented state and the new organization.

This notion of "creating the container" provides an environment that a Lean Enterprise group could work. The group would not necessarily be a static bureaucratic function like Lean groups of yesterday, but rather a team of integrated functions. Ideally, this group would have its own allocation of funds and would be tasked with creating other seeds throughout the organization both on a corporate as well as site level. These seeds would be the catalysts for change and would orchestrate all Lean activities to include the "latest craze".

Cochran views this unique approach, the 4+10 System Design & Implementation Process, in combination with the MSDD as a powerful change agent. The MSDD specifically targeted the Logical and Physical domains but missed the People element. The 4+10 System Design includes the people element to complete the container and Cochran believes this will have a dramatic impact on tomorrows manufacturing centric organizations.

Figure 8: The 4+10 System Design & Implementation Process



3.3.3. Requirements of a Business System

Requirements of the business system to be installed at the site really need to be evaluated by a cross-functional team at the site in question. The team charter that was developed during my internship should aid in that process. It is necessary for the evaluation to be performed by the team to increase communication across functions and identify processes that cross functional boundaries, as well as to identify interface points between functions. It is also necessary that the business systems that are chosen interface cleanly together. Many of these interfaces between functions and business systems are considered proprietary. For this reason, this thesis focuses primarily on the generic requirements of a business system.

Generally speaking, the systems should consist of an ERP component, MES component, and a PDM component. Since interaction is required between many Boeing sites, the systems in use at those sites need to be seriously considered. The cost associated with upgrading all of the sites at the same time would be prohibitive. With the vast differences in products manufactured at the sites, the same system may not make sense for every site anyway. My recommendation to Boeing is to perform an analysis, like that underway at Houston. Identify sites that have similar requirements and lump them together into groups. Once this has been done, system selections can be made for the similar groups to create a business system vision for the future with specific business systems identified. As sites obtain funding for system upgrades, the system's upgrade path will have been identified and this will eventually stop the propagation of mismatched, numerous systems across Boeing.

New information about requirements of a business system that were identified as a result of this thesis includes:

1. Requirement that the business system be capable of working with Theory of Constraints.

2. Identification of a challenge for the site to meet the necessity to quickly identify and resolve problem conditions in the process flow and value stream across functional organizations. As a result aspects of the interface between functions need to specifically be investigated and addressed

3. For shop floor, look at placing computers at each work station that will display electronic work instructions.

4. For shop floor consider electronic inventory storage and control system with pick-to-light technology.

If an assumption is made that there is more demand for these specialized products then, investments for improvements can be justified not only by cost savings that could be reaped from efficiency, but also from the revenue increase that can be achieved with the resulting throughput increase.

Having stemmed from MRP, ERP carries with it many of the same approaches for manufacturing resource control. Although ERP is required to pull functions together, the MRP portion may not be the right tool for a make-to-order facility such as is the case for non-repetitive manufacturing. Specifically MRP makes some basic assumptions that may not be valid in a make-to-order environment (Table 7) [14].

Table 7: MRP Assumptions

MRP	Make-to-Order
• emphasis on planning and managing inventory • most items will be held in stock • many items will be ordered in economic batch quantities • all items will have meaningful standard lead times • bills-of-material will exist for items to be made or purchased before they need to be ordered • purchased items will be received into stock before being re-issued to work-in-progress • capacity planning can be on an infinite capacity basis with no direct links between work orders for components and the sub-assembly work orders on which they will be used • costing will be by item and product, on the basis of standard costing • cost variance analysis will be focused on the individual materials, components and sub-assemblies, and the resources being used, and will be compared on a batch by batch basis over a period of time • the costs of functions such as design and production engineering can sensibly be absorbed into 'over-heads'	• emphasis is on planning and managing work-in-progress and/or purchase commitments • only a few raw materials and very common components will be held as stock items • most items are never held in stock, only being procured or manufactured for each individual customer order • the quantity procured or manufactured will be that required for each order – except for the few stock items which may be ordered in economic batch quantities • long lead time materials and components required for a customer order may need to be purchased long before a formal or complete bill-of-material is available • the mix of items in production on the shop floor can be extremely variable and hence the lead times of individual items can very significantly • realistic delivery dates need to be promised, usually requiring finite capacity constraints to be considered, and for the order as a whole, not just individual components or assemblies • many items purchased for individual customer orders are issued directly to production from goods inward/inspection

MRP	Make-to-Order
	inward/inspection • costing is on the basis of actual or standard costing of individual customer orders • actual costs will often include the contributions of salaried functions such as design and production engineering as well as direct labor and materials • cost variance analysis is on the basis of individual customer orders, and often involves the monitoring of committed as well as actual costs for each customer order against budgeted or estimated costs

When selecting a business system ensure the software tools take these aspects into account.

3.3.4. General Discussion

A much stronger link needs to be established among product development, manufacturing and support functions. The entire process needs to be run as a project, and at times leadership may be required from different sources. For this reason a new approach is needed. This approach may incorporate many of the previously discussed concepts, and will certainly need an organizational mind set shift and potential reorganization. A structure or "production system" which is agile and able to adjust on the fly is required.

The concepts and aspects discussed in this paper ranging from organizational structure to intricacies associated with non-repetitive made-to-order manufacturing tie into the creation of a rapid response facility. Not only must this facility provide rapid response but also contend with difficulties inherent in the Space Flight Hardware product specialty. The design, assembly, integration, and test of such products are challenging tasks. Throughout the process the customer often changes product requirements or overall design. In the creation process customer funding may dry up, the customer may change their priority preference of products to be completed, and the product creation may need to be coordinated with Boeing and customer teams from multiple sites across the country.

The Boeing Company has been extremely successful in this specialization, but like any good company they want to improve. One approach they have taken to improve is through the use of Lean Manufacturing. As discussed in Section 2.2, Lean has been taking the manufacturing world by storm. Toyota had so much success that others saw the value in implementing the same principles. The unique challenges associated with Boeing's specialization make it difficult to implement the current understanding of lean systems and manufacturing control.

Lean Manufacturing is based on having a relatively stable demand and a limited degree of customization. These are required for successful implementation of a "pull" system. Womack and Jones [3] support much of this notion of the lean environment by stating that "end-use demand of customers is inherently quite stable and largely for replacement." In his book Rajan Suri explains [5] "for a company that custom designs and fabricates each product: the pull system fails at the very first step". He clarifies by explaining "There is no product in finished goods, since the parameters of the product are not known till the order is received." And that "the intermediate stages cannot have the required inventory to pull from either, since stages whose operations depend on the parameters of the final product cannot start production until the actual order is engineered."

The above discussion is not meant to suggest that Lean Manufacturing has no place in non-repetitive manufacturing, but rather to emphasize that not all components of Lean are applicable. The Lean Aerospace Initiative states [16]: "A primary concept of Lean thinking is that all actions and resources of a firm should be focused on *creating value for its customers*." This notion is valid and important to the facility. In one sense the creation of the Rapid Response make-to-order facility, like that which is being created, takes this idea to an extreme. Other Lean principles such as the elimination of waste also make sense. Similarly, many Lean concepts are designed into the MSDD, which we have found to provide great insight to the operations of this type of facility.

Rajan Suri has devoted significant time to the research of "Quick Response Manufacturing" (QRM). He defines QRM in two contexts as follows [18]:

> (i) Externally, as perceived by customers, QRM means responding to those customers' needs by rapidly designing and manufacturing products customized to those needs. In so doing, we will show that QRM goes beyond the established goals and even the capabilities of Lean Manufacturing.
>
> (ii) Internally, in terms of a company's own operations, QRM focuses on reducing the lead times for all tasks in a company, resulting in improved quality, lower cost, and of course, quick response.

QRM's focus is directly on the reduction of lead times to attain the desired results of a rapid response facility. Rajan Suri states "70 percent of the policies in use by managers and their companies were major obstacles to lead time reduction" [5]. What Rajan Suri has done is move the focus from the relentless emphasis on the elimination of waste, which is the mantra for Lean, to the relentless emphasis on the reduction of lead-time, the mantra for QRM. The inevitable result of reducing lead-time is increase in the speed of the company and reduction of the time to market for a product. This is an excellent strategy to solicit in the quest for creating a rapid response facility.

Reducing lead times in all aspects of a company at the same time could require significant resources. A phased approach may become practical. To identify which processes should be lead-time kaizened why not use TOC to identify the bottlenecks and make that the target. The use of TOC provides an additional benefit. As previously discussed TOC provides the ability to level resources in the production schedule and creates a "critical chain" which can act as a pull mechanism to operations.

Lastly, the "seeds" throughout the organization should guide coordination of effort and tactics implemented in the quest for a "Rapid Response Facility".

3.4. Implementation of Identified Requirements

With the requirements of a rapid response facility identified, a transition plan needs to be created so that solution implementation can begin. Many of the strategies discussed have implementation processes associated with them. During my internship I began what I believed the most appropriate method of implementation. In hindsight I would have executed the steps in a different order but they are presented in Table 8 as they were executed. **Error! Reference source not found.** Table 8 contains abbreviated implementation steps for various strategies too provide a perspective and comparison of leading strategies.

Commonalities of the implementation procedures tend to focus on gaining top management support, with some instances even incorporating the philosophies into the strategic plan. The reason for this is simple: without the support of top management any implementation will eventually fail from starvation of resources or lack of interest.

Another commonality is the requirement that existing processes and their various interactions be understood. It is not until existing processes are understood and documented that they can be improved. LESAT [16] states "Lean requires a deep understanding of the fundamental aspects of an Enterprise and a vision for its interactions with the rest of the world." And that "in a complex Enterprise, it is useful to visualize and consider the balance of the primary value streams that flow to all of the primary "stakeholders." It is important to optimize across these value streams by taking a global systems view."

Table 8: Implementation Steps for Various Philosophies (Step 1 through Step 4)

	Step 1	**Step 2**	**Step 3**	**Step 4**
LESAT Lean Transformation	Enterprise Strategic Planning	Adopt Lean Paradigm	Focus on the Value Stream	Develop Lean Structure and Behavior
Process Management	Identify company processes, typically 5 to 10	Make people throughout the company aware of the processes and how their work fits in	Create and deploy measures of end-to-end process performance, derived from customer and shareholder needs. Assess current process performance and set targets	Designate process owners: senior managers with end-to-end authority for a process, responsible for ensuring consistently high performance
QRM	Get top management support	Steering committee and champion	Pick a potential product and set rough goals	Put together the planning team
TOC	Describe your system	Verbalize your systems goal and necessary conditions.	Imagine in what ways the organization would look differently if it were in a throughput world.	Examine the organization with the point of view that there are leverage points.
My Internship ERP Plan	Identify existing business systems in use	Create cross functional team	Begin process and value stream mapping. Share mappings across functions.	Create charter to gain greater management support from all functions
10 System Design Steps	**The Thinking**—Establish the system design relationships in terms of Requirements and Solutions.	**Bubble Diagram**—Define a bubble diagram for each value stream.	**Know the Current State**—Understand the present system (VSM) and operating measures.	**Evaluate Current State**—Assess how well the system design FRs are being satisfied by the current state DPs.
4+10 System Design	Leadership Recognition of Need to Win through System Design	Create the Sponsorship:" Establish Structure and Environment for	System Design to Achieve Customer Needs (Use the 10 System Design Steps)	Determine Who in the Leadership is Needed

		System Design		

Table 8: Implementation Steps for Various Philosophies (Step 5 through Step 8)

	Step 5	Step 6	Step 7	Step 8
LESAT Lean Transformation	Create and Refine Transformation Plan	Implement Lean Initiatives	Focus on Continuous Improvement	
Process Management	Select 2 or 3 processes for redesign and improvement. Implement those new designs in staggered fashion	Over time, align the company's management systems with the new prominence of its processes		
QRM	Invest in team building	Get rough measures of current system performance	Refine scope and set more precise goals	Conduct detailed data gathering and analysis
TOC	Look for people and policies that can block implementation	Implement five-step improvement process		
My Internship ERP Plan	Use process maps to identify critical capabilities of systems	Perform GAP analysis	Brainstorm solutions to fill GAPs	Make recommendation
10 System Design Steps	**Design Future Ideal**—Based on the gaps in FR achievement, define future state system design to meet these FRs.	**Contrast Physical Simulations**—Create physical working model of the future state value stream with all team players and organizations in agreement.	**Integrate, Infuse and Implement**—Clearly define the work, train, and implement the system design	**Alignment of Measures**—Define and align new performance measures to drive behaviors to support the system design requirements.
4+10 System Design	Repeat			

Table 8: Implementation Steps for Various Philosophies (Step 9 through Step 12)

	Step 9	Step 10	Step 11	Step 12
LESAT Lean Transformation				
Process Management				
QRM	Brainstorm solutions	Present recommendation	Create implementation team	Team-building and training for the implementation team
TOC				
My Internship ERP Plan	Perform installation			
10 System Design Steps	**Evaluate New System Design—** Determine if the new system design meets the FRs consistently.	**Leverage the Learning—**Reduce cost by improving 'the work' of the system design via a Continuous Improvement Process.		
4+10 System Design				

Table 8: Implementation Steps for Various Philosophies (Step 13 through Step 15 and Notes)

	Step 13	Step 14	Step 15	Notes:
LESAT Lean Transformation				Extracted from the LESAT [16]
Process Management				Extracted from "Process Management and the Future of Six Sigma" [17]
QRM	Implement recommendation	Progress review, presentation, and recognition	Repeat process with additional QRM Products	Excerpt from QRM [5]
TOC				Derived from questions asked in Newbold, 1998 [6]
My Internship ERP Plan				In order as experienced.
10 System Design Steps				As described in Cochran and Isaacs, 2002: [11]
4+10 System Design				As described in Cochran and Isaacs, 2002: [11]

4. FUTURE WORK

To date only the beginning of the process of evaluating needs of a Business System have been started at the Houston Site. The other aspects of this paper have not been implemented. A test site needs to be identified and the combination of ideas expressed in this paper needs to be tested.

The MSDD evaluation tool proved itself useful for performing a general evaluation of a non-repetitive environment because many of the underlying concepts were portable. The actual decomposition could be modified to explicitly describe FR-DP pairs required for a rapid response design assembly integration and test facility of non-repetitive products.

5. Conclusions

Through the internship process and supported by the creation of this thesis I have observed that there are many strategies used to improve the efficiencies of corporations. All claim to be the next best thing. All vie for precious resources. It is not possible for any organization to perform all of these strategies at once. The many acronyms that fly about are mind-boggling and can create a workforce that is non-responsive to the next effort. After all it is just "the flavor of the day."

A cross-functional team could be created to fill the role of the current initiatives. All of the initiatives boil down to a process flow, a value stream. The cross-functional team created should be in charge of documenting and improving this flow. They should be given latitude to use the most appropriate tools called for by any given process, not by the latest, greatest initiative. The team should be provided resources, should communicate regularly at all levels of the organization, and in my opinion this team should have some rotating membership from various functions to further enhance communication and awareness. The team must be cross-functional and must have decision making authority for their respective functions. Improvements must be at a "systems level" not a local level. "Local, one-person or one-area improvements are insufficient to enable an organization to keep up in today's world" [6]. Ideally this team will have a thorough understanding of how the systems components interact with each other, and how the entire system interacts with its environment. Ultimately an organization's success or failure is a function of how well the different enterprise component processes interact with one another.

To create a "Rapid Response Design, Assembly, Integration and Test Facility of Non-Repetitive products" a team of this sort must be created. The team must then complete process mapping and implementation of the requirements identified in Section 3.3.

For this team to be effective in the new environment they must be supported and embraced at all levels of the organization. They must be supported through "seed containers" created across the organization. The establishment of this environment will have significant impact on the organization's ability compete effectively in the new environment.

A rapid response facility can be created. Before it can be effective the culture, processes and policies must be established and continuously improved using a standard structure, which can also be improved. A company cannot be transformed over night but through the use of a structured approach that ties requirements, solutions, and performance metrics together it can be accomplished through an iterative approach.

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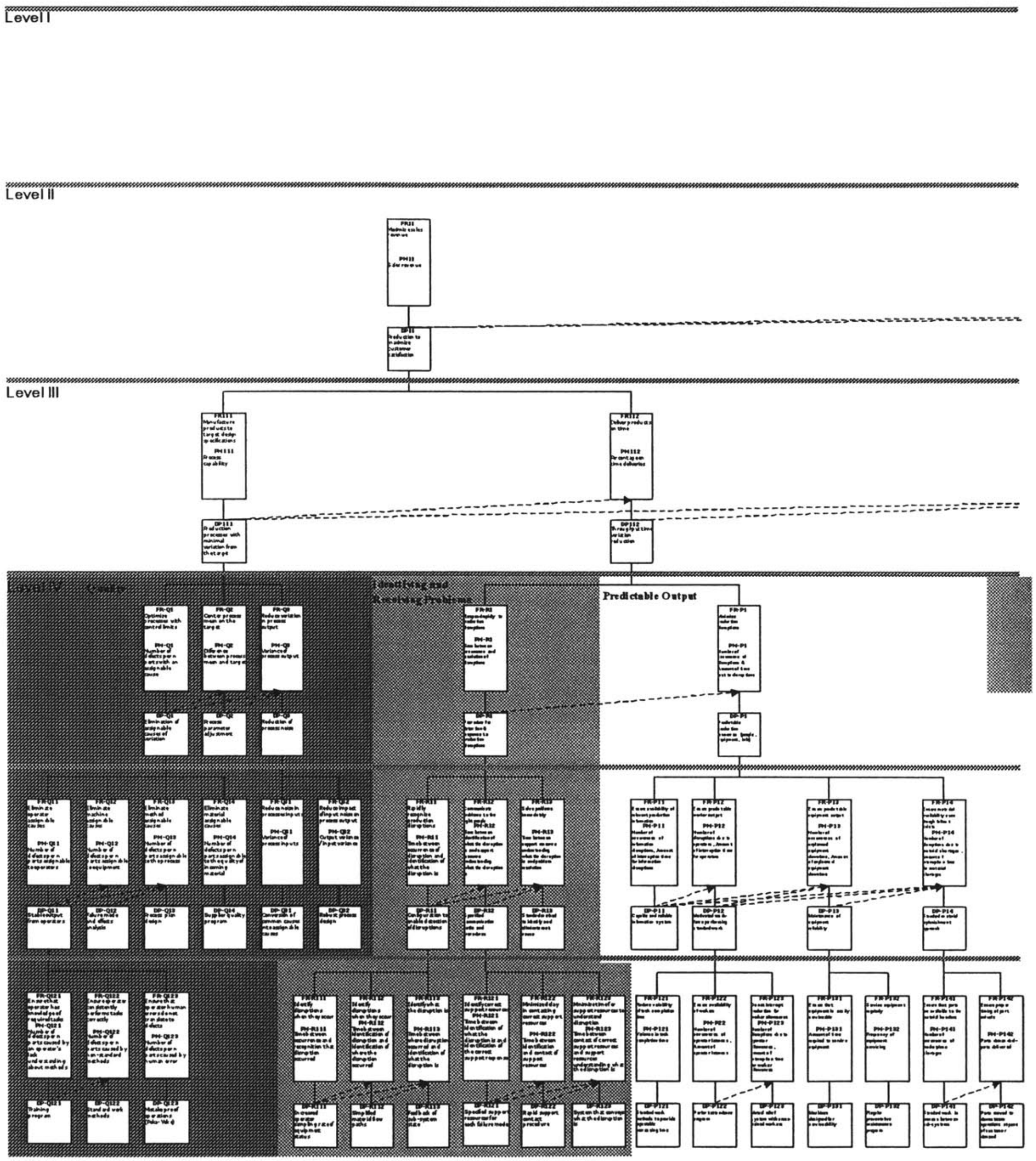
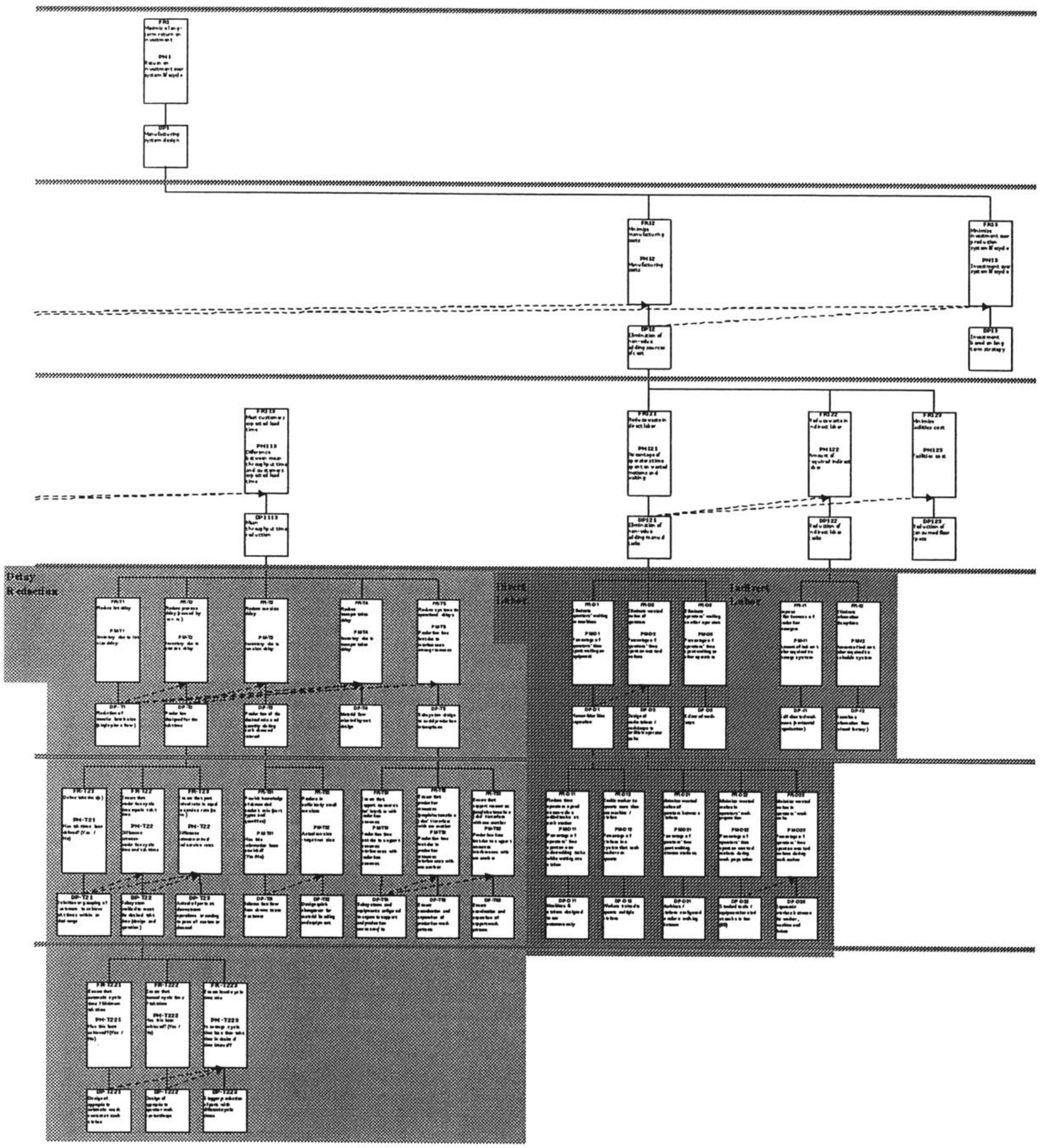
7. APPENDIX

7.1. Manufacturing System Design Decomposition Layout



Manufacturing System Design Decomposition Layout (Continued)



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7.2. ORGANIZATIONAL INITIATIVE ANALYSIS

ORGANIZATIONAL INITIATIVE ANALYSIS
For The
LFM Internship Project
with

Boeing Space and Communications
(Houston, TX)

Organizational Processes Evaluation for
Boeing Internship (June through December 2001) by
Eric P. Schmidlin

Questions and Outline Developed by
T. Kochan (tkochan@mit.edu)

INTRODUCTION

One of the major assignments for the organizational processes class is to analyze your internship project as an organizational change initiative using the concepts and tools introduced in this course. You are responsible for preparing a 15-20 page report analyzing your project as an organizational change initiative. We encourage you to include this as part of your thesis. In addition, we expect you will discuss these aspects of your project in your oral presentation at the "Knowledge Review" when you return to campus In January.

This guide outlines a number of topics and questions to consider in planning your data collection and analysis and in preparing your report.

TOPIC #1: Background & Brief Description of the Project

As a first step in your analysis, describe briefly the organizational and technical features of the project, its history, and the organizational context in which it is situated.

Consider the following questions:

-What is/are the ultimate goal/goals of the project?

As with most LFM internships the project description and the actual internship project activities are often very different. The original project description for this project was as follows:

> Boeing is the prime contractor of the International Space Station, with headquarters linked to the Johnson Space Center in Houston, TX. While the technical, political, and international coordination issues related to this project receive frequent media coverage, significant business challenges also apply. In particular, the highly uncertain and unknown manufacturing needs of a project such as the Space Station compromise both cost and schedule. This condition hampers decision-making related to systems architecture and jeopardizes contractor profitability. An LFM intern would help develop tools to develop these issues, perhaps by tailoring integrated product development modeling techniques from more "predictable" industries to apply to the Space Station. The significant archive of historical data from Space Station work to date could be used to form the basis for making future estimates and building trends. Ultimately, these tools would provide the ability to better forecast production performance on development contracts and possibly provide the basis for a new type of parametric product development modeling.

To keep inline with internship project goals, described above, and specifically to provide a project that will "have a significant impact on the host company" Boeing chose to redirect the project focus. As site focus and site needs continued to evolve and change, the project boiled down to the identification and implementation of an appropriate ERP system for the Houston site. The process of implementing this type of a system is very intricate and challenging. It called for creating a cross functional team and the internship concluded with the creation of a charter to guide the activities of the team through process mapping, value stream mapping, identification of core capabilities of the business system (ERP system) and ultimately implementation of the ERP system.

-Why was this project chosen, i.e., what problems, needs, and/or opportunities is it intended to address?

The Boeing Company is the prime contractor for the International Space Station and the developer of the Space Shuttle. Through acquisitions they now own most of the contractors who provide components and devices for the above equipment as well as many other trinkets required of NASA engineers and astronauts. As such NASA inundates Boeing with requests to design and manufacture many different things. At the beginning of the internship Boeing had five facilities used exclusively for supporting these types of demands for the International Space Station alone. Boeing felt that continued support of the rapid response design, assembly integration and test of various hardware components as well as the main projects are crucial components of customer relationships and helps them to stay in the driver's seat for business with NASA.

With the increased cost reduction pressures placed on the International Space Station, Boeing has been looking for ways to reduce the cost associated with providing this quality of responsive service, without reducing quality or increasing lead times. To address this issue Boeing has decided to consolidate their support operations. A new facility has been built in Houston to house these operations that include two primary tasks: design development and fast track manufacturing. In essence what Boeing is creating is a high quality Job-Shop tasked with fast track manufacturing of products with "perfect quality, right quantity, right mix, and the ability to identify problems immediately."

With the multitude of systems in use across Boeing as well as within the Houston Site, my research turned toward an analysis to identify the critical capabilities of such a system for the Houston Site. Implementation of an ERP system would aid in the support and creation of a rapid response facility.

-What are the technical requirements/specifications for the project and deliverables expected?

Since the project was designed on the fly, project deliverables and expectations were not clearly defined at the onset. Originally we felt that an analysis of the business systems could be performed relatively quickly along with a review of other systems in use across Space and Communications (S&C) and once a system was chosen I would be able to relatively easily create a business case and begin implementation of the system.

What we found was that there were a number of systems in use across the Houston site as well as across Space and Communications. In addition to that we determined that communication, as it pertained to business systems, within the Houston site was poor. My investigation of existing systems would repeatedly turn up new business system initiatives of individual functions trying to improve their results. When I felt I had them all identified, yet another would surface.

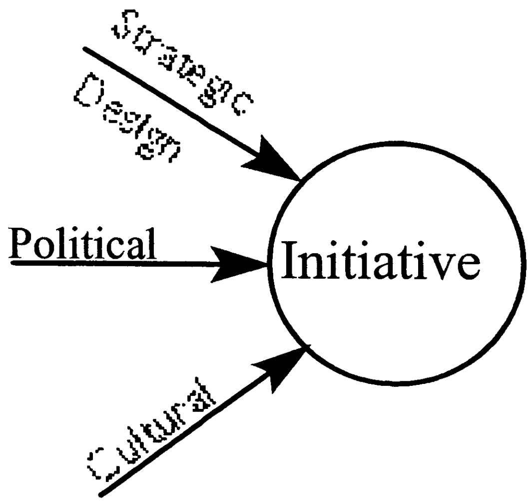
Once the most appropriate system to install was identified, through my work and guidance from S&C Corporate, I began an effort to implement that system. At this point in the internship many of the organizational issues associated with large corporations with many stakeholders began to affect the project. Some of the challenges will be discussed in this analysis and final results will be discussed under TOPIC #4.

-What is your role: Team leader, team member, individual actor? (NOTE: **If you are working as part of a team, or leading a team, you may want to review the concepts and tools regarding team processes in Modules 3-6 of the OP text [2]).**

My role initially was as an individual contributor. As an individual contributor I performed substantial research of company processes, and research of existing business systems as well as planned future business systems. At the point that an appropriate system was identified, I was charged with pulling together an implementation team to implement the chosen system. Having done significant research about ERP implementations, I recognized that for the implementation to be successful I needed to have support and contribution from all functional groups. To satisfy this requirement I started to solicit support from the various functional groups within the Houston site.

TOPIC #2: Using the Three Perspectives on Organizational Processes

Examine your project from the three different perspectives we discussed for analyzing organizational processes: strategic design, political, and cultural.



STRATEGIC DESIGN: Consider the following questions to understand how the formal structure and strategy of the organization influence the project:

-What is the strategy of this organization or work unit and how is it related to your project?

One of the key strategies of Boeing is to be able to Design anywhere and Build anywhere. A major benefit to this type of strategy is that it allows for capacity sharing. This notion suggests that there must be substantial information sharing as well. As my internship was geared toward the implementation of an ERP system this strengthened my stance. An ERP system would significantly enhance information sharing.

Additionally Boeing went through a series of acquisitions in the mid through late 1990's. This seems to have been done to increase market share and to strengthen their position with key customers. This presented a challenge to the internship because there are significant differences in the cultures of these organizations. There are also many different legacy business systems between the different companies.

-How does the project fit with the needs of the environment of the organization?

Successful implementation of this project will enhance communication between functions and provide accurate, timely, reliable information from which to make educated management decisions. In this respect, the project significantly fit the environment of the organization. Be that as it may one might ask, "Is the timing of this project appropriate?"

As mentioned above Boeing was under significant organizational change. At the time of my project they were managing the consolidation of sites, from 5 to 3. They were also still working to merge the acquisitions of McDonnell Douglas and Rockwell. This type of organizational restructuring is a tremendous task to undertake. For a large portion of the internship the operations functional organization structure within Houston was not clearly defined. Organizational structure was in substantial flux.

These activities were on the forefront of management's mind. For individuals within the consolidation there were questions of personal and positional power. Would they be promoted, demoted, or moved laterally in the organization? Along with this consolidation there were many discussions about how the organization should be structured. Should the operation's manufacturing group [Houston Product Support Center (HPSC)] maintain its independence with representatives from each function reporting to the head of HPSC or should everything be split out functionally? Who should be the head of HPSC? What type of manufacturing capabilities should the HPSC have? How can all this reorganization stay in line with corporate Boeing and Space and Communications (S&C) initiatives?

These are some very significant changes taking place within the site. Successful implementation of an ERP system requires significant support of all functions as well as executive level support when, at this time, these individuals had other major decisions to make. At the onset of the project there was no budget set aside for a project of this magnitude. Identifying implementation costs and reserving funds in a time of cost cutting was also a challenge for my project. Who should pay for such activities?

-Draw the formal structure or design of this organization or work unit in which the project is embedded. How does the formal design of the organization facilitate or hinder project efforts?

History shows that most corporations were structured after the model of the military. These structures, also known as "bureaucratic", are very much a command and control type of structure. The command and control structure has a very clearly defined authority associated with it. This structure is typically divided into functional groups with clearly delineated boundaries. As outlined by "Managing for the Future" this structure had four key strengths: predictability and reliability, Impartiality, expertise, and clear lines of control. In today's world companies have found a need to become more agile. Techniques used to accomplish this have been to transition organizations to a flat structure with fewer layers of management, transition to a flexible environment where strict rules are becoming amorphous and latitude is given to individuals for decision-making, and transition toward diversity for greater perspectives and input for creativity and problem solving. The OP Text [2] outlines some of the contrasts between what they term the old and new models (Table 9).

Table 9: Contrasting Features of the Old and New Models of an Organization

Old Model	New Model
Individual/Job as basic unit of organization	Team as basic unit
Relations with environment handled by specialist boundary-spanners	Densely networked with environment
Vertical flows of Information	Horizontal and vertical flows of Information
Decisions come down, Information flows up	Decisions made where Information resides
Tall (Many layers of management)	Flat (Few layers of management)
Emphasis on structures	Emphasis on processes
Emphasis on rules and standard procedures	Emphasis on results and outcomes
Fixed hours	Flexible workday, part-time workers

Old Model	New Model
Career paths upward, linear	Career paths lateral, flexible
Standardized evaluation and reward systems	Customized evaluation and reward systems
Single strong culture with strong expectations of homogeneous behavior	Diversity of viewpoints and behaviors
Ethnocentric mind-set	International/global mind-set
Specialist International managers	Boundary-crossers at all levels
Local value chains	Value chains crossing borders
Environment defined in terms of country of location	Environment seen as global

Like most well established companies, Boeing's organizational structure originally resembled that of the "Old Model". As the environment changed, Boeing adjusted their structure to incorporate many of the "New Model's" advantages. Some of these changes were a result of mergers and acquisitions while others were inherent in the new strategic design of Boeing.

The strategic design of an organization incorporates "strategic grouping". This grouping establishes basic command and control processes as well as internal and external Interface points. The grouping of an organization and how effectively those groups have been formed can have significant Impact on the effectiveness of the organization. Strategic grouping can be centered on activity, output, user, customer or geography.

Recently Boeing made a strategic design decision to move their corporate headquarters from Seattle, Washington to Chicago, Illinois. One of the reasons headquarters was moved was to disassociate headquarters from the Boeing Commercial Aircraft Group (BCAG) which is headquartered in Seattle, Washington and allow for BCAG to operate more autonomously. The move also allowed the other Boeing groups to be more visible.

Boeing has used strategic grouping on many levels. Primarily the organization has been grouped by Industry segment: Commercial Aircraft, Military Aircraft, and Space and Communications. Each of these groups is operated as if it were Its own business entity and the executive Vice Presidents of these groups now each hold the title of CEO. Within each of the groups there are further strategic groupings by project (product). For example in the Commercial Aircraft Group, each type of aircraft has its own line of management (717, 737, 747, 757, 767, 777, and sonic cruiser). In the Space and Communications Group (S&C) similar product teams are established such as the International Space Station and Space Shuttle. Functional management is still maintained and a matrix management structure has been established.

The matrix consists of functional management and Integrated Product Team's (IPT). The idea of the matrix is to strategically group individuals together on two primary facets: activity and output. The functional management portion of the matrix is the activity-based grouping. The output-based grouping is the IPT's. IPT's are centered on the programs (product), such as the International Space Station. The IPT's consist of members from all functional areas and are designed in a manner that allows for and enhances integrated product development. Because many of these programs expand across multiple geographic regions, formal structure of functions and projects are located at each site. Many of the sites will have separate site leadership.

To aid in conflict resolution of functional vs. project management, Boeing has established bylaws that distinguish between host and project and how the decision process is executed. To allow for knowledge sharing and for best practices to be incorporated and distributed across the organization process councils have been established. The process councils are functionally based and cross the organizational boundaries by having representation from each of the main corporate groups.

-How does the way in which jobs are designed influence the project and your work on it?

With the organization set up in the matrix it made my internship very difficult. There were multiple stakeholders and no single person to whom I would report. In addition there were three prominent views for the future of the Houston site. One vision suggested that the site was going to grow significantly; another was that the site was going to stay about the same in size, and yet another questioned if the facility should perhaps be closed down. This project required soliciting support from S&C functional leaders, site leaders, program heads, and site functional heads. With the recent acquisitions of McDonnell Douglas and Rockwell there were many business systems in use. Some were newly being implemented, and some were old. Business processes were different between functions, sites and programs. Communication between these stakeholders was poor, there was little direct discussion or focused attention on business systems. There was a major effort to consolidate and settle on common business processes. There was also significant effort to optimize functional performance. Unfortunately much of this effort was not performed as a "systems level" approach, but rather a local optimum. This created additional challenges in the selection of business systems and new systems would not necessarily interface with systems from other groups and may have negative effects on another function. So although there was an improvement in the local "functional optimum", the local and/or global system was negatively affected.

The structure of the organization created an additional challenge: Who should fund a business system project? Pressure was being placed on the site from the operations functional management of Space and Communications headquarters, to have a system common with the other S&C sites. Pressure was being placed on the project from other sites to influence the business system selection to be compatible with their system. And pressure was being place from within the Houston site by functions that had recently changed to systems which where not on the pre-selection list. Additionally headquarter pressure was coming from operations, should engineering, procurement finance or any other function have to contribute to such an exercise? Was it worth their time? Would anything ever really be implemented?

The position I was placed in was as an individual contributor. My supervisor was recently moved to the Houston site and was in an operations role, but his official title had not officially been released and was not released until my internship was halfway completed. Additionally as a result of the consolidation efforts, the organizational structure for the site was in flux and seemed very fluid. Business systems were not a priority for the site. I had no positional power and little influential power from my supervisor, as his role in the organization was not clear.

One additional challenge is the ability for a program manager to solicit quotes from different Boeing sites as well as outside contractors for portions of the project. This created competition between sites and extended that competition against outside contractors for a project that was managed by internal Boeing. This created an interesting atmosphere.

-Are coordinating systems in place to support the implementation process?

Yes through process councils and the use of site bylaws. The process councils provide commonality of functions across business groups and the site bylaws help for coordination between functions. Additionally the use of IPT's was supposed to aid in coordination between functions.

Communication was breaking down between engineering and operations so an additional change that was made on the S&C corporate functional level was to move the vice president of operations under the vice president of engineering.

-What, if any, changes in the structure will be needed to implement your findings/recommendations?

Boeing is working very hard to create a Lean organization. The S&C group places Lean Enterprises management under the operations portion of the organization structure. If Boeing is serious about the use of Lean as a strategy for world competitiveness, then placing lean management under operations is not the appropriate control location. If Lean Enterprise is to be a real driver in the organization, it needs to gain a stronger stance in the group. It needs to have its own budget and some influence over the operation of all of the functional areas. Boeing has created an organization that is tasked with tools development for engineering. It is called New Engineering Organization (NEO). As defined by Boeing "The NEO initiative is a rapid and aggressive Engineering/Operations-focused initiative designed to define, evaluate, develop and deploy common and preferred systems, processes, tools, and methodologies across the S&C enterprise. These may often be referred to as "Known Best Practices." The desired NEO end-state is one that provides timely enablers for the S&C enterprise to achieve business & technical excellence through systematic, methodical and disciplined use of known best practices."

NEO does an excellent job investigating and developing tools for company-wide rollout and it has representation from all corporate groups and as a result, has limited focus. NEO is provided a substantial budget. Although NEO crosses corporate groups, it lacks the additional focus in functional groups other than primarily engineering, and has limited influence in operations. NEO does not look at ERP or MRP systems but rather has primary focus on product development tools. Lean Enterprise is not a tool limited to operations, but rather a corporate strategy. Lean Enterprise needs to be embraced and supported from the executive level if it is to be successfully implemented and used as a corporate strategy. It needs to be structured much like NEO but with the incorporation of Lean practices and implementation tools.

One additional structure that I found very useful, which Boeing has implemented in their Delta Launch Services IPT of S&C, was a Process Based Management (PBM) group. This group was in charge of documenting all of the processes of the group and validating the adherence to those processes. Metrics were established and tracked. This type of structure could be very valuable for the Houston site. With the three prominent cultures of Boeing, McDonnell Douglas and Rockwell, coupled with the culture and process differences of the programs, this could be a significant benefit. It would provide a process warehouse and help to educate the workers as to the processes and interfaces.

POLITICAL: Consider the following questions to understand the different interests and goals that guide individuals, groups, and departments both within and outside of the organization that have a stake in the project:

-Who are the stakeholders involved in and affected by the project and what are their interests? What does each stand to gain or lose from the project?

There are many stakeholders involved in my internship project as well as in the outcome of my thesis. It would take too long and may reveal proprietary information if I were to go into depth, so only higher level views are identified in Table 10.

Table 10: Internship Project Stakeholders

Stakeholder	Interests	Gain	Lose
Me	• Have an educational experience	• Satisfaction	•
LFM	• Provide educational experience to student • Provide significant value to Partner Company	• Increased funding if project successful • Gain support from S&C instead of just BCAG	• Reduced future internship if poor project
Boeing Corporate	• Same as LFM	• Savings in the long run	• Potentially large upfront expenditure
Boeing S&C	• Same as LFM	• Same as Boeing • Influence standard tools	• Same as Boeing
Houston Site	• Providing highest value at lowest cost • Standardization of processes	• Better understanding of Houston Processes • Have common processes between programs	• Could negatively affect Houston Rates
International Space Station Program	• Providing highest value at lowest cost	• Address key customers' documented concerns • Have better understanding of Value Chain	• May need to change processes
Shuttle Operations	• Providing highest value at lowest cost	• Have better understanding of Value Chain	• May need to change processes

-Map out the different stakeholders and indicate with plusses and minuses whether they are for or against the project

It seemed that everyone I spoke with was in favor of certain aspects of the project, but not necessarily all aspects. Everyone was in favor of increasing communications. Everyone was in favor of identifying and documenting their operational processes. The place where we ran into some dissent was on what the processes should be and what software systems should be implemented. Should we implement one turnkey system? Should we piecemeal a system together from what we have? Should we do a gap analysis on what we have and just fill in the holes? Which of the existing S&C systems makes the most sense for Houston? Should we even implement anything at this time?

There was some challenge in gaining support of all the functions. Many of them viewed the project as an operations driven project. The project was viewed this way for a couple reasons. First, my supervisor was in operations so I was associated with them. Second, operations had the largest gaps to be filled by the new system.

-Are these interests compatible? Can they be changed to be better aligned?

Yes, the interests of the stakeholders are compatible when it comes to benefits sought by the project. The challenge comes in determining what systems to install. In an attempt to better align the views on what system to install, I relented on the identified solution and tried to gain more support form the functional groups by taking a new approach.

We decided that an analysis of the existing business systems needed to be performed and a gap analysis created which would identify what the critical capabilities of the business systems would be for the Houston site and where the current systems currently fell short. In an effort to identify critical capabilities we began process mapping and value stream mapping of each of the functions. We wanted to ensure that whatever recommendation we made was the correct solution for Houston and its particular situation.

When a function had their system mapped we would begin sharing that process and value stream with the other functions. This enhanced communication between the functions and allowed for shared learning. It also identified critical touch points between functions and showed the importance of standard procedures. This process and value stream mapping will provide the Houston site additional benefits to include: a better understanding of how the organization creates value, a better understanding of the interface points between functions, where there is a potential for lead time reduction in process steps, and identification of waste in processes, to name just a few.

The final tactic used to align the efforts of the team was to create a steering committee consisting of the site functional and project heads. Each member as well as the VPGM for the International Space Station, who is also the site manager, then signed this charter. The charter outlined specific tasks required of the project.

-What sources of power do the various parties bring to the initiative? How is power distributed among them? How might the outcomes change this?

Power was an interesting perspective in the discussion. Since there was substantial organizational change occurring in parallel to the program, power positions were not always clear.

-Is the history of the relations among the different parties involved in the initiative amenable to effective conflict resolution and problem solving?

Yes.

-Have there been conflicts or disputes about this initiative? How have they been resolved?

Yes. There were disputes on what systems to implement and if anything would or should be implemented at all. There were also issues brought up, such as the true reason the new manufacturing facility was built. These issues were discussed and often solutions were come to behind closed doors.

-Are there any measures to allow the less powerful parties to voice their interests as they relate to the project?

Yes. Being in a relatively neutral role as an outsider I was able to hear the voice of many of the interested parties. With this knowledge I was able to adjust group meetings as needed to get those opinions on the table.

CULTURAL: Consider the following questions to understand how your project relates to, is affected by, or may affect the culture of the organization:

-What symbolic meaning does this project have for the organization? Does it have different symbolic meaning for different people?

To some this project was just another project that would never come to pass. To others it was a project that was finally getting done. In the beginning of the project we were having great support and we were making substantial progress. We reached a point where we needed guidance from a higher level. At this point I had not codified the steering committee and we were not able to get guidance as quickly as we needed it. The result was the withdrawal of a couple of key team members. Their high hopes for progress had been let down.

-How is the project related to the norms, values, and basic assumptions of the organization? Will it change them or reinforce them?

I did not fully understand or recognize all of the norms, values, and assumptions of the organization. However, I was often told that "Rockwell didn't do it this way" or "McDonnell Douglas did it this way." Clearly cultural values associated with these companies were still strongly represented in the Houston site. Adherences to legacy cultural norms created significant resistance to change of processes. Often contractual obligations were different for different projects and these were used as justifications for not complying with new initiatives or processes. This project and the required close interaction provides the opportunity to work through this and to have an equal say in the new policies, procedures, and business systems so it has the potential to alleviate some of these issue, but these issues present a challenge to the project as well.

-What is formally being communicated to others about this project? How is it being packaged or framed?

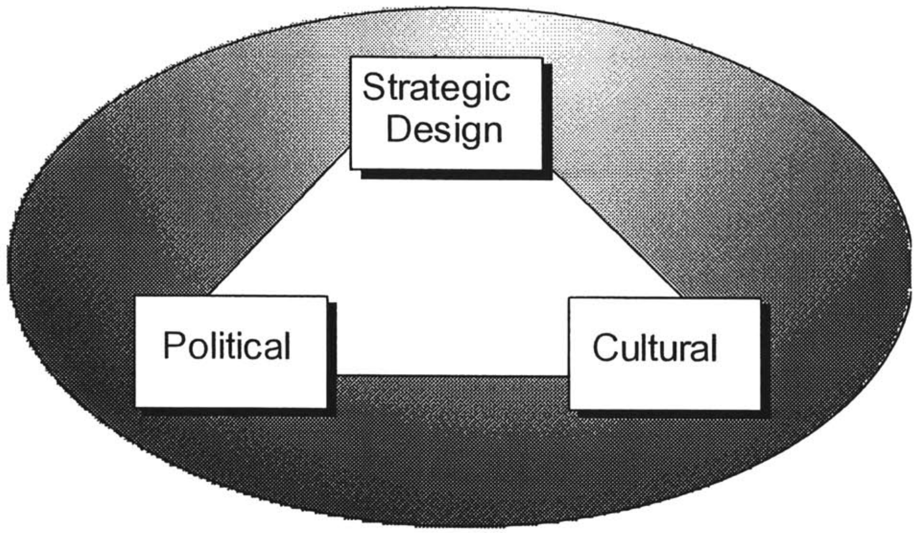
Originally it was framed as an S&C operations initiative, so it was difficult to gain the needed support of other functions. As a result I worked to reframe the project as an initiative from the site VPGM. This added some credibility, but to enhance it we worked to have the steering committee championed by a functional leader other than from operations. This signified that it was a site initiative and that contribution and inclusion was required of all site functions and programs.

-How were you and your role introduced to other organizational participants, members of your project team, and/or work unit?

Originally I was introduced through my supervisor. This had varied success. He had only been at the site for a limited amount of time so his network, although strong globally, had not fully been developed on the local level. The other challenge I had with this approach was that I needed to coordinate three schedules: mine, my supervisor's, and whomever I was to meet. I eventually suggested that I cold call these individuals on my own. This seemed to work better with some individuals, while more persistence was still required with others.

-Are there different sub-cultural responses to this project and how are the people in these subcultures appropriating the initiative for their own use?

Sub-cultures are "groups of people who share common identities based on characteristics that often transcend their organizationally prescribed roles and relationships." The differences in the acquired companies are perfect examples of this because the way they influence the project is varied. The largest impact is in their preference of business systems. There was also significant input from various functional groups, some of which just recently upgraded their business systems or were in the process of doing so. Although these groups saw the value in performing the project they tended to play the role of slowing discussions to ensure their voice was heard.

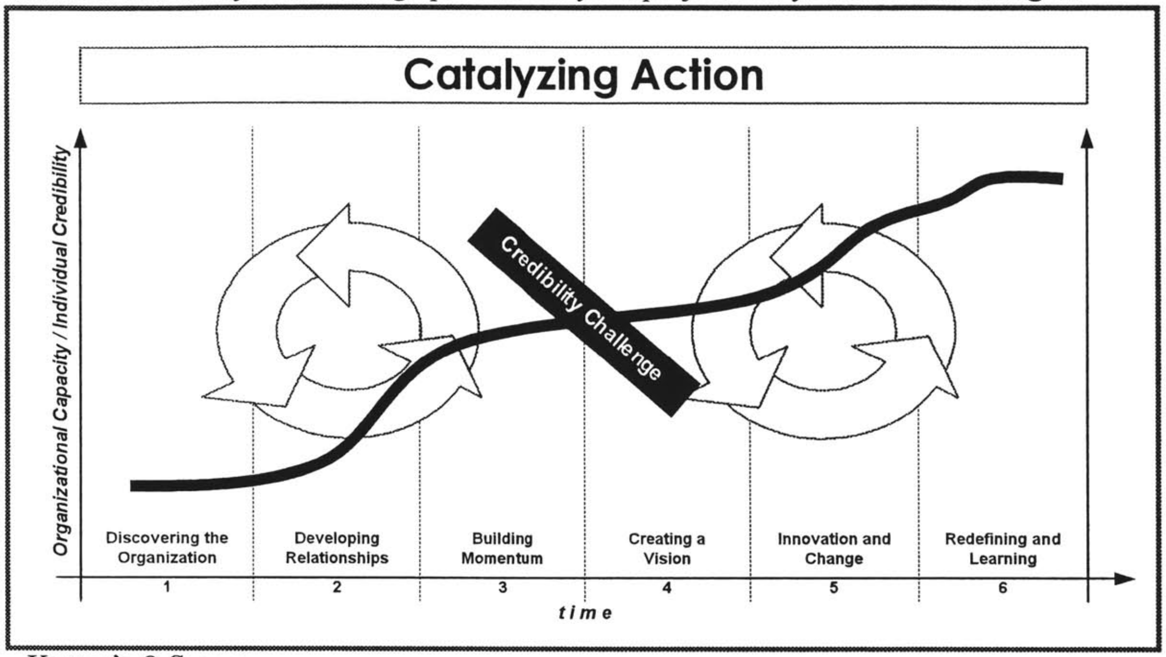


- Consider how looking at the project from the three perspectives influences the data you collect and how you interpret what is happening. Do the things you see through one lens change your view of the things you see through another lens? Consider how each perspective can inform the others.

In this project, looking through each of the three lenses does not significantly change the perspective of data. It does, however, show some difference. For example there was a prevalent lack of communication about business systems in the Houston site. Looking through the strategic design lens one might associate this deficit with a lack of any knowledge sharing mechanism between functional groups. Through a political lens one might assume a power play where each functional head is creating a fiefdom. And looking through the cultural lens one can see the possibility that communication is poor because of the evident commitment to legacy cultures and their business systems.

TOPIC #3: Leading the Change Process

Use the elements in the MIT Leadership Model for Catalyzing Change and/or Kotter's "Eight Steps to Transforming Your Organization" (see below for both frameworks) to describe and analyze the change process for your project and your role in leading it.



- Kotter's 8 Steps:

Establishing a Sense of Urgency
Forming a Powerful Coalition
Creating a Vision
Communicating a Vision
Empowering Others to Act on the Vision
Creating Small Wins
Consolidating Improvements and Creating More Change
Institutionalizing the Change for after you leave

-If you worked as part of a team, or led a team as part of your project, assess the quality of the team's internal processes (see Module 5 of the OP Text [2]) and boundary management (see Module 6).

According to the OP Text [2] the major categories of team process are: task and maintenance functions, decision making, communication, influence, conflict, atmosphere, and emotional issues. The text asks questions to aid in the evaluation of each of the identified team process categories. To see a copy of these questions please reference the OP Text [2].

In general the processes of our group were very good. The area where we had the most difficulty was in the Task Functions area. The attributes that reside in this section that we fell short on include: keeping on target, due times for deliverables, and dates and times of next meetings. The topic was so large and encompassing that the discussion could take a number of turns. Also the tasks for the team were not clearly articulated by me at the beginning. I was hoping that the team could help identify what tasks we needed to accomplish to meet the project objective. This was not the case here.

The deliverable due date issues stemmed from the next meeting time issue. The team was making significant progress until we started having some difficulty with guidance from our steering committee that was just beginning to form. As a result of this and the periodic absence of the team leader, myself and another gentleman, we needed to cancel a couple of meetings. These events had drastic effects on the team, and it took a number of subsequent meetings to get back on track.

Boundary management consists of managing the organization outside of the team. The boundary would include functional heads, Houston site leadership, and S&C leadership. We felt we had a good method for this, but as expressed in the example above, it is clearly where we fell short. We were unable to get answers to critical questions in a timely manner. The tactic that the team took to rectify this problem was to form a steering committee for our "implementation team" as well as create a charter that would guide both steering committee and implementation team.

TOPIC #4: Evaluation and Recommendations

-Evaluate the outcomes of the project against the metrics most important to its key stakeholders.

The metrics of most importance to the stakeholders were not clearly established prior to the beginning of the internship project. As a result this is a difficult question to answer. Personally I was not happy with my performance. I felt as though I should have pushed harder and/or found more creative ways to get through the many obstacles that were in path of this project. On the other hand the feedback I have received from my team members as well as my supervisor was very positive and that significant gains have been realized as a result of my efforts.

In essence the results of my internship were in the creation of a charter that empowers the implementation team, with guidance from the steering committee, to continue to perform an evaluation of existing business systems in use across the Houston site to identify and recommend an appropriate solution. The evaluation is a continuation of the process and value stream mapping that has already been started. The charter outlines specific tasks that are required of both the steering committee and the implementation team. We were also able to secure funding for the continuation of this project.

-Evaluate project as a change process considering the following issues:

Acceptance of your findings and/or recommendations

The findings and recommendations of my internship seemed to be well received. The signing of the team charter supports this impression.

Implementation and follow-through

At the completion of my internship, Boeing seemed committed to continuing the study that, with the assistance of my team, was outlined in the team charter.

Sustainability of changes recommended and/or implemented

At this point in time the biggest change that has occurred is the increased communication across the functions and programs residing at the Houston site. A recommendation was made to perhaps add a process control group. This group could be chartered to maintain and update the processes and value stream for the site. This would help to sustain and enhance site communication and understanding.

A second recommendation is to move the lean organization to a higher level within the organization. If Lean is to be a true strategy within Boeing this must be done. This recommendation extends beyond the internship and incorporates some of the thesis. However, it needs to go higher in the organization than the internship project recommendation. Be that as it may, I feel that the recommendation will be well received and will be seriously considered.

Organizational learning from the project

I know I learned a lot about the political and cultural workings within a large corporation. I believe that Boeing was able to recognize their poor communication in the area of my project focus, and they have implemented corrective actions.

Diffusion of learning to other units in the organization

Through the operations council, the learnings from this internship will be shared with other sites.

-Based upon your experience, develop recommendations for those who might attempt a similar project in this setting in the future. What should they replicate from your effort and what should they do differently?

The biggest thing that I did well was the establishing of a charter. This should have been my first step. If someone is going to attempt something like this in the future they should do this first. Gaining the support of the key functional and project heads and documenting that support helps to drive the implementation. Establishing a budget to perform the evaluation and business case is also tremendously helpful. Not having a budget made it difficult to gain support from cost centers like IT who is also critical in this type of project.