Root Cause Analysis and Mitigation Paths for Persistent Inventory Shortages to an Assembly Area

By

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B.S. Chemical Engineering, Rice University (2004)
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Submitted to the MIT Sloan School of Management and the Department of Materials Science and Engineering in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration

AND

Master of Science in Material Science and Engineering

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ABSTRACT

The strategic alignment of a company impacts the culture of the organization, which in turn reinforces the strategic alignment. The corporate behavior resulting from the combination of alignment and culture determines the organization's ability to handle disruption and change. This thesis explores the intersection of these two elements in the context of experience gained at Spirit AeroSystems through an internship.

The importance of alignment and culture of Spirit comes to light in observing the response of different parts of the organization to a supply shock caused by an industry wide titanium and aluminum shortage. A method to analytically assess delinquent part delivery and determine the optimal balance of increased upstream labor capacity versus downstream cost avoidance is presented. This information requires a supportive organizational structure to be utilized fully, and the form of this structure depends heavily on the existing culture to determine its viability. Several organizational structures are proposed to internalize the external costs of delinquency, and the cultural viability of these options is explored. The key attributes of this viable, effective structure are control by the Fuselage customer and cultural infusion and strategic coordination with Supply Chain Management.

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Other individuals were essential in navigating the day to day of Spirit AeroSystems. The entire Methods Technology group was tremendously helpful, especially Dave Logback. Patrick Blackwell was an outstanding source of tactical guidance. It was great to work with all of you, and I hope to be able to do so again in the future.

The entire LFM class was of tremendous value in serving as a sounding board for the most difficult problems, and providing moral support. I have done my most valuable learning throughout the Leaders For Manufacturing program from all of you. I have appreciated every opportunity to learn, laugh and travel together. I look forward to maintaining this bond as we move out into the world as professionals.

Lastly, I would like to thank my parents and others whose love has sustained me throughout the LFM program. You have always been great listeners, and a source of inspiration throughout the program. None of this would be possible without you.

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Biographical Note

The author is a native of no state, but a guest of many. After attending high school in New Mexico, the author graduated from Rice University in 2004 with a B.S. in Chemical Engineering and a B.A. in Economics. For the two years following graduation, he worked at Deloitte Consulting in the Strategy & Operations practice as a Business Analyst.

During this time, the author sampled a variety of industries, including healthcare, oil & gas, but spent the majority of his time on telecommunications projects. These experiences covered a range of strategic and operational analyses, including competitor positioning analysis, performance benchmarking, product offer rationalization strategy and capital investment strategy. He also led several initiatives at the firm, including charitable and outreach programs, as well as contributed to the development of training programs for new analysts.

In 2006 he joined the Leaders For Manufacturing (LFM) program at the Massachusetts Institute of Technology (MIT), where his thesis was completed in 2008. At MIT, he earned an MBA from the Sloan School of Management and a Masters of Science in Material Science and Engineering from the School of Engineering.

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1. Introduction

The purpose of this chapter is to provide an overview of the thesis, as well as provide the reader with a context and motivation for the underlying research. The chapter highlights the challenge addressed by the thesis and explains the environment in which the analysis was conducted. The chapter also presents a brief outline of the structure of the subsequent chapters.

1.1. Context and overview

A firm's culture and structure are inextricably linked. The strategic alignment of a company impacts the culture of the organization, which in turn reinforces the strategic alignment. The corporate behavior resulting from the combination of alignment and culture determines the organization's ability to handle disruption and change. It is also inescapable that manufacturing strategy, competitive strategy, environment and structure are interlinked, and the choice of one facet directly influences the remaining pieces. (Ward, Bickford, & Leong, 1996)

Clearly, disruption and change are constant in every industry. This potential is only increasing as vertical integration decreases. The potential critical impact of disruption is more significant than ever now that the purchased Cost of Goods Sold (COGS) for many firms has grown to more than 50% of sales. (ASCET) The lengthening of the supply chain implied by this outsourcing of over half the value of the finished product necessitates an investigation of a company's response to such a supply disruption, and influence of organizational structure on that response. With this increased awareness, different avenues can then be explored to find ways to improve the organization's response.

1.2. Problem Identification

Spirit AeroSystems Inc. (Spirit) had experienced lingering issues with on time delivery between an internal supplier, Fabrication, and an internal customer, Fuselage Assembly. Not only was the original growth of the delinquency problem in Fabrication rapid, the rate of recovery was slow. The pace of recovery in Fabrication was driving both significant disruption and frustration throughout the value chain. This frustration was leading to reduced cooperation between the leadership of the two organizations. Many stakeholders, including some within Fabrication, had limited visibility into facets of Fabrication's current performance, and future expected performance that would result from the existing recovery plans.

The significance of the problem was beyond understanding the cause of delinquency. The desired outcome would increase visibility for all stakeholders, and include a solution to prevent future persistent delinquency – a method to help leaders proactively manage disruption to yield an optimal plan for site-wide recovery.

1.3. Setting

This research was conducted over the course of a six month internship with Spirit AeroSystems as partial fulfillment of the requirements of the Leaders For Manufacturing program at the Massachusetts Institute of Technology. The models presented in this thesis were developed in conjunction with leadership and technical staff of the Fabrication functional area, the Fuselage business unit and Corporate Support Services. These organizations will be detailed in later chapters.

1.4. Objectives and Methods

The author's objective during the internship was to provide tools to management for increased visibility into the expected operations within Fabrication. These tools were to be used as both a common communicating language for the various operating elements of the value chain, and a business planning tool supporting recovery planning. This thesis will then use these tools, the author's experience during the internship, and academic literature to explore different avenues for exploiting this increased visibility for optimal recovery planning in the environment of Spirit.

The methods were generally straightforward and collaborative in nature. The various tools were developed in cooperation with the relevant functional areas, as well as validated with external parties. Further information was gathered through formal and informal interviews to provide depth and contrast to organizational concerns. Literature reviews were conducted to provide structure and framing for these sources of information.

1.5. Chapter Outline

The thesis is divided into nine sections. The following brief summaries introduce these sections and provide an overview to their content.

Chapter 2, Culture and Current Organizational Alignment of Spirit, introduces the subject of this analysis. It also establishes the "as-is" situation for the company. This background information will be referred to frequently, and provides context for recommendations.

Chapter 3, Inventory Shortage Impact on Customer, discusses the methodologies to understand the consequences of late delivery. The results of this analysis at Spirit will be presented and discussed.

Chapter 4, Supply Disruption Impact on Supplier, will investigate and discuss the causes of lateness within the supplier organization. As the root cause pertains to global metals supply shortages, the global aerospace metals industry, and the processing of these materials will be introduced.

Chapter 5, On Time Delivery Forecast Data Methodology, will introduce a model to understand the expectation delinquency from the supplier organization. This model will demonstrate the results of this modeling, and discuss how this information can be used to arrive at optimal operating decisions for Spirit's Wichita facility.

Chapter 6, Potential Alignment of Internal Supplier/Customer, will explore several different alternatives that would allow the balancing the impact of late delivery and the cost of increased staffing.

Chapter 7, Interaction of Existing Culture and Potential Alignment Structures, will discuss the influence of the "as-is" case for an organization on the effectiveness of an alternate alignment scheme. The influence of the existing culture of Spirit Wichita will be highlighted.

Chapter 8, Conclusion, summarizes the analysis and conclusions of the research and contents of this document. This section ends with recommendations for future research in the area of organizational behavior, and potential projects to benefit Spirit.

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2. Spirit AeroSystems – History, Structure and Culture

This section will introduce Spirit AeroSystems, then focus on the site in Wichita, KS. This overview will show the organizational and operational structure of the company at the time of the author's internship. After introducing the existing organizational structure, an organizational analysis will be conducted using a Three Lens Analysis.

2.1. Introduction to Spirit AeroSystems

Spirit is a very unique company. Parts of the company (namely the Wichita site) have been producing airplanes since the 1920's as part of Stearman Aircraft. In 2005, the Boeing Company, then owner of most of the sites, sold assets to the Onex Corporation, a private equity firm, which formed Spirit AeroSystems. (Spirit AeroSystems) This makes Spirit an 80-year old start-up company.

At formation, Spirit consisted of the Wichita facility, which became the corporate headquarters, a Tulsa, OK facility and a McAlester, OK facility. These sites produced parts almost exclusively for their former owner, Boeing. In 2006, the company acquired a portion of BAE Systems, with sites in Prestwick and Samlesbury, UK. This provided a means for Spirit to expand its customer base. The locations where Spirit currently operates are marked in the figure below, although the company has also recently announced a plan to build a factory in Malaysia.

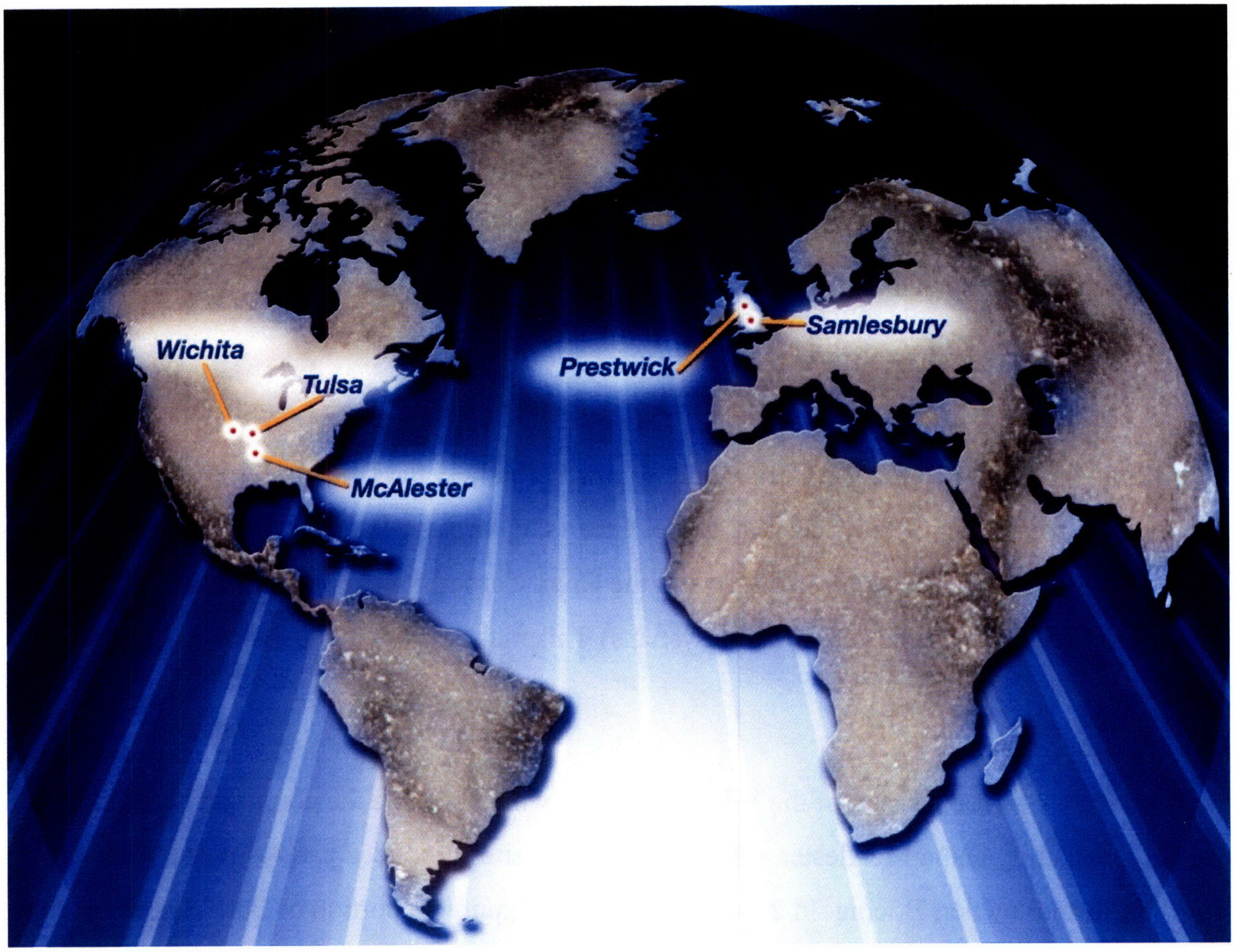

Figure 1 - Spirit's current operating locations

Currently, Spirit supplies Boeing with structural components for the 737, 747, 767, 777 and the new composite-based 787. It also supplies Airbus with wing components for the A320 and A380. The colored portions in the following figure demonstrate the kinds of products that Spirit is responsible for engineering, manufacturing and delivering to its customers.

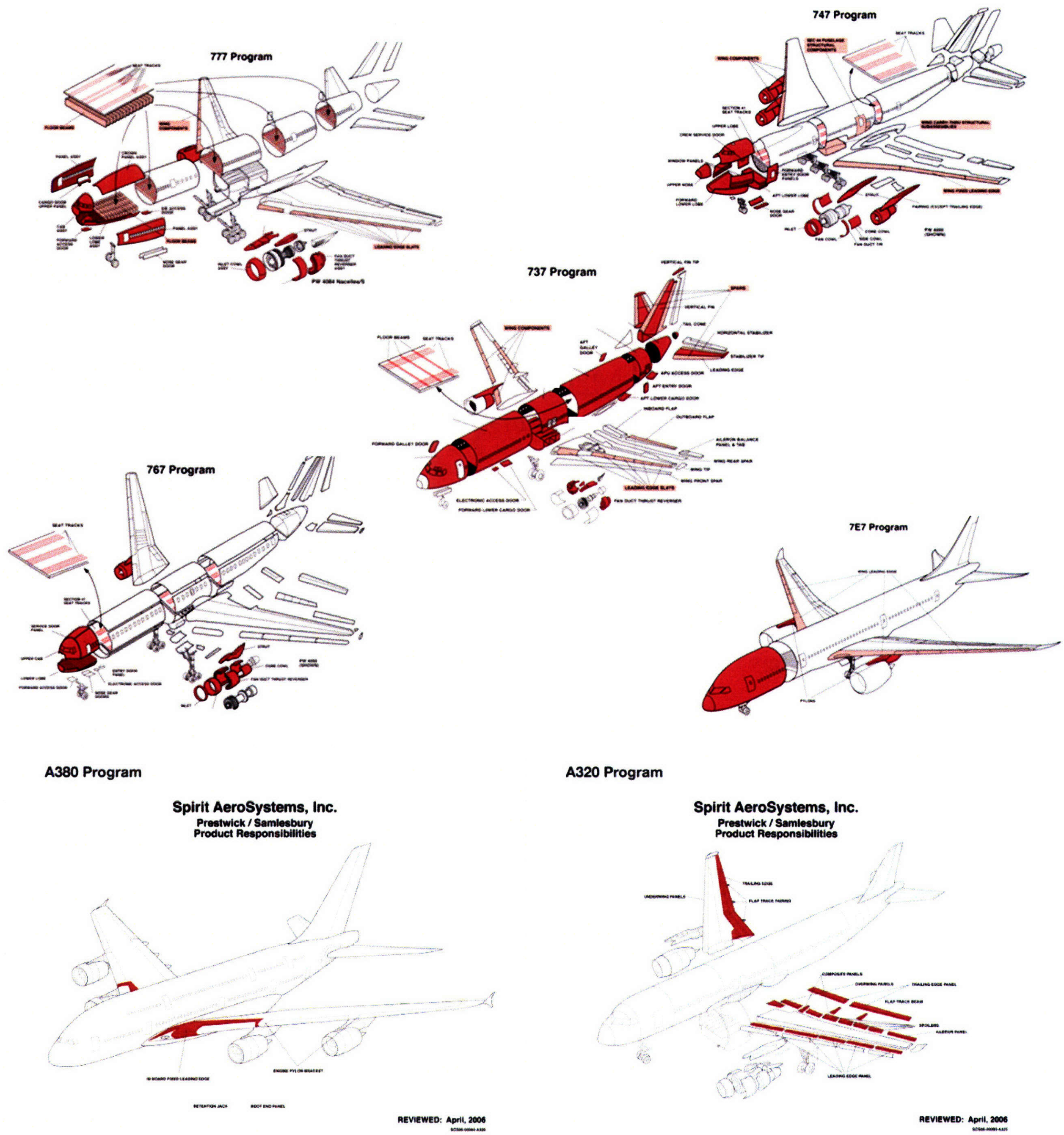

Figure 2 - Demonstration of Spirit AeroSystems product range

Spirit has extensive engineering capabilities. This makes them a strong partner for new customer programs. This has been shown in the development of Boeing's 787. This new aircraft, utilizing a revolutionary carbon fiber structure, is currently undergoing limited production and is expected to enter commercial service in the fourth quarter of 2009. Spirit also offers extensive Maintenance, Repair and Overhaul (MRO) operations to assist their customer base.

This thesis will not introduce the broader aviation industry. This topic has been covered extensively in other theses. The author recommends "Advanced Aerospace Procurement Models" (Jason Kary,2006) for an industry overview.

2.2. Current Organizational Structure of Wichita Facility

As broached in Chapter 2, Spirit Aerosystems is currently situated in three locations: Wichita, KS, Tulsa, OK and Prestwick, Scotland, with Wichita being the largest site, containing corporate leadership as well. This section will focus on the organization of operations in Wichita, and the corporate functions that interact with them.

The following figure introduces the organization for the Wichita site. Note that organizations that are organized as profit centers composed of several divisions are called Business Units (B/U) and have a VP/GM. Cost centers or subdivisions of a B/U are known as a Functional Areas and are lead by directors, with the exception of Supply Chain Management. VP/GMs of non-Wichita locations have their own cost center representatives.

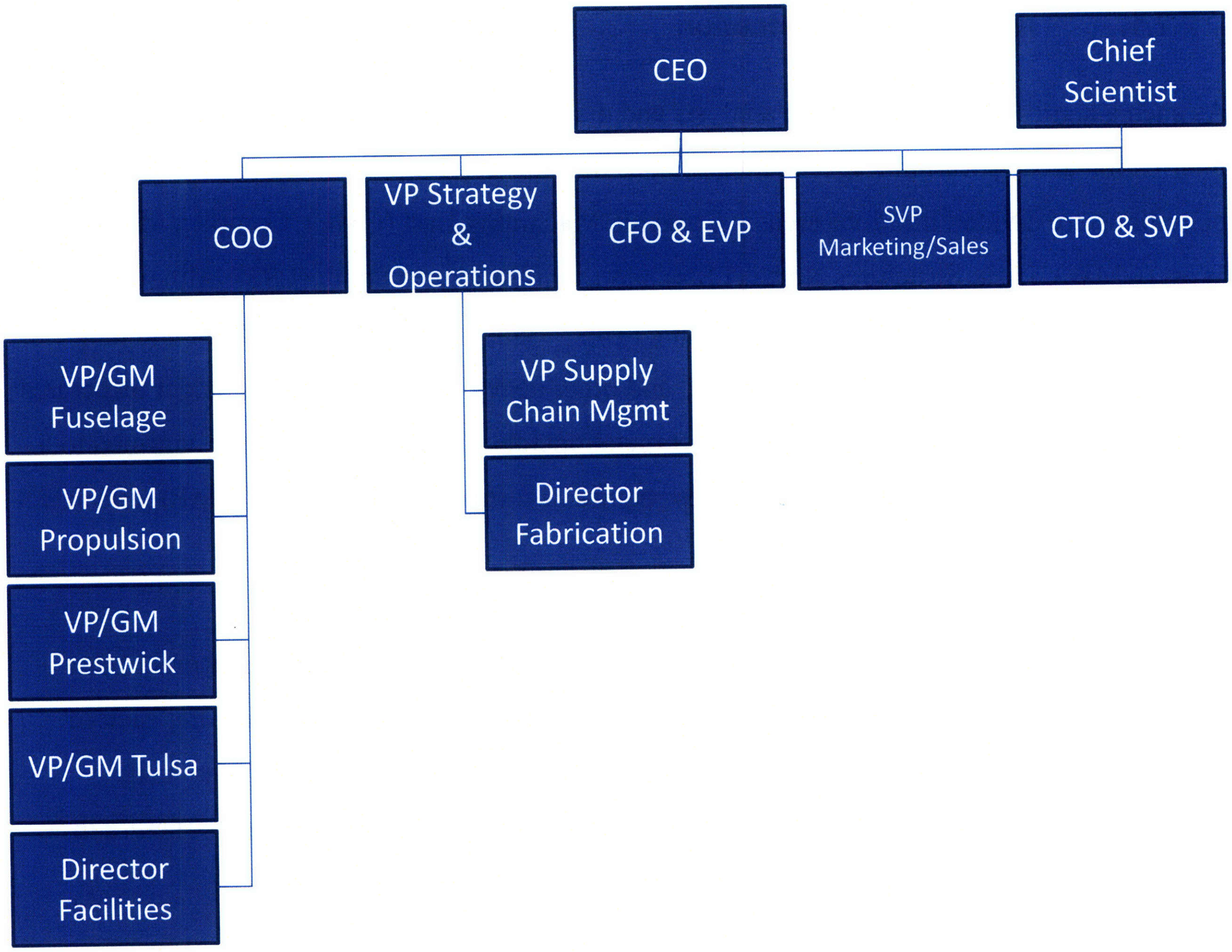

Figure 3 - Organizational Structure for Wichita Site

This organization is very similar to the structure of the operations areas prior to the spin-off of Spirit AeroSystems from the Boeing Company. In fact, most of the senior leadership of the company, including the CEO, COO, VP/GM Fuselage, and the Director of Fabrication are in the same or similar position now as they were prior to independence. It is relevant to understanding the company that the Wichita site was essentially operated as a cost center to the larger parent company. The company, now independent, is now clearly responsible to its shareholders to maximize profitability. This transition is, however, quite recent and still has strong lingering impacts on the organization, which will be discussed further in the Three Lens Analysis section. The following sections will describe in detail the areas most relevant to the analysis conducted during research, and then describe the process flow between them.

2.2.1. Area Focus: Fabrication

As such a significant portion of the analysis and discussion of this thesis dwells on the Fabrication area, it warrants special attention, as does the Fuselage business unit. Fabrication's operations are divided into four areas – Complex Machining East (CME), Complex Machining West (CMW), Light Structures North (LSN) and Light Structures South (LSS). Although there are some exceptions, the Complex Machining areas largely handle both aluminum and hard metal parts requiring multi-axis machining, and other heavy capital operations. Light Structures areas deal predominately in aluminum sheet metal operations. Orders are largely confined to a single area while in Fabrication, unless they require heat treatment (owned by CME), or a select other operations.

Each of these areas is lead by a Production Line Manager (PLM), who in turn reports to the Director of Fabrication. As Fabrication runs with a very lean management structure, each of these PLMs bears additional responsibilities. For example, the PLM of CMW also leads Fabrication's Lean organization. The following figure outlines the management structure in Fabrication. Note the multiple roles held by many of the managers.

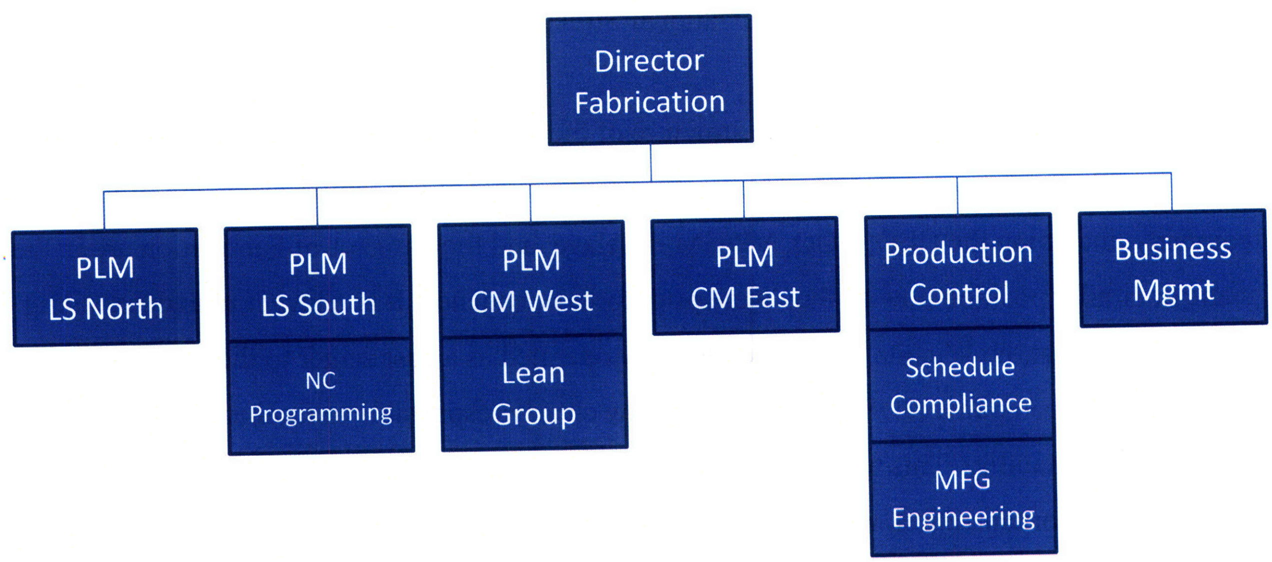

Figure 4 - Organizational Structure for Fabrication Functional Area

Fabrication is managed as a cost center. This implies that certain performance agreements or expectations are established, and Fabrication is then tasked to meet these at the minimum possible cost. As a consequence of this cost focus, budget adherence is a significant focus of management.

2.2.2. Area Focus: Fuselage

Fuselage is an extremely important group within Spirit. The Fuselage product line brings in a substantial portion of the company's revenues. As the link to the customer in a highly customer-centric culture, it enjoys significant political power. It also occupies a large physical footprint in Wichita, and employs a large number of technicians. The following picture shows the final integration assembly area, and provides the reader with a sense of the scale of the operations of the business unit.

Figure 5 - Fuselage 737 Final Integration Assembly Area

The organizational structure of Fuselage as a business unit is more complex than that of fabrication. The Fuselage business unit includes a number of major divisions. The Fuselage Assembly area has two major divisions - Single Aisle (consisting only of the 737 program) and Twin Aisle (747, 767, 777 programs). These divisions are then subdivided into Assembly Areas where a given task is performed. Pictured above is part of the 737 Final Integration Assembly Area. External sheet panels ("skin panels") are provided by Skin Fabrication, which is also part of the Fuselage organization. The Chemical Finishing Facility (MPF) applies chemical surface treatments and paint to skin panels, most parts from Fabrication, and some parts from Supply

Chain Management (SCM). There are several other areas that are part of the Fuseluage business unit, and they are reflected on the organizational chart below.

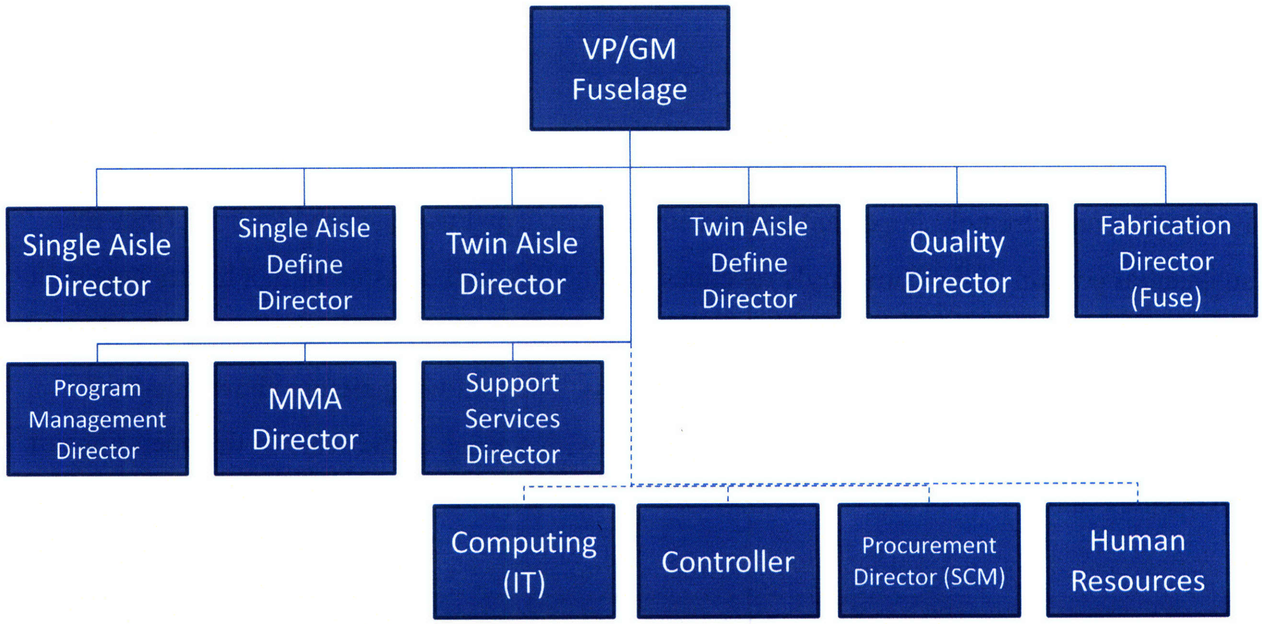

Figure 6 - Organizational Structure for Fuselage Business Unit

2.2.2.1. MPF Capabilities

The MPF provides a variety of processing for aluminum and steel parts (although not titanium). Its capabilities include paint finishing and surface treatments, such as degreasing and anodizing. Most paint and surface treatments are handled by automated processing lines, and a separate manual capacity exists to expedite critical orders. About 90% of MPF's orders[1] require only a single trip through the MPF, but the remainder require multiple passes. Multiple passes often involve an intervening step. For example, a part may be degreased, then return to Fabrication for shot peening or drilling, then return to MPF for final paint. Delinquent parts requiring multiple passes are a significant disruption for MPF, since these parts tend to by physically larger, more critical to assembly area, and generally have to leave the MPF between passes.

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[1] Discussion with Steve Foster, MPF Production Analyst, 16 July 2007

2.2.3. General Process Flows

The process flow for parts arriving at fuselage can vary significantly, and can ultimately touch several functional areas. This section will detail the principle paths that parts can take, and briefly evaluate each path's relevance to the problem faced. The process paths not directly relevant to the on-time delivery problem are presented here to be considered later in exploration of alternate organizational structures.

Parts produced in Fabrication have a complicated path. Raw materials suppliers are contracted by SCM, and then the contracts are executed by Fabrication. Raw materials are received and stored by Fabrication. Parts are released from storage by either Master Schedule or Impact List requirements. Once processed through a Fabrication Area, the parts are then transported by Spirit Transportation Personnel to the MPF. Many of Fabrication's parts, and especially those from Complex Machining areas, require multiple passes. As parts requiring multiple passes transfer between Fabrication and MPF, ownership and schedule accountability become blurred, and as a consequence the handling of these parts is frequently contentious. Understanding delinquency on this processing path is the primary focus of the problem faced in this thesis.

The simplest path for a part reaching fuselage is Purchased Outside Production (POP) parts. These finished goods are bought from vendors and are ready for assembly. These parts, ordered by SCM, are received in an onsite warehouse which is managed by a contracted Third Party Logistics Provider (3PL). Not all suppliers have surface finishing and paint capacity, so some POP parts require surface finishing and paint upon arrival. This is handled by the MPF. After arriving at the 3PL receiving warehouse, 3PL transports the parts to MPF, and then back to stores before arriving at Fuselage Assembly. Issues do exist with on time delivery from outside vendors, but this processing path was out of scope of the analysis conducted.

Other processing paths exist, such as that for Skin Fabrication. Similar to Fabrication, contracts for raw materials are created in SCM, but then executed in the functional area. Skin Fabrication stores and processes the skin panel. It is transported and stored in the MPF until processed and stored by 3PL. These processing paths are completely within the Fuselage B/U, and are not a focus for the development of on-time delivery tools.

2.2.3.1. Third Party Logistics Provider (3PL) Services and Scope

3PL is responsible then to bring parts to Fuselage Assembly according to a mix of MRP inventory push systems (Master Schedule), and pull systems (Line of Balance (LOB) Schedule or the Impact List). Most Fuselage areas operate using the Master Schedule, although some areas have implemented LOB. The Impact List serves to expedite late parts, and accelerate ("heat up") parts that are now required earlier due to local changes in the production schedule.

3PL requires a three day window from upstream part availability to downstream delivery, although 3PL's current average performance is faster. 3PL maintains an expediting capability to identify critical parts as they arrive from either internal or external sources and send them to the assembly area, without first sending them to the stock shelves. A premium is charged for parts requiring expedite, and generally can be processed in less than an hour.

3. Inventory Shortage Impact on Customer

It is readily apparent that supply issues, and part shortages impact an organization's production efforts. The absence of a part for production affects the operations of an area both directly, and indirectly. The direct effects include delay, out of sequence work and lower labor productivity. This then fuels growth of safety inventory and overtime required to correct the shortages once the part is available.

These impacts are most visible in an assembly environment such as the Fuselage Assembly functional area. Assembly's sequential processing route can be significantly disrupted by the lack of a part, as this can prevent subsequent steps or assemblies from being completed. The use of a pulsed line production system further complicates this difficulty, as a disruption would either require a line stoppage, or that the disruption is shipped down the line even though it is incomplete. Spirit's management has chosen in these situations to move these jobs down the line. These out of sequence tasks are referred to as traveled work, as it generally requires Assembly technicians to leave their area, bringing their tools to where the task has traveled to.

3.1. Sources of Traveled Work

There are several sources of traveled work, and while all are disruptive, some are more so than others. The first, and perhaps conceptually simplest, is a shortage of labor at a given station. This could be caused by changes in the station's work statement, or the unexpected absence of a technician. When there is not enough labor capacity available to fulfill the labor required, the incomplete tasks travel downstream. While disruptive, this cause can be attacked directly by Fuselage Assembly managers by adjusting work statements and proactive labor planning. For example, Spirit plans a higher percentage of absenteeism in its labor planning during hunting season, when many technicians utilize time off with a short notice.[2] By slightly "over-staffing" Fuselage minimizes this impact.

[2] Conversation, Business Management Manager – Fabrication 31 July 2007

Quality can also cause work to travel. When a quality issue emerges, such as a skin blemish or mis-drilled hole, additional work is required to either rework or replace the affected part. If spare labor capacity or a replacement part is in short supply, the issue will travel downstream until it can be addressed. This issue is also under the control of Fuselage management, although not quite so directly as staffing. Perfect quality may be nearly impossible to obtain, but management can design assembly processes that minimize quality-issue-prone production methods, and train assembly technicians to recognize and avoid situations where quality may be compromised.

Work can also travel for reasons outside the direct control of area management, and it is these that perhaps cause the most frustration. Late engineering support can cause work to travel, while manufacturing engineering investigates an existing issue, or provides direction for new work. This has been a significant problem for the Fabrication area's production of new program parts (such as the 787) but it can be an issue in a mature program such as Fuselage's 737 program. Solving these issues require a proactive partnership between manufacturing and engineering. In the author's exploration of Spirit's Fuselage Assembly area (which doesn't include the 787 program), this was not a significant problem, and was placed out of scope in subsequent analyses.

Part shortages from suppliers cause significant issues for the assembly process. If a part is unavailable when it is required, there is no choice but to travel the work. If this part is central to a final assembly to which many other parts are attached (referred to as an "imbedded" part) this can be of significant cost in travelled work. This significant cost arises from the high likelihood that "imbedded" parts are larger and more difficult to manipulate, and the difficulty of performing any subsequent tasks. Management in the assembly area has only a few levers to address this problem.

The prime difficulty in solving the root cause of this kind of traveled work is that the benefit of improvement is enjoyed by Fuselage, but the cost of correction is absorbed by the supplier. Selecting a supplier that will not become behind schedule is a strategic solution to this problem, but this can be outside the control of the assembly area. At Spirit, this process is controlled by Supply Chain Management, although Fuselage does have some say in the process. Other strategic concerns such as protection of intellectual property, export restrictions, and maintaining supplier support capacity may dictate the selection of an internal supplier, with these other concerns overriding issues around performance criteria. To solve the issue tactically, the assembly area must maintain safety stock, or process buffers. Not only is this expensive in terms of inventory holding costs and factory floor space, it is difficult in practical terms. It is virtually impossible to hold safety stock for all parts of an assembly process, and ordering safety stock after at-risk parts are identified will only put more pressure on the supplier.

Another source of traveled work, disruption, is the most elusive to properly identify. Each of the above sources requires a technician's time to address. While a technician travels to work a downstream traveled job, another job could go unworked at his home work station. In addition, missing parts or quality issues affect labor productivity through non-value added time spent on activities, such as searching for parts, filling out forms or packing tools for transport to other parts of the factory. This subsequent traveled job would then appear to be caused by staffing, but its true root cause is whatever caused the first traveled job. Conceivably, this type of traveled work could be caused by any of the previous sources, and as such the mitigation paths consist of the options outlined above.

3.2. Metrics Currently Available in Fuselage Assembly

Fuselage Assembly has several tools to assess the health of the production process. One of the key metrics used is Jobs Behind Schedule. This is the metric mostly commonly shown to the organization as a whole and corporate leadership, and is part of the weekly performance update distributed to the entirety of Spirit (along with analogous charts from other assembly areas). This metric charts the total number of jobs that have not been completed by their master schedule dictated date, and includes upper control limit and goal lines that management strives to stay under and reach, respectively. In the case of Fuselage, Traveled Jobs are a subset of Jobs Behind Schedule. Information on the originating area and total quantity of each of these metrics is readily available within Fuselage.

The Fuselage Assembly aggregate Jobs Behind Schedule chart is built up from program specific charts for each aircraft program, each of which has its own control limits and goals. Both of these lines are established by historical performance and negotiation with B/U management. An example of this chart for the Single Aisle area is shown below.

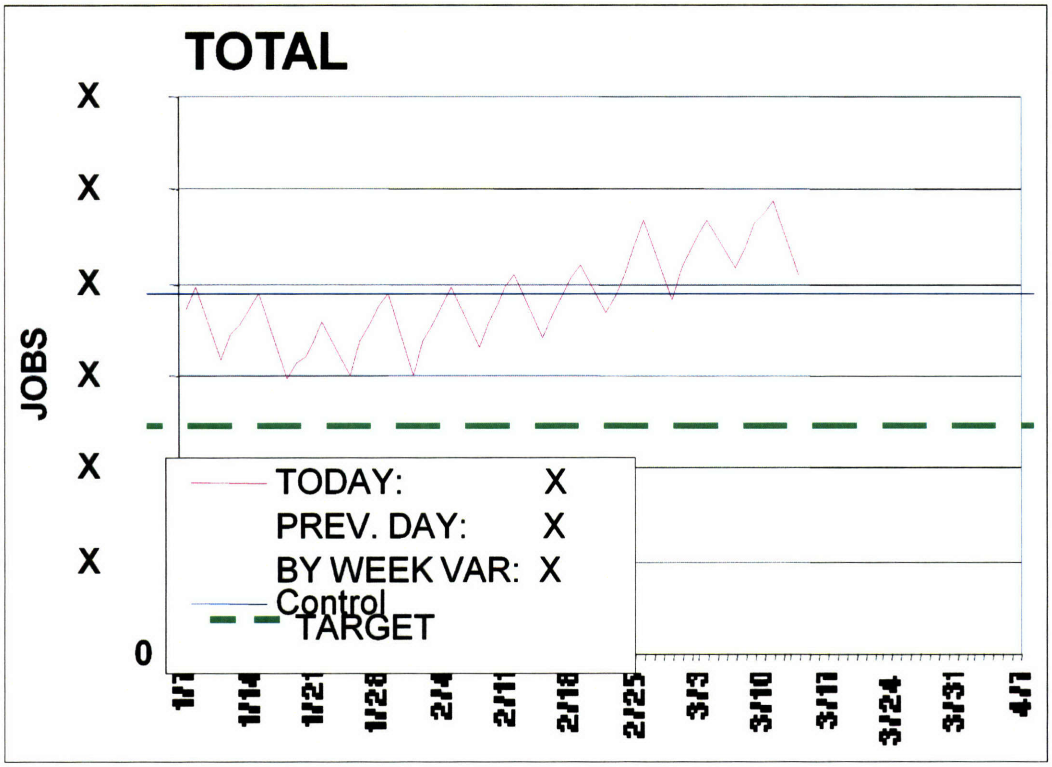

Figure 7 - Example Jobs Behind Schedule Metric for Fuselage Single Aisle Assembly

Jobs Behind Schedule may lose meaning as a metric when Spirit transitions to SAP, and as such, these charts may soon be obsolete. Even though their further lifespan as management tools may be short, there are a number of important critiques of these metrics that are worth mentioning. Firstly, the charts do not indicate where in the process the jobs behind schedule have surfaced. Jobs behind schedule early in the process are comparatively more worrying than those later in the process, due to their potential to disrupt downstream efforts. Certain parties have suggested a chart of scheduled jobs completed versus actual jobs completed by Line Unit (aircraft through production) to address this issue.[3]

[3] Discussion with Dave Logback, Methods Technology Analyst 20 June 2007

Another issue involves the control limit and goal setting. There are readily evident differences between programs in terms of reevaluating these metrics in light of process improvement, and a lack of common practice between different operating units. Aligning these processes across the organization will increase the credibility of these tools.

Lastly, these charts do not aid greatly in identifying the drivers of jobs behind schedule. Unfortunately, the drivers of jobs behind schedule and traveled work are not well illustrated at an aggregate level in Fuselage. Much of this information appears to be communicated up management chains anecdotally. This makes root cause analysis and impact assessment of each driver of Jobs Behind Schedule and Traveled Work difficult. Since these charts are shown throughout the organization, they have great potential to show impacts from other organizations along with the traveled jobs that are internally generated.

3.3. Methodology for Direct Impact and Cost Assessment

In order to understand the benefit of improving delivery from Fabrication, the cost impact of inventory shortages must be assessed. In the absence of existing assessment tools and data to illustrate the prevalence and impact of Fabrication inventory shortages in Fuselage, a methodology for a reasonable estimate had to be generated. Also, given the time constraints of the author's research period and the dependence of other parts of the overall project on the results of this assessment, an expedient method was critical as well.

These requirements led to a focus on the area of greatest absolute impact within Fuselage. As the Single Aisle program has the highest flow rate, and is such an important program for Spirit, this area seemed a natural choice. As discussed, Traveled Work is highly disruptive, and is one of the largest contributors to the cost variance of a line unit. The prevailing thought is that these traveled jobs required an additional 50% of a technician's time to complete to account for transit, the inconvenience of completing the work without certain assembly aids, and manipulating surrounding components.[4]

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[4] Conversation, Business Management Manager – Single Aisle Fuselage, 10 September 2007

The first step in understanding this cost driver was to attribute new traveled jobs to a general source. For a period of 15 manufacturing days, this information was collected, and new Traveled Jobs were attributed to general categories. These categories are shown below.

Traveled Job Reason	*Short Description*
Open Skin Quality	Job awaiting repair or replacement resulting from Skin Quality
Workable	Job ready for completion, requiring only labor
Held for Parts	Job waiting for parts from supplier
Held for Other	Reason unknown
Held for Doors	Job awaiting Door from Fuselage internal supply group

Table 1 - Traveled work general categories

From these categories, clearly the category of primary interest is "Held for Parts," and comprises an average of 21.3% of all traveled jobs during this period. The "Workable" category does bear some discussion however. This comprises jobs that are waiting only on a technician to complete the tasks. "Workable" then covers a job that is "Held for Parts" after the part in question has arrived in Fuselage, but before the job is worked. A job could be labeled "Workable" because a technician with a given specialty was unavailable when the task was scheduled, which could be for reasons of staffing, or because the disruption of a technician working on another Traveled Job. Given these possibilities, many traveled jobs in the "Workable" category could be attributed to a "held for parts" traveled job, either directly or indirectly through disruption. The "workable" category comprises 40.6% of the traveled jobs during this period.

The raw ERP shortages affecting the Single Aisle program can be used to allocate the "Held for Parts". A raw ERP shortage is defined as an order not clocked to its appropriate work center or assembly code according to Master Schedule when a daily report is run. This metric is tracked by the organization, and eventually is used to generate portions of the Impact List. By analyzing the raw ERP shortages from Fabrication supporting Single Aisle, the "Held for Parts" jobs that are awaiting inputs from Fabrication can be determined, and the costs associated with them can be determined. The figure below shows the portion of Raw ERP shorts attributable to Fabrication over the period of data collection.

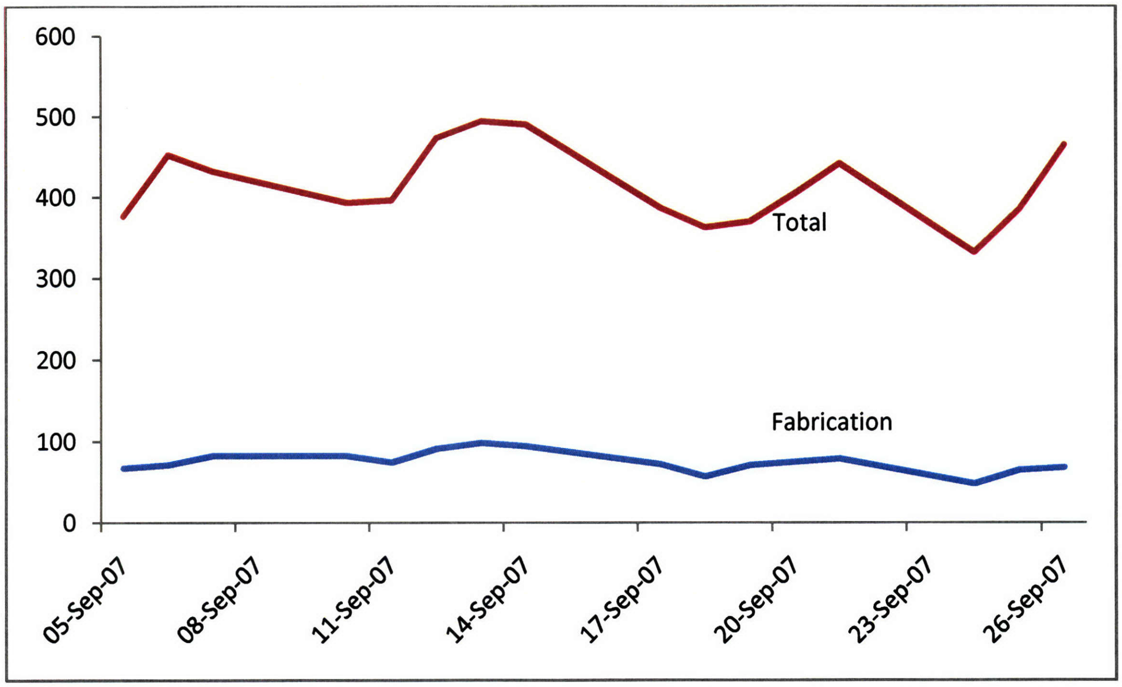

Figure 8 - Daily raw ERP shortages affecting Single Aisle Program

Based on this data, on average, Fabrication is the parts supplier for 17.9% of parts short to the Single Aisle program. The remainder is mainly attributable to SCM, but also Skin Fabrication and others.

Annualizing the number of travel jobs, their causes and the suppliers from our very limited data sample would tell us that Fabrication is directly responsible for about 3.8% of all traveled work in Fuselage. Most traveled work is completed on overtime, and traveled work has a fairly well understood standard time to completion. This data taken together, at a minimum yields a material amount for the annualized cost of Fabrication delinquent parts although the exact amount is confidential.

This, however, is a lower bound. The "Workable" category could contain additional jobs attributable to "Held for Parts" and to Fabrication. Given that roughly 41% of all Traveled Jobs are "Workable" (almost double the number of jobs "Held for Parts"), it is very reasonable the true number of jobs that ultimately are held for Fabrication parts could be double what they currently appear. The total annual cost impact could then be double that of the minimum amount..

This data is somewhat limited by the short period of its collection. The narrow collection range introduces significant uncertainty into the annualized projection. The high correlation factor in adjacent data points also limits the meaningfullness of such statistical concepts as "confidence interval" for this data set, given that these methods depend on random sampling. Anecdotally, the period of collection was during a "push" period for the Single Aisle program, during which a concerted effort was being made by Single Aisle and its suppliers to get current, which could lead to further understating of this data compared to the expected annualized period. These factors should be considered by users of this data.

However, this information could prove highly useful if it were available realiably and consistently. The management of Fuselage may wish consider additional projects focused on systematically generating this data. It could help prioritize internal and external drivers of out of sequence work, and help focus efforts to improve the production process.

3.4. Indirect Costs of Inventory Shortages

The previous section outlines the determination of a minimum operational cost of shortages, to provide an order of magnitude for the benefits achievable by improved schedule adherence in Fabrication. There are other indirect costs that could be improved by improved on schedule performance. These are in many cases difficult to quantify, or entirely attribute to the performance of any one area, but they are worth considering all the same.

First and foremost, inventory shortages are a detriment to worker efficiency. Shortages create a variety of non-value added activities, ranging from search time for the missing part, to paperwork and tracking materials, as well as additional time spent walking across the factory to complete the necessary work. If the materials a technician needs are available on time, every time, it will have a tremendous positive impact on the amount of work they can accomplish.

Inventory shortages also make it difficult to identify and implement process improvements. It is difficult to justify reduced buffer inventory or reduced flow time where process uncertainty exists. Fuselage management has expressed this sentiment, pending improved schedule compliance from Fabrication. If a flow day was removed from each of the Fuselage programs, it would be worth several million dollars as a onetime benefit in reduced Work in Process inventory.

Tracking of inventory shortages also creates significant non-value added work. It may be unreasonable to think that many of these tracking efforts could truly be dispensed with, but they are a tremendous drain on human resources. Three people at the Wichita site are dedicated to site-wide shortage reporting full-time. The daily reports generated from these individuals rely on contacts within each organization on site, who must spend some portion of the day generating data for these reports. Once it is determined which parts are needed downstream, the management of upstream suppliers must spend time communicating with the customer, then tracking and working these parts, and communicating with the customer again. The senior leadership of Fabrication, comprised of seven people, had 66 person-hours of scheduled shortage meetings in a representative week. Shortage parts must be frequently expedited through the MPF's manual line, or the 3PL's cross-dock function, each of which implies added costs.

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4. Supply Disruption Impact on Supplier

In order to understand the persistent schedule delinquency in Fabrication, it is important to understand the initial driver of the delinquency. Delivery from Fabrication has in recent history maintained an on time delivery acceptable to the organization, although it had rarely been 100% on schedule for a significant duration. This pattern has most recently been disrupted by the industry supply situation surrounding titanium and aluminum raw materials supply. This impact can be seen in the organization through the history of raw ERP shortages.

4.1. Fabrication Schedule Position from Disruption to Present

As introduced earlier, raw ERP shortages track orders not registered ("clocked") to the work center or assembly code at a given time. A report of this information is collected daily at a consistent time. An order clocked several stations behind its master schedule station will appear on the report only once. If a single order is not clocked to a correct work center for several days, it will appear on the report once each day. This report is aggregated on a functional area basis and is now used to assess the overall health of the production process at the Wichita site. It is important to note that this measure is intended to denote the ownership of a behind schedule order, rather than the cause. For example, a quality issue in Fuselage could necessitate a replacement part from Fabrication. The replacement part would be "behind schedule" when it is released, since it is needed immediately, and show up as a raw ERP shortage.

The figure below shows the history of raw ERP shortages for the Wichita site as a whole, and for Fabrication.

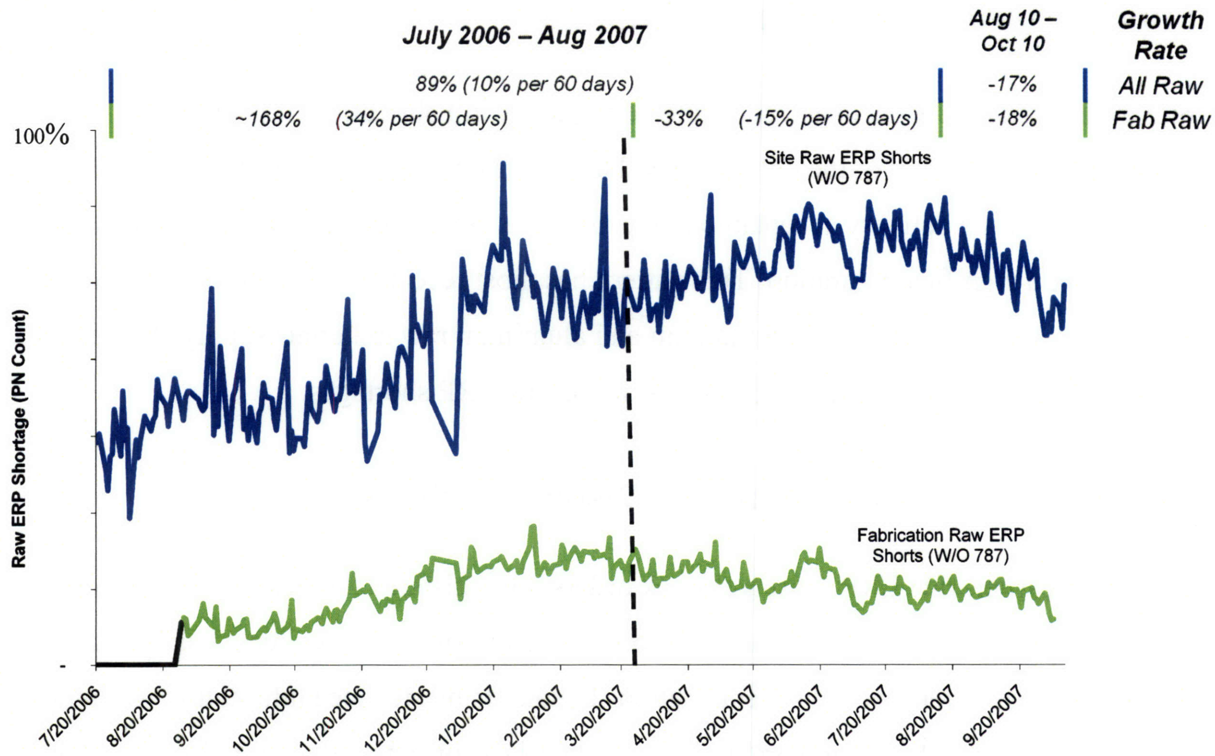

Figure 9 - Raw ERP Shortage, Fabrication and Site-Wide

Note the rapid growth of the site-wide shortages, and even more rapid growth of Fabrication ERP shortages from August 2006 through late March 2007. The dashed line in the chart above denotes the reversal of the growth trend in the Fabrication delinquency.

4.1.1. Discussion of Raw ERP Shortage Trends

There are clearly a number of factors that could influence the production process and yield the above behavior in raw ERP shortages. It is also evident from the continued growth of the site-wide shortages significantly after Fabrication's shortages began to decrease, that factors other than Fabrication are impacting the site as a whole. Fully dissecting these trends is difficult, and, lacking complete data from history, may well be impossible.

An accumulation of factors contributed to the growth in Fabrication delinquency. A few major factors are most significant. CNC instruction tape proving for new programs consumed labor productivity and machine time. Planned capacity offloads lead Fabrication leadership to limit hiring. Fuselage increased production rates in early 2007, which required Fabrication to ramp production to match. Lastly, the global supply situation for aluminum plate stocks and titanium stocks in late 2007 and early 2008 was quite dismal.

All of these factors came to bear on Fabrication in close proximity. Several in Fabrication described this combination as a "perfect storm" leading to a delinquent situation in Fabrication. However, in the period shown in figure 9, only the raw materials and hiring trends have appreciably reversed, and hiring only began in late April, which is after the improvement in Fabrication schedule position.

4.2. Industry Raw Material Shortage Emergence

In order to understand the rapid emergence, and then dissolution of the global aerospace raw materials shortage, this section will focus on the economic and technical drivers of this effect. The alloys of titanium and aluminum commonly used in aerospace will be introduced, and the characteristics of the metals that make them appropriate for applications in this industry will be discussed. The production process will be presented, and the technical and economic drivers in this process that contributed to the industry wide raw material shortages will then be explored.

4.2.1. Commonly Used Aerospace Metals

Titanium is highly desired in aerospace applications for its high strength and light weight. Titanium is roughly 60% the density of steel, while maintaining the same tensile strength. Titanium also can be used up to temperatures just above 500-°C without creeping, making it useful in engine applications. It is highly corrosion resistant, giving structures formed from it a long useable lifetime. Titanium can be forged or wrought, or formed through investment casting and joined via fusion welding, brazing, adhesives, and fasteners. (Donachie, 2000) This versatility enhances its usability and facilitates design.

The most commonly used titanium alloy in aerospace is Ti 6–4, and it accounts for nearly 50% of all alloys used in aircraft applications. (Donachie, 2000) Other common alloys are Ti 6-2-4-2, Ti 6-2-4-6, and Ti 8-1-1. (Vacha, 2007) The composition of these alloys is shown in the table below. Additions of aluminum, tin and zirconium are considered alpha-stabilizers, while molybdenum and vanadium are beta stabilizers. The concentrations of these alloying materials are quite small, and yet have a significant impact on the processing characteristics and material properties of the resultant material. The complexity of control of the alloy production process adds significantly to the cost of titanium production. (Kalpakjian & Schmid, 2005)

MATERIAL	Al %	Mo %	Sn %	Ti %	V %	Zr %
Ti-6-2-4-2	0.06	0.02	0.02	0.86	0	0.04
Ti-6-2-4-6	0.06	0.06	0.02	0.82	0	0.04
Ti-6-4	0.06	0	0	0.9	0.04	0
Ti-8-1-1	0.08	0.01	0	0.9	0.01	0

Table 2 - Composition of common titanium alloys

Aluminum is desirable as an aerospace metal for many of the same reasons as titanium. Aluminum alloys are generally lighter and more corrosion resistant than plain carbon steel, although they can be subject to rapid galvanic corrosion if they are in contact with steel or other materials with negative corrosion potential (such as carbon fiber). Electrolytic isolation of aluminum from these other materials via encapsulation or surface treatment can add significantly to the cost of a finished aluminum part.

The most common aluminum alloys in aerospace are 7075 aluminum, 6061 aluminum, 6063 aluminum and 2024 aluminum. These alloys have varying uses. For example, 7075 is a higher strength alloy with reduced corrosion resistance but cannot be joined by welding. Alloy 6061 is used where welding is required. 6063 lends itself to extrusion, and is often used where part architecture lends itself to extrusion formed raw materials.

Al Alloy	Si %	Fe %	Cu %	Mn %	Mg %	Cr %	Zn %	Ti %
7075	0.4	0.5	1.6	0.3	2.5	0.23	5.6	0.2
6061	0.4 - 0.8	< 0.70	.15 - 0.4	< .15	0.8 – 1.2	.04 - .35	< .25	< .15
6063	0.2 - 0.6	< 0.35	< 0.10	< 0.10	.45 - .90	< 0.10	< 0.10	< 0.10
2024	< 0.50	< 0.50	3.8 – 4.9	.30 – 0.9	1.2 – 1.8	< 0.10	< .25	< .15

Table 3 - Composition of common aluminum alloys **(Alcoa)**

Aluminum is still generally cheaper than titanium, although not quite as strong. Consequently, aluminum is used over more aerospace structural applications, with titanium restricted to the most demanding structural components (landing gear struts), or high speed parts (engine turbine blades, engine internal components).

4.2.2. Production and Processing of Aerospace Metals

Aluminum and titanium are mined from the earth and reduced to raw metal in a very energy intensive process. Both materials are generally found combined with other materials in ore, rather than as a free material. Titanium is most often commercially extracted from ilmenite and rutile ores, although it is present in several other kinds of igneous rocks. It can be difficult to find these ores in high concentrations however. (Roberts, 2006) Significant deposits are found in Western Australia, Canada, New Zealand, South Africa and Ukraine. These deposits supply roughly 86.4% of the world's titanium production. (Cordellier & Didiot, 2004) In the case of aluminum, the ore used commercially is bauxite. Bauxite is more widely available than titanium ores. The top producing countries are Australia, China, Brazil, Guinea, Jamaica, India, and Russia. These producers comprised 87.9% of the global supply in 2007. (U.S. Geological Survey, 2008)

Both metals must be reduced from their ores via complex batch processes. In the case of titanium, the Kroll process is used to convert rutile or ilmenite (both containing TiO_2 and $TiFeO_3$) into raw metal. In this process, the TiO_2 or $TiFeO_3$ is heated and exposed to petroleum coke, and chlorine gas. This produces $TiCl_4$ and side products. Fractional distillation is used to concentrate and condense this gas. It is then exposed to molten magnesium metal, yielding titanium metal sponge, a porous solid form of the metal. (Habash, 1997) The utilization of magnesium in the extraction process is one of the major cost drivers for titanium, given that magnesium is itself an expensive metal. Consequently, there is immense process focus on recovering and recycling the $MgCl_2$ in this process. These reactions are summarized below.

$$2TiFeO_3 + 7Cl_2 + 6C\ (900\ ^\circ C) \rightarrow 2TiCl_4 + 2FeCl_3 + 6CO$$

$TiO_2 + 2Cl_2 + C > TiCl_4 + CO_2(CO)$

$TiCl_4 + 2Mg$ (1100 °C) $\rightarrow 2MgCl_2 + Ti$

The titanium sponge must be purified by vacuum distillation or leeching. Then it must be jack-hammered out of the batch reactor, where it is then crushed and melted in a consumable electrode vacuum furnace. The ingot is then cooled under vacuum before it is further processed into billets, bars or plate, which is the raw material used in manufacturing.

For aluminum, the first step for production is to extract alumina, Al_2O_3, from bauxite, via the Bayer process. Alumina comprises roughly 30 – 40% of raw bauxite, with the remainder being silica, iron oxides, and titanium dioxide. (Industry Commission (Australian Government), 1998) The bauxite is washed in hot sodium hydroxide, dissolving only the alumina within the ore. The resulting aluminum hydroxide in solution is then cooled to precipitate the solutes. Once dried, the solids are heated, decomposing the aluminum hydroxide into purified alumina and water vapor. These chemical reactions are summarized below.

$$Al_2O_3 + 2\ OH^- + 3\ H_2O \rightarrow 2\ [Al(OH)_4]^-$$

$$2\ Al(OH)_3 \rightarrow Al_2O_3 + 3\ H_2O$$

This purified alumina is converted to aluminum by the Hall-Héroult process. This process passes low volt (3-5 V) high amperage (150,000 amp) current through a carbon lined bath of alumina dissolved in cryolite (Na_3AlF_6). The dissolved aluminum oxide in cryolite has a much lower melting point than bulk alumina, roughly 1000-°C when dissolved, and about 2000-°C when in bulk. When current passes between the anode and the cathode, aluminum is reduced and deposited on the cathode. The carbon anode is simultaneously oxidized into carbon dioxide. The net reaction is shown below.

$$2\ Al_2O_3 + 3\ C \rightarrow 4\ Al + 3\ CO_2$$

The aluminum, while still molten due to the heat of the bath, is denser than the surrounding molten cryolite, and falls to the bottom of the bath. (Grjotheim & Kvande, 1993) The aluminum is periodically collect, and is then cooled into ingots, which are passed to mills for refining.

4.2.3. Technical Drivers of Metals Shortage

Titanium is produced in a batch process, in contrast to steel which can be produced in a continuous process. This batch process confines all the material to a closed system during processing, and this processing takes a considerable amount of time. These factors, combined with the expense of magnesium, and the complexity of its recovery systems, make it difficult for titanium producers to quickly change the volume of their production.

This significant investment in capital and long length of time to bring new capacity online also leaves the suppliers highly exposed to changes in market conditions. Learning from past market cycles, metal suppliers are very reluctant to commit to expanding capacity. In the past, this has left the producers with excess capacity as programs were canceled or cut back. This manufacturing system is also difficult to stop and start, even though it is a batch process. (U.S. Geological Survey) As such, titanium producers have been reluctant to match the business cycles that are very common within the aerospace industry.

This problem will only grow more severe as time goes on. The following figure shows the utilization of titanium on various new airframes. This clearly indicates that the trend in the industry is towards higher titanium usage, which will make industry cycles more strongly felt by the titanium suppliers.

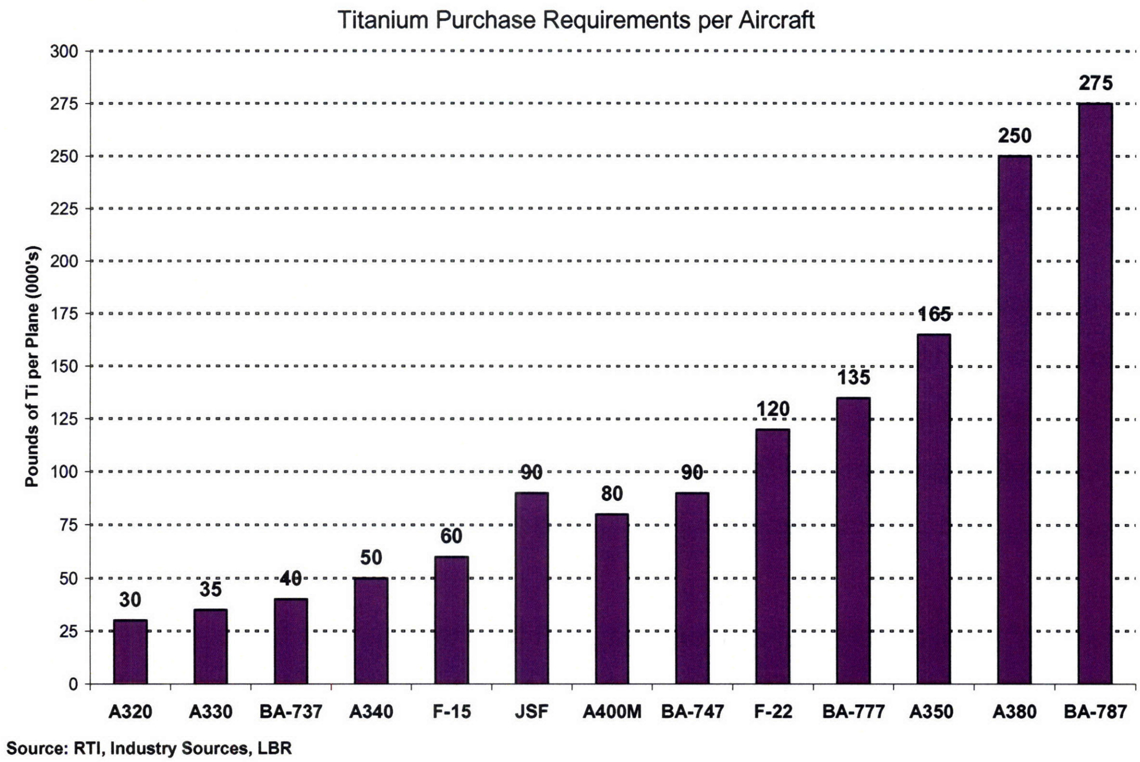

Figure 10 - Titanium utilization by airframe

The high energy costs for aluminum contributed significantly to the shortage affecting the industry. Like titanium, the aluminum industry is highly capital intensive, but does not bear the same degree of industry concentration risk. The rising price of energy has induced many companies to idle their capacity. (U.S. Geological Survey, 2007) This constrained an already tight market, and raised prices significantly.

4.2.4. Economic Drivers of Metals Shortage and Rapid Recovery

The shortages of these metals were exacerbated by economic factors. As alluded to previously, the risk aversion in high capital industries such as aluminum and titanium processing leads them to lag the industry cycles of their customers. These suppliers will only build capacity when there is a proven need, rather than co-invest with an uptick of their downstream customers. Given the downturn of the aerospace industry following 9/11, and the subsequent resurgence recently, the available supply was then largely outstripped by the demand. This can be seen for titanium, in the following table. This table shows survey results from titanium suppliers regarding their opinion of their inventory condition. Note that the titanium supply is not rich until the December 2006 timeframe.

Titanium Product Inventory Level			
Period	Higher than Desired	Desirable Levels	Lower than Desired
Feb '06	0%	10%	90%
Apr '06	0%	0%	100%
Jul '06	5%	55%	40%
Sep '06	5%	65%	30%
Dec '06	6%	75%	19%
Feb '07	11%	72%	17%
May '07	16%	77%	7%
Aug '07	25%	70%	5%
Nov '07	45%	50%	5%

Table 4 - Titanium supplier inventory opinion survey **(Longbow Research, 2007)**

As these inventories rose (and overshot desired levels in the 4th quarter of 2007), lead times for titanium products fell by 25% for many products. The titanium market was generally favorable to customers by March 2007 as prices began to fall. Note the rapid rise then fall of the price of the 6–4 products in the following chart.

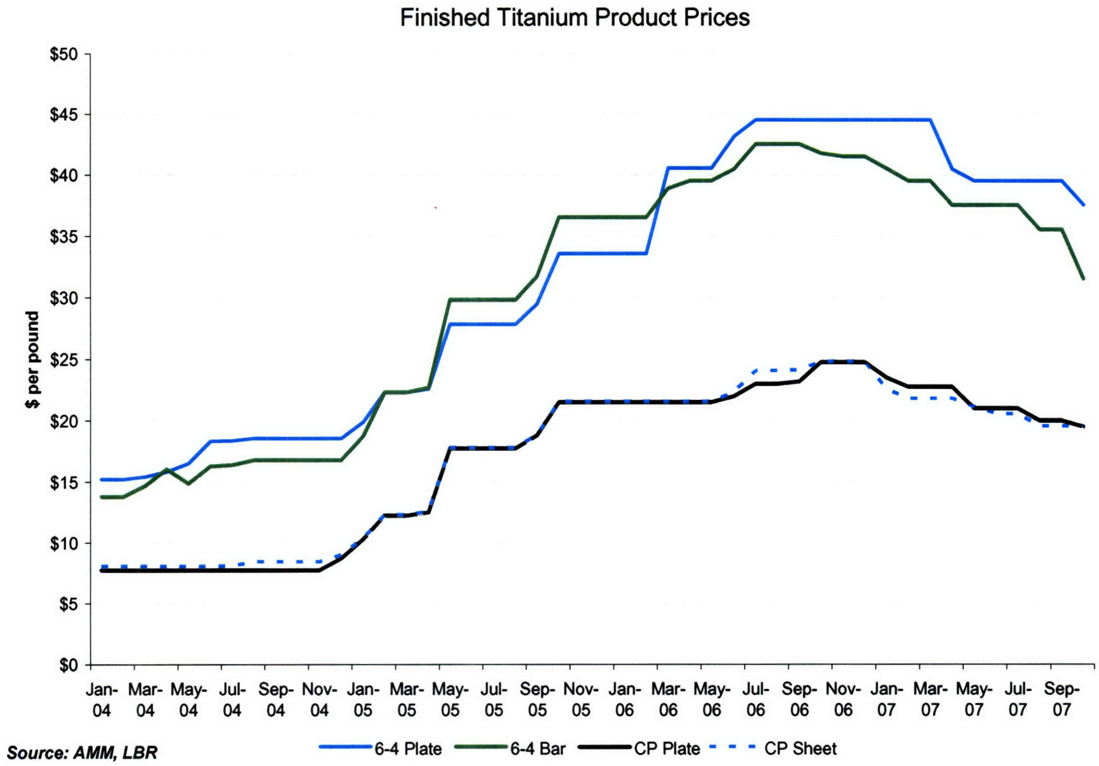

Figure 11 - Prices for milled titanium products

The rise in prices presents another interesting challenge of operating in a market with constrained raw materials. As prices rise, the expectation of future prices rise as well. This can lead to "hoarding" behavior, where customers attempt to buy before prices increase more. This further constrains supply, and creates a reinforcing loop. (Sterman, 2000) It can also lead customers to create "phantom orders" where demand is artificially inflated, as it is assumed that only a fraction of the order will be fulfilled. This can further drive the reinforcing loop, and make it more difficult to recover. These individually optimal behaviors ultimately produce a suboptimal situation for the industry as a whole.

Boeing has recognized this challenge, and has centralized the buying for many critical raw supplies, including aluminum, titanium and carbon fiber composites. TMX Aerospace has been contracted to supply cut metal raw materials to Boeing's supply base. The contracts stipulated by Boeing generally discourage spot buying and phantom ordering. This enables Boeing to achieve volume discounts from centralized buying, and as a major customer in the metals market, insure that the industry does not engage in destructive loops that could prolong shortages. Occasionally, however, as can be seen with Spirit, selective spot buying could prevent significant operational disruption. Boeing may wish to consider allowing for TMX contracts that allow for spot buying in select circumstances.

4.2.5. Potential Future Materials Issues in Aerospace

Carbon fiber is supplied for the 787 program exclusively by Toray Group to all of Boeing's partners. This mirrors the situation of aluminum and titanium for Boeing's legacy programs. This centralized control of supply can lead to a macro-optimal result to supply constraints by preventing the destructive and reinforcing mechanisms discussed previously. It is possible that the additional operational disruptions caused by enforcing globally optimal behavior could create a similar challenge to what has been experienced at Spirit. This could become especially true as the market for carbon fiber expands, and has a similar number of diverse users as is the case with titanium. It is worth considering the aluminum/titanium disruption as a case study for potential future disruption of the carbon fiber supply. Allowing for a diverse number of raw material suppliers, and permitting spot buying in select circumstances are possible actions to consider.

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5. On Time Delivery Forecast Data Methodology

In order to understand the internally generated costs of reducing late deliveries to Fuselage, a predictive model needed to be developed to illuminate behind schedule position. This would allow a forward looking view of the impact of current operational plans in Fabrication, and the additional labor requirements to reach a certain rate of delinquency. This process would also yield a tool that could create a common communication language around performance between Fuselage and Fabrication, and identify opportunities for improvements.

Raw ERP shortages paint an incomplete picture of production health. Firstly, an order 40 days behind its scheduled first step, or only a day late on the final date count equally even though the costs of one instance is greater than the other. Secondly, it may not matter if every order is started 40 days behind its scheduled start if the order is ultimately delivered on schedule. These factors necessitated an alternate base from which to forecast the future schedule performance of the Fabrication organization.

Further, this forecasting model would need to be driven at the level of each operating area within Fabrication. This would be the level at which performance would be managed, and is the level at which strategic operational plans are made within Fabrication. Other operational activities are prohibitively difficult to allocate on a shop or all-Fabrication basis. Some examples of the plans include offload related headcount changes, which were only planned at the Area level, and loan-ins and –outs, where workers in one particular shop would temporarily work in a different shop. Most loan-ins were within the same Area, and labor hours were irregularly transferred at the shop level, which could lead to skewed results in a shop level based model.

5.1. Standard Hour-Based Forecast Model

These factors led to the decision to develop a standard production hour based forecast model, supplemented with a chart to show the delivery condition clearly between Fabrication and MPF, the immediate recipient of most of Fabrication's output. This section will detail the standard production hour based model.

5.1.1. Production Hour Requirements

Fabrication had previously developed a daily chart in the Fabrication Visibility Room that showed a thirty day view of the standard production hours. These standard production hours are the accumulation of the standard production time required by each order. This standard is maintained by the capacity planners, and is updated from time to time. The chart shows the current day's scheduled hours, and the hours of production scheduled for each production day for the next 30 calendar days. It also shows the number of production hours that are currently delinquent. The chart divides each of these categories into released orders and planned. The chart also divides orders that are clocked into the correct Work Center for the scheduled work to be completed ("In Shop"), or in route to the Work Center ("In Route"). For clarity, the In Shop and In Route Divisions will not be shown in the model output.

The Fabrication visibility room also shows a six-month forecast chart, allowing the expected incoming production hour estimate to be expanded to a six month horizon. Production requirements more distant than six months must be projected from the existing requirements, or adjusted by manual intervention. The incoming volumes are also adjusted to account for planned capacity off-loads, which will effectively reduce the expected incoming production load.

5.1.2. Labor Capacity Allocation

The other half of the model determines the labor capacity, and how it is distributed between production requirements that are on, ahead, or behind schedule. The total labor is calculated according to the following equation:

$$Total\ Labor\ Capacity = \frac{Headcount * (1 - absenteeism\ \%) * (1 + overtime\ \%)}{Performance\ Index}$$

Headcount represents the number of workers in a given area, and the absenteeism fraction represents the planned daily absenteeism percentage. Overtime represents the time past the standard productive eight hour day worked in an area. It is worth noting that the Fabrication area operates at significant absenteeism and overtime, nominally 10% and 20% respectively on an ongoing basis. Headcount, absenteeism and overtime levels are based on the strategic plans maintained by the PLMs for their areas. Although they may be adjusted as time passes, the model incorporates plans for two years into the future.

Performance Index, or P.I. is a historic efficiency measure, calculated as follows:

$$PI = \frac{Actual\ Labor\ Hours}{Standard\ Labor\ Hours\ Produced}$$

It should be noted that the model uses a historical PI to compute the forecast. This implicitly assumes that activities reducing productivity, such as raw material stock-outs, machine downtime or machine tape proving, will continue at their current levels, rather than being eliminated. If in actuality these factors were expected to improve compared to history, the forecast would appear conservative, and would appear optimistic if the P.I. were to degrade. Note that an "improvement" to P.I. moves the number closer to zero, and a degradation of P.I. corresponds to the number increasing.

Historically, it has been shown that a portion of this total labor capacity is absorbed by work that is currently on or behind schedule according to master schedule, with the remainder being allocated to work ahead of schedule. In both Complex Machining areas, this ratio has historically been consistently in the neighborhood of 67% labor capacity to on and behind schedule work. In the Light Structures areas, which operates with many fewer production hours in backlog, this ratio has fluctuated in the range of 20% to 60% labor capacity to backlog. The Light Structures areas have typically focused more labor to the backlog as schedule position slips to more delinquency, then focus less attention to backlog as the total size decreases.

In all areas, analyzing the behind schedule hours at a shop level shows the majority of the behind schedule work resides in the early processing shops. This would imply that ahead of schedule work happens mostly in later shops that are starved for delinquent work, rather than a situation where the most delinquent jobs are not being worked as available. It is important to remember that the allocation of labor capacity to ahead and behind schedule work doesn't fundamentally affect the ability of an area to match the incoming production hour requirements, unless it impacts the PI. It will have the effect of "smoothing" out an uneven distribution in incoming work.

5.1.3. Results of Production Hour Model

Once labor capacity is allocated, all portions of the capacity model can be computed. Using these elements in concert can show the expected performance of the areas within the Fabrication area under the influence of the existing plans. These results are shown and discussed in the sections below.

5.1.3.1. Complex Machining Production Hour Model Results

The results of the above modeling methodology are show in the figure below for the Complex Machining areas, with CME being shown first. Note that the date of the analysis reflects the final iteration of agreement on the methodology of the analysis, before actions were taken based on the results of the analysis.

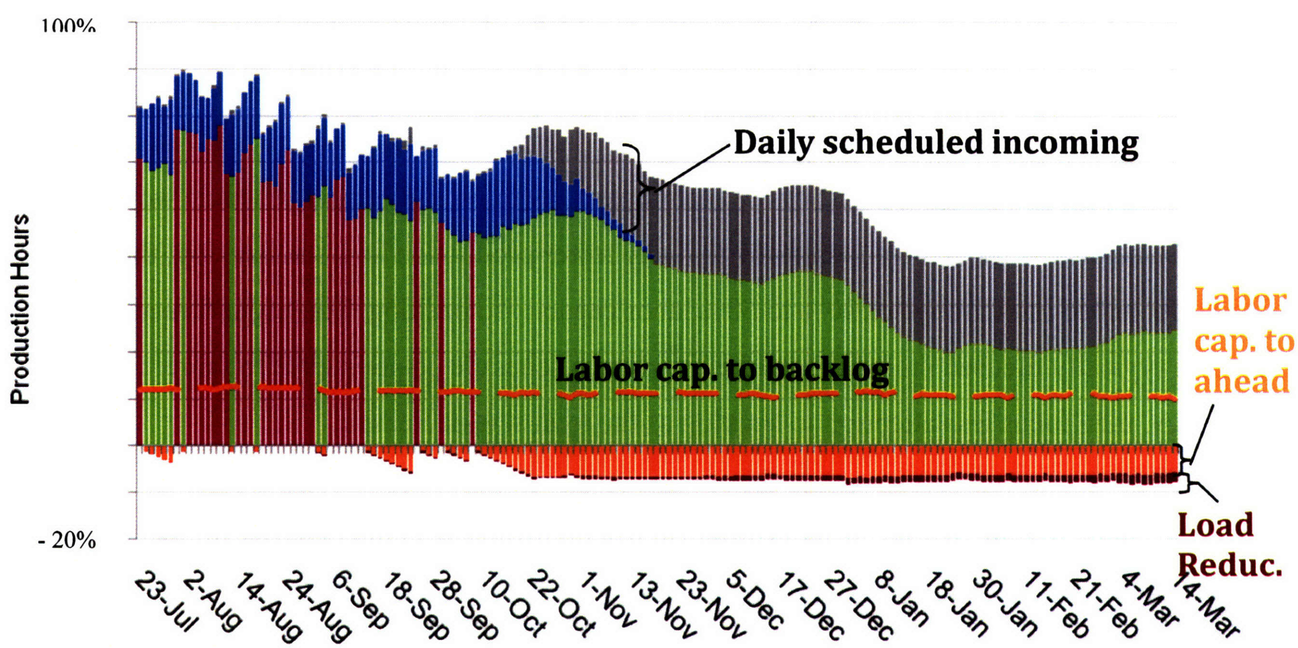

Figure 12 - Complex Machining East Behind Schedule Production Hour Forecast

In the above figure, the blue colors represent daily incoming volumes of production that are currently released, whereas the gray bars are hours of work that are planned. As the model is updated, the planned work converts to released. The maroon, negative quantities are the hours of work expected to be offloaded from that day's current planned work. The orange dashed line, and negative bars indicate the labor devoted to behind schedule and ahead of schedule work respectively. The purple bars represent actual hours of production in backlog. The green bars are the estimate of future delinquency, and are the result of calculations of the above inputs.

In the case of CME, the forecast would lead us to expect continued improvement in behind schedule position until the new year, at which point the delinquency would begin to slowly rise. While this would be an improvement over the immediate situation, this does not show a complete elimination in backlog (the green line disappearing). In would be unreasonable to expect the backlog to reach zero in reality, given the friction inherent to the production environment. However, this would indicate spare capacity availability, which would enable Fabrication to meet new strategic needs, or weather the next disruptive event without developing a substantial growth in delinquency.

The situation in Complex Machining West shows a markedly different trend. The figure below shows the parallel model methodology as applied to CMW.

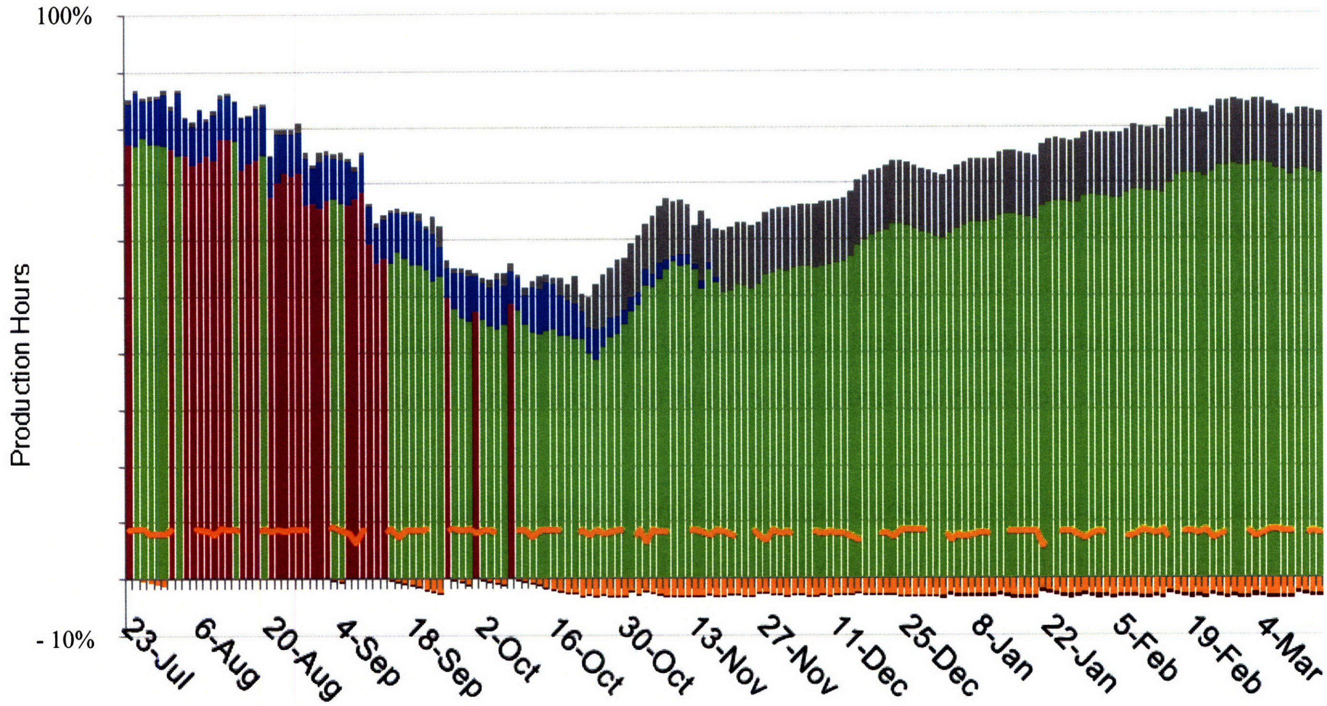

Figure 13 - Complex Machining West Behind Schedule Production Hour Forecast

The model shows that in CMW, the expected production hour delinquency will grow substantially over the next six months, potentially erasing the recent improvements in schedule position. This situation would indicate that the existing labor and offload plans will be insufficient to meet growing demand from rate increases. In order to make improvements over this case, efficiencies in PI would need to be achieved, or additional labor capacity would need to be added in the form of headcount or overtime. To maintain the current level of delinquency, labor capacity would need to be increased by roughly 3%, which would correspond approximately to an additional five workers at current overtime rates.

5.1.3.2. Light Structures Production Hour Model Results

The Light Structures areas operate significantly differently than the Complex Machining areas. They operate at a much lower amount of delinquency, and their labor allocations to behind schedule work vary significantly more than the Complex machining areas. The figure below shows the model results for Light Structures North.

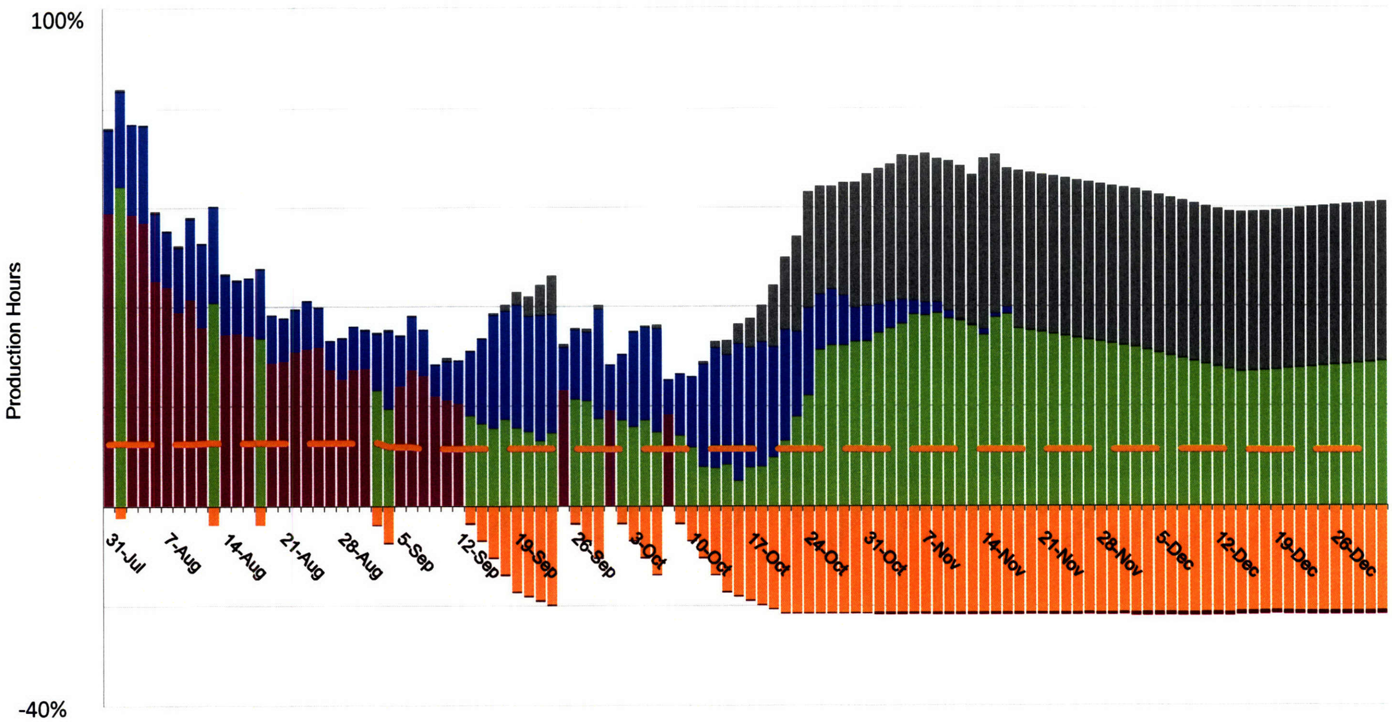

Figure 14 - Light Structures North Behind Schedule Production Hour Forecast

The forecast for LSN shows a sustained level of behind schedule work into the future. It is reasonably of the same order of magnitude as the current delinquency. The same concerns as for CME apply, but the LSN plans appear to be sustainable. Given the historical observed behavior of LSN, it is likely they would work further ahead of schedule after the last data point, leveling the amount of delinquency between its current expected trough and rise. Light Structures South, whose results appear below, show a significantly different trend.

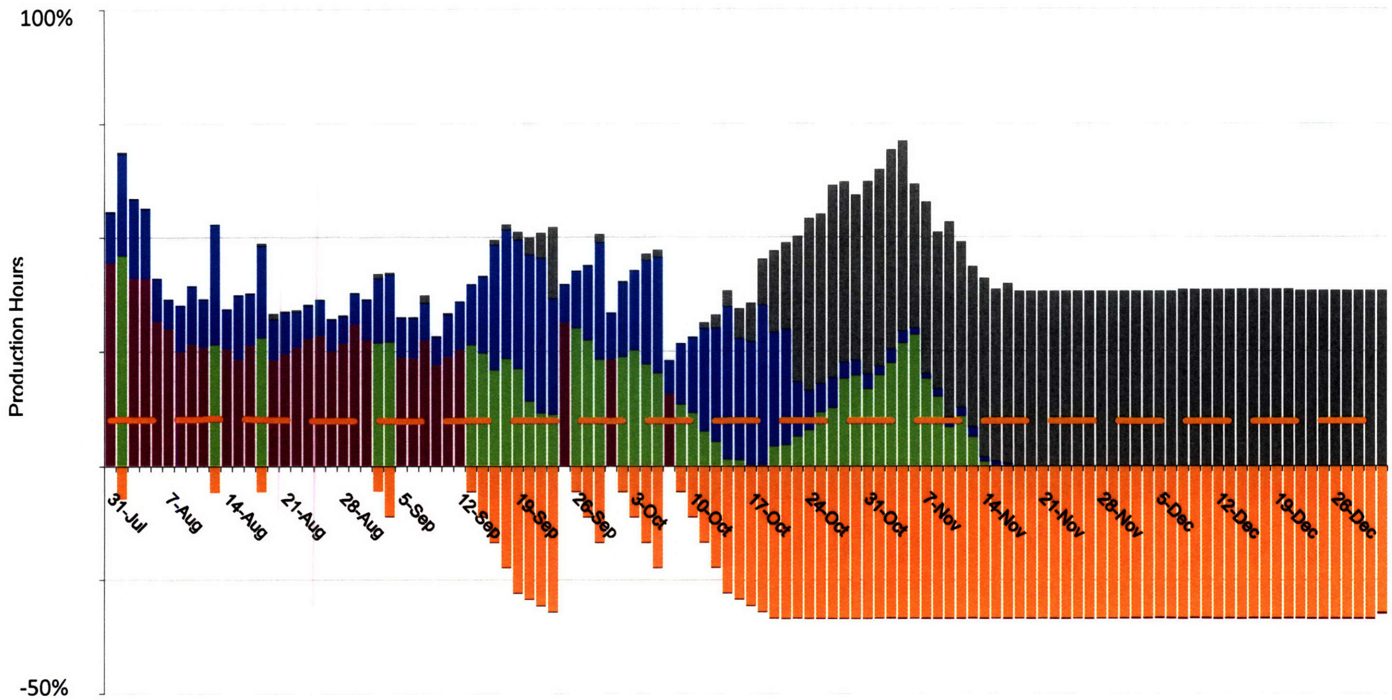

Figure 15 - Light Structures South Behind Schedule Production Hour Forecast

The behavior shown above shows that LSS is well prepared to meet future requirements. Although the green bar of expected delinquency reaches zero, the expectation of zero delinquency is unlikely. Instead, as the delinquency decreased, past behavior would indicate that the area would reach more heavily into ahead of schedule work to keep the area productively utilized, or the area's P.I. may degrade slightly as certain shops become starved for work.

One way to interpret the current forecast is that LSS is richer in resources than it needs to be, but that is not necessarily negative. Instead, LSS is well positioned to recover from disruptions in the supply chain or operations. While supply shocks could drive up delinquency in the area as orders couldn't be worked, the rate of recovery in LSS would be expected to more immediately follow the recovery of the supply chain. Given the current situation in the other areas of Fabrication, a temporary measure may be to move some resources from LSS to areas that have more delinquency.

5.1.4. Model Considerations

This model provides a basis to understand the operational results of Fabrication's strategic plans. They also provide a scenario analysis tool, allowing an understanding of the requirements to reach a required level of delinquency. By balancing cost avoidance in Fuselage with increased resources in Fabrication, a globally optimal labor allocation can be reached.

Any model will have critiques, and these must be appreciated to understand the limits on the output of the model. A few of these are discussed below, and will serve to highlight some of the limitations of the existing labor model.

As with any analysis, the results can only be as good as the input. A number of concerns exist with the standard production hours currently in use. The standard hours, while regarded as reasonably accurate in aggregate, vary in quality significantly on a part by part basis. This is, to some degree, mitigated by the use of P.I. which corrects for historical differences in actual time taken versus expected. However, the standards can be changed by Fabrication's capacity planners, and no standard process exists to determine when and how to update the standards for an order. This can result in a somewhat apples-to-oranges comparison of incoming standard hours of production, and labor capacity based on historical P.I. This results in some reluctance to make fine tuned decisions based on the output of the model.

Other human factors add difficulty to this model. Plans can be made in the model, which are unattainable in reality, if the user is overly optimistic. Offload packages may not be offloaded as quickly as hoped or improvements in P.I. may not be achieved. The model at present must also be maintained by manual updates to many inputs. Performing these updates irregularly will result in model errors. Further, many of the current data sources will be unavailable after the conversion of SAP, and many terms, such as "delinquent to master schedule," will change definition completely under the new system.

More fundamental issues exist as well. 787 production volumes, which flow through Fabrication areas are not included in the existing ERP environment, and don't appear in the incoming production hour requirements. These hours are removed from labor capacity in the model, in essence saying that these requirements are completed before all else. This is certainly not the case, and this adds turbulence to the model's expectation and actual performance.

Lastly, the model is based on available labor capacity, which does not take machine capacity into account. By observation, machine capacity is not the limiting factor within Fabrication, but this could lead in some cases to lower returns than expected of additional headcount.

5.1.5. Model Effectiveness and Accuracy

It is difficult in many cases to assess the accuracy of a model such as this. Most fundamentally, once the future is predicted, and the affected take action based on this knowledge, the forecast is then no longer accurate. Fluctuations in the allocations of labor capacity to ahead- and behind-work can also shape the results, even if they don't affect the long-term ability of the area to meet its capacity requirements.

Perhaps most significantly, the model has no mechanism to account for unanticipated disruptions in the production process, or supply shifts. For example, significant work was brought in-house to support failures in the supply base, significantly increasing the demand load on Fabrication. This added significant production requirements to the Complex Machining areas, and especially CME. As indicated by the forecasting model, these requirements added on the delinquency in the area and are being reduced slowly. The figure below shows these results.

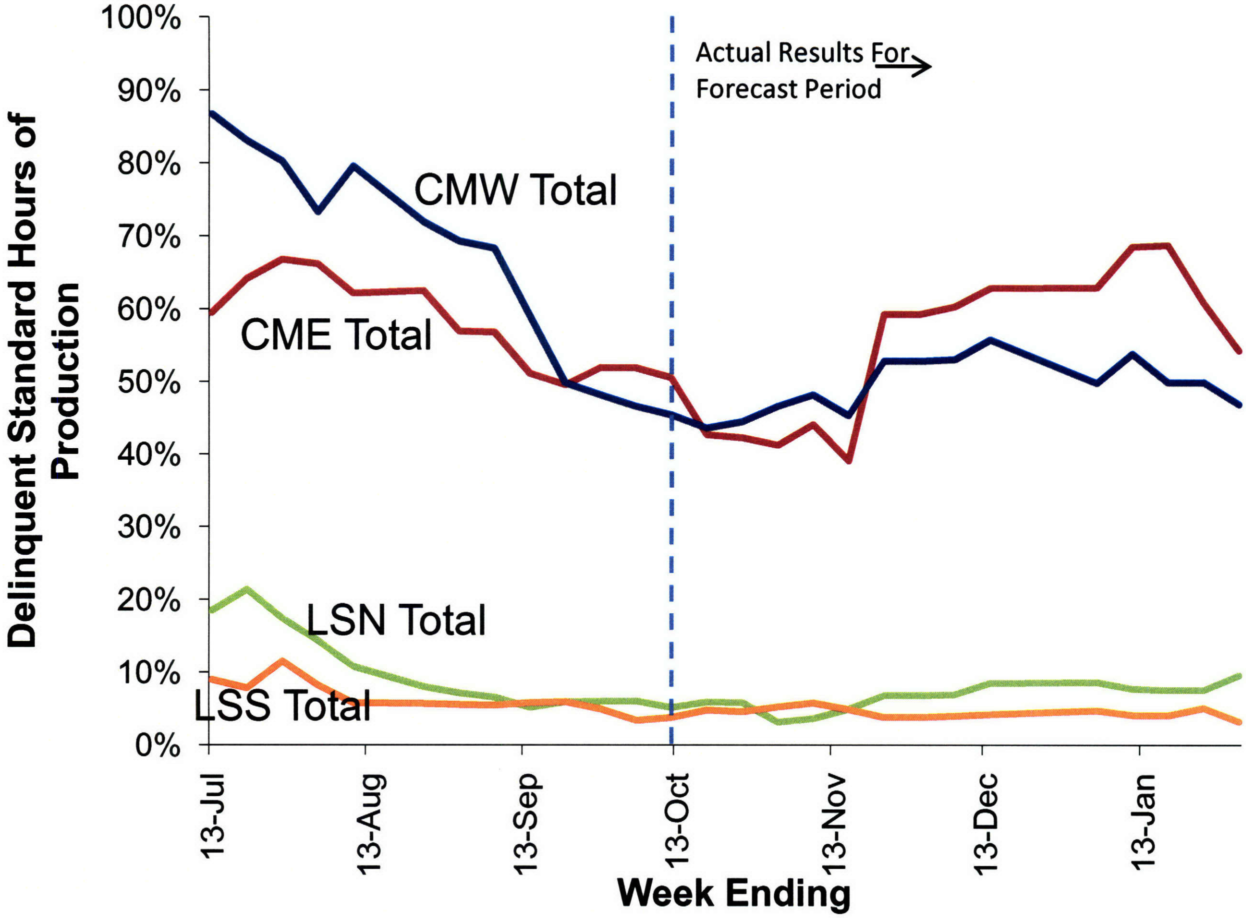

Figure 16 - Actual Results of Fabrication Behind Schedule Production Hours

5.2. Disambiguated Delivery Metric for Fabrication On-Time Delivery

Quantifying on-time delivery for Fabrication is more challenging than it appears. Much of Fabrication's production must pass through the MPF for paint and surface treatment. Most of these parts then return to Fabrication to affix attachment points (completed in a group called "nut-plate") before moving on to 3PL stores. Some of these parts jockey between Fabrication and MPF several times as several different surface treatments are completed in MPF, and intervening operations such as drilling or shot-peening are completed in Fabrication. A part delivered on time to MPF at the beginning on the first pass, may no longer be on time when it returns to MPF for the second time, or the reverse. Further, given the limited queue space in MPF, parts delivered too early could be almost as disruptive as those delivered too late.

These factors were somewhat ambiguously included in the existing metric describing on time delivery of parts to MPF. Establishing a more clear definition of on-time delivery would enable more productive communication between the two groups. After some discussion, the leaders of the two groups assigned a joint team to develop a new metric to be used in governing this handoff. This metric was intended to go into effect with the transition to SAP.

This team established a metric which would show the daily distribution of on-time, ahead of schedule and behind schedule orders as delivered to MPF.[5] This metric was split by single and multi-pass orders, allowing management to distinguish between the smaller orders that were more easily handled, versus the physically larger and more disruptive orders. An example of this chart is shown below.

[5] Development led by Steve Foster (MPF) and Ron Powers (Fab)

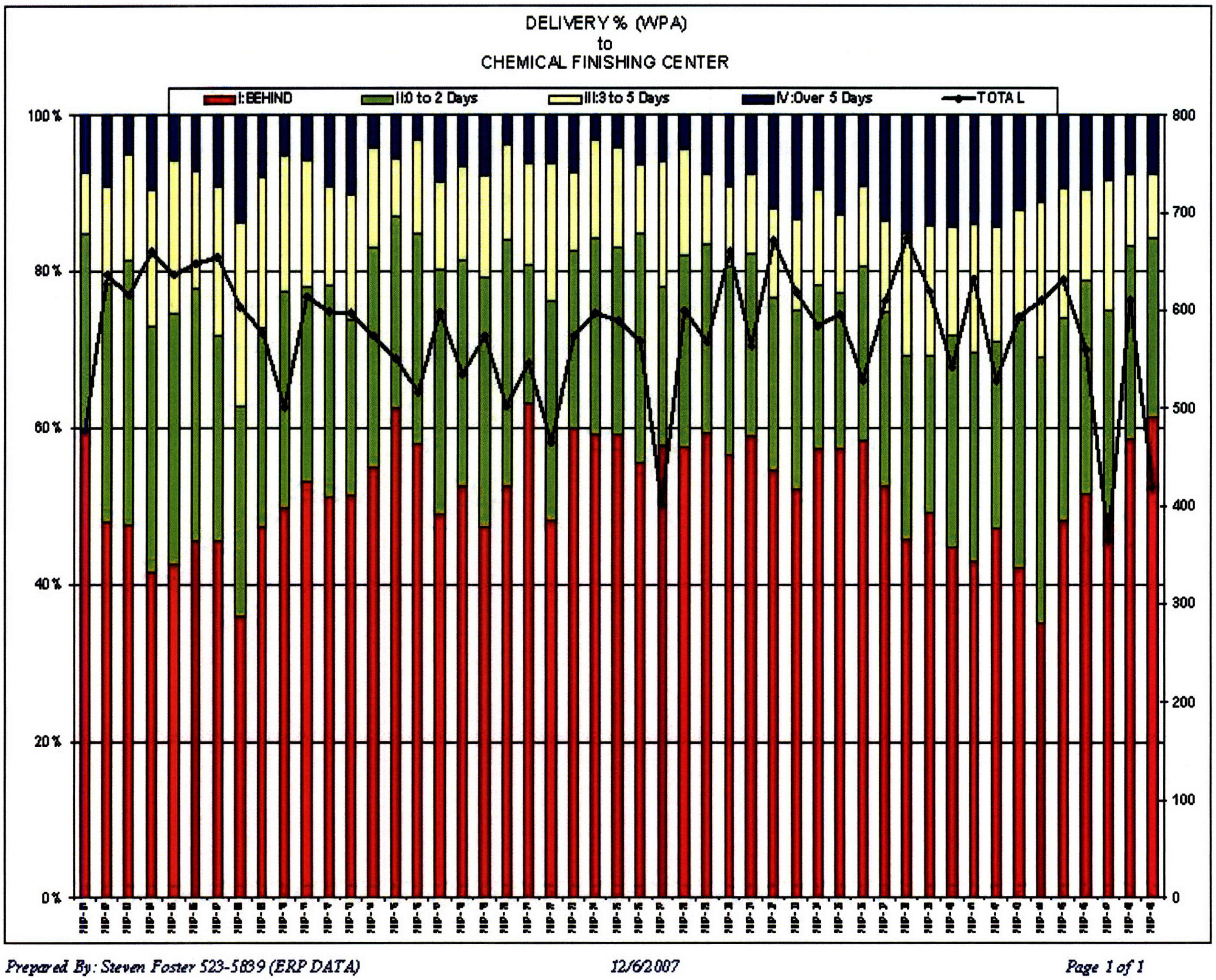

Figure 17 - Revised Metrics for On-Time Delivery to MPF

In this chart, the buckets for the condition of each order as it is transferred to MPF are shown. This late, on time (0 – 2 days early), and earlier buckets are normalized between days to compare on a percentage order basis. These buckets are then stacked on top of each other. In the case of the first day of the chart, 60% of the orders were delivered to MPF behind schedule, 23% were delivered in the "on-time" window, and orders 3 – 5 days early and more than 5 days early were about 9% of total orders each (totaling 100%). On the secondary axis, the aggregate number of orders is tracked.

This metric is an important companion to a production hour delinquency model. Used in concert, this pair allows the user significant insight into the current and future performance of Fabrication. For example, Fabrication's customers currently decry the on time delivery rate, and demand more work be completed on schedule. This leads Fabrication to prioritize on-schedule work over delinquent work, in order to make all deliveries to MPF "on-time". However, the production-hours chart would then show the delinquency staying steady or climbing as a result of this action. Conversely, the production-hours chart could show Fabrication reducing its delinquency significantly, which would result in very low on time delivery currently, but indicate to the customer that these rates would climb in the future as backlog was reduced.

6. Potential Alignment of Internal Supplier/Customer

The tools illustrated in chapter six allow management new insight into the current and future performance of Fabrication. By using the revised On-time Delivery Metric, management on both sides would have a more clear picture of the current Fuselage shortages that were sourced from Fabrication, and the length of delinquency. The production hour based forecasting model would provide visibility into the expected movement of the on-time delivery for the next six months. Used in combination, these tools could provide an understanding throughout the organization of the external benefits generated by reducing Fabrication delinquency, and the costs created in Fabrication to achieve those gains.

This still leaves a situation where costs of improvement are endured by one organization, and the benefits are reaped by another. The underlying dilemma of locally optimal behavior leading to global sub-optimization could still prevail, even with these tools. This section explores several possible organizational structures that would induce the balancing of these costs and benefits in the organization on an inherent rather than ad hoc basis. Although the primary analysis thus far has investigated Fabrication and the associated Fuselage value stream, this section will incorporate other organizations where strategically appropriate. As the author's work has dealt less completely with these other organizations, the analysis of them will be, of necessity, less complete as well.

Some core assumptions will help reduce the strategic options to a manageable number. Firstly, this section will not reconsider Fabrication's assets relative to core competency. Subsequently, the options discussed will not consider additional outsourcing as a strategy. This will exclude any scenarios where Fabrication may continue to produce its current scope of work at lower rates with an external supplier providing identical components (sometimes referred to as dual sourcing or taper integration). Secondly, it is assumed here that the internalization of external costs in the production cycle is the most vital strategic concern. While other major strategic concerns will be briefly explored for each option, the list of concerns is not intended to be exhaustive.

6.1. Maintaining the Existing Organization

The most obvious option is to leave the organizational system currently in place at Spirit unchanged. Given that our goal is the incorporation of external costs, this option would imply that the increased visibility from the suite of new tools would serve to increase communication and coordination between Fabrication and Fuselage. This communication would require frequent management interaction to discuss the balancing of downstream cost avoidance and cost incurred upstream.

There are a number of advantages to this option. Out of all the possible courses of action, this will require the fewest resources, and minimize disruption of the current mode of doing business. This will also allow Fabrication's capacity and resources to be centrally managed, which will permit them to be most efficiently understood and utilized. This will be especially key if Fabrication will be part of the work package for new work being brought to Spirit.

Disadvantages exist as well. Communication requires significant time, and this is in short supply in any manufacturing environment. Further, with no clear final authority to mediate this discussion, its possible that these discussions could become lengthy as both sides balance competing priorities of the mismatch in cost incurred versus benefit received. This strategy also will not directly encourage communication on a broader array of topics such as quality that may benefit both organizations.

It is clear that the disadvantages above have significant sway in the current system. In essence, this option has been in place at Spirit since the finalization of the model methodologies. Although the level of communication had increased, the pace at which operational plans were changed in response to cost avoidance remained slow. Creating excess capacity to mitigate future potential disruption also is difficult to justify in a cost center model. However, as is evident in the actual results shown in Chapter six, this disruption can have a profound impact on the delinquency in Fabrication.

6.2. Conversion to Profit Center

Another option would be to make Fabrication a profit center, in essence its own entrepreneurial organization with an obligation to be the supplier-of-choice for Fuselage. It would effectively compete with SCM (as the surrogate for the rest of the supply base) to supply Fuselage. Fabrication would be able to market itself externally to win new work, as Fuselage does. Now that Fabrication is acting to maximize profit, transfer pricing could be used to affect its behavior. (Chen, Peng, & Saparito, 2002) To induce globally optimal behavior, the transfer price economics could incorporate an additional cost for delinquent work, and a payment for emergent requests from Fuselage (such drop in re-work for Fuselage induced quality issues).

Properly tuned transfer pricing would also directly incent both parties to make globally optimal operational plans, and explicitly obligate them to incorporate the external cost impacts of the actions taken. The transfer pricing would also be useful for each organization to identify opportunities for process improvement by attaching explicit costs to them, and providing incentives for both parties to track them. (Eccles & White, 1988) The information to establish this transfer pricing is not currently available, as witnessed during this analysis, but as long as a charge of the appropriate order of magnitude is established, it will still directionally incent the desired behavior.

A number of factors make this factor strategically advantageous. This system could, with some effort, be incorporated into the ERP systems at Spirit, reducing the manual communication and coordination required. By winning external work, Fabrication could increase utilization on machines, which would improve the business case for new capital. Diversification of Fabrication's customer base would provide for more modularity of Spirit's core business of assembly. A more modular structure improves the profitability of the business by increasing flexibility and returns on capital. (Dess, 1995)

Additionally, external customers for Fabrication would help lessen the imbalance of Fuselage being able to approach external suppliers through SCM. Fabrication would be more accountable for its inventory, and freer to set an inventory strategy most effective for it. Additionally, the inventory destined for Fuselage would no longer be attributed to the Fuselage value stream, leaving Fuselage with direct control over the all inventory on its books.

There are strategic disadvantages as well. It will be more difficult to strategically control the core competencies that remain within the company, (Dess, 1995) and Fabrication may choose to exit lines of business that are critical for the future of the company. A system of transfer prices may lead to gamesmanship where the system doesn't work well. Additionally, the extra transfer pricing may well incent Fabrication to pursue more external work, as these contracts would most likely lack these extra fees. It may also be difficult to implement a system that won't be worked around, given the close physical proximity to Fuselage.

6.3. Value Chain Division & Forward Integration with Assembly Areas

Another possibility is to divide Fabrication into lines that serve each Assembly area. The leadership of these value chain segments of Fabrication would then report to the leadership of the Assembly areas. This split can be made efficiently at the machine level. The majority of Fabrication's production assets send at least 80% of their output to either Strut/Nacelle or Fuselage.[6] These assets could be aligned directly to these assembly areas. The machines which support both programs could then be duplicated to allow the complete disintegration of Fabrication, or all aligned to one assembly area with the understanding that they will continue to serve both areas.

This organizational structure would ultimately allow a single manager to determine the balance of additional upstream costs and downstream cost avoidance. This would allow the most direct control in making the optimal cost decisions for the production system. Moreover, this model already exists to some degree, since Strut/Nacelle Fabrication serves a sizeable portion of Strut/Nacelle's production needs. While the organizational transition would undoubtedly cause some production impact, the presence of an existing, functional model will help limit this. This more integrated, coordinated business model would also allow for the more rapid adoption of

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[6] Interview, Paul Boyd 12 June 2007

technological or process improvements where the change would impact both parties. (Robertson & Langlois, 1995)

Space limitations in the Assembly areas would likely prevent the physical realignment of these productive assets at a reasonable cost, making this alignment predominately organizational in nature. This would leave physically adjacent assets under different organizational structures. This could potentially limit cooperation in Fabrication areas for critical activities like loan-ins. The effect of this separation could in essence erase economies of scale and scope (Robertson & Langlois, 1995) that currently exist in Fabrication.

Even if Fabrication was left organizationally whole, but transferred to the control of an Assembly area, strategic issues would still exist. Management bandwidth at senior levels would become even more constrained by the additional responsibilities, which creates additional costs. (Barringer & Harrison, 2000) Fabrication, although similar to businesses already aligned to the Assembly areas such as Skin Fabrication, is a significantly different manufacturing process. It is possible that this increased coordination would result in increased costs and reduced performance in Fabrication. For example, many operations in Fabrication require the least labor when produced in batch and inventoried until needed in Fuselage, yet increased coordination could pressure use of smaller more responsive batches to reduce inventory, or set-up breaks to produce immediately required parts. These changes would decrease labor efficiency (increase the P.I.) in Fabrication areas, and could ultimately prove to counterbalance the extra labor and cost avoidance balancing shown in the production hour model. Consequently, policies to drive improvement in the Fabrication area could create balancing feedback mechanisms that would reduce or eliminate the desired improvement. (Sterman, 2000)

6.4. Aligning with Supply Organization

The last option to be explored is a combination of Fabrication with Supply Chain Management. This would create, in essence a "one stop shop" for the Assembly areas to specify their needs for inputs. Leadership in SCM would then make an internal decision on the best way to meet the requirement, either through internal production from legacy Fabrication assets or from outside suppliers. This completely internalizes the Make/Buy decision to the new SCM functional area.

This position could be further strengthened by incorporating Strut/Nacelle Fabrication into SCM as well, which would normalize the supply structures of the two Assembly areas.

This option approaches the question of internalizing the external costs of delinquent production in much the same manner as the option of maintaining the existing organizational structure. It depends heavily on communication between the organizations to continue the optimal balancing of costs. However, in this scenario, Fuselage has only one place to address concerns around on time delivery, reinforcing the imperative to cooperate, and a single leader in charge of the supply organization will ultimately be responsible for meeting those needs. This contrasts significantly with the current situation between the three parties. This will be discussed further in the subsequent chapter.

By continuing to maintain the centralization of Fabrication resources, assets will be used in a more efficient manner. By owning the Fabrication resources, SCM will have increased leverage and knowledge when dealing with external suppliers. This will place Spirit in a more desirable position to negotiate pricing. (Barringer & Harrison, 2000) This will centralize all components of the Make/Buy decision, and allow for more informed choices about choosing lowest cost providers versus where other transaction and strategic costs prove too high. (Barringer & Harrison, 2000) Through a better understanding of Make/Buy decisions that this alignment will enforce, new capital justifications can be made in the context of costs of supplier non-performance.

This structure would require some external monitoring however. Caution must be taken to appropriately align strategic notions of core competencies with the more tactical decisions of Make/Buy on a cost basis. A series of tactical decisions, left unmonitored, could gradually form a direction that dictates strategic decisions, rather than a strategy driving the tactical decisions. As described by the Director of Business Management – Corporate, the strategic vision for Fabrication's mission could be envisioned as:

> *"First, Fabrication should take care of parts that are internally critical, for which we will pay a premium. Second, they should provide a safety net for the supply*

base, and we'll pay a premium to make sure we have that capacity. And third, we want them to help push technology and help us understand what's new, and for that we're also relatively cost indifferent."

It would be easy to lose these strategic notions during more tactical decision making. Of specific concern in Fabrication would be offloading parts for cost, while total overhead remains the same. This would increase the overhead allocation to the remaining parts, and make them appear progressively less cost competitive. This resultant strategy would be an exit from fabrication activities. However, this would contradict the strategy articulated above.

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7. Interaction of Existing Culture and Potential Alignment Structures

The various organizations within Spirit have significantly diverged cultures, although they do contain uniting elements of both culture and structure. Still, the cultural clash between partners in an interorganizational relationship can make the cooperative management of the alliance difficult, and ultimately lead to its failure. (Barringer & Harrison, 2000) This must be taken into account when exploring solutions that otherwise satisfy the strategic imperatives of the relationship, or else the desired outcomes may prove elusive. (Weber & Camerer, 2003)

One of the defining characteristics of the cultural interactions at present is mistrust. It is very common in a monopsonistic environment, such as with Fabrication supplying only Spirit customers that this mistrust will develop. (Robertson & Langlois, 1995) Without credible mechanisms to exit the relationship by either party, and the relatively informal nature of many agreements, both groups will engender mistrust while attempting to leverage their position to improve operational performance. This condition will be one of the strongest cultural impacts to consider while exploring any alternative.

7.1. Three Lens Analysis

The Three Lens Analysis provides insight into the elements that collectively govern the way an organization functions. This analysis is based largely on the experience of the author while conducting the research for this thesis, and is supplemented by interviews of site leadership where appropriate. The analysis is intended to provide insight into the function of the company as a whole, and not as a critique of any particular feature of an organization. Understanding the nuance of certain behaviors across the company is in fact critical to exploring the significance and impact of any analysis or the viability of any potential alternatives.

7.1.1. Strategic Lens Analysis

The goal of the Strategic Lens is to explore the formal linkages, incentives and alignment mechanisms in place in a company. The goal is to provide a general overview of the entire organization. In places, this section may reiterate some of the more detailed descriptions of the last section.

The strategic alignment of the Wichita site is largely functionally aligned. Supply Chain Management provides the organization with outside purchased parts ready for assembly and establishes contracts for raw materials, Fabrication is responsible for conversion of raw materials into parts for assembly, and then final assembly is handled by two product focused organizations, Fuselage and Strut/Nacelle. A central Corporate function presides over these business units. There are significant deviations to this simple organizational model, due in significant part to the localized decisions of business unit leaders. These will be discussed as part of the Political Lens Analysis.

The Corporate function is essentially new, dating from when Spirit spun off of the Boeing Company in 2005. When the corporate function focuses their attention on operations, they have been able to instigate significant changes. However, they are significantly focused on continuing to develop the capabilities needed in an independent company, such as contracting and marketing, as well as winning work from new customers. The corporate function is also still assessing the balance of centralizing versus decentralizing control, and is leaning toward expecting more responsibility for operations at the business unit level.

Incentive alignment across the Wichita functional areas vary. The assembly areas are managed as profit centers, whereas Supply Chain Management and Fabrication are managed as cost centers. On time delivery goals are part of Fabrication's performance agreement. However, according to the Director of Fabrication, "My customer would say the single most important criteria (for Fabrication) is… on time delivery. My bosses would care more about cost."[7] There is a tension created by managing for minimum costs versus maximum profit, as in general these optimums are not necessarily aligned. It also creates difficulty in diagnosing issues such as optimal inventory levels. Normally this deviation is mediated by the COO, to whom all these

[7] Interview, Director of Fabrication 4 Dec 2007

organizations report, to prevent too great a disparity. In the interim, some organizations such as Fabrication and Supply Chain, are being managed by the VP of Strategy and Operations.

Operating metrics are not collected consistently across the company. Although all organizations clearly focus on Safety, Cost, Quality and Delivery as key metrics for operations, there is no common methodology or format for the collection of these metrics. Some organizations even have different metrics to assess the same performance. Facilities, which maintains Fabrication's equipment, measures machine availability on a 24 hour a day, 7 day a week basis, whereas Fabrication measures availability based on time during staffed shifts. Other organizations disagree on delivery metrics, such as Fabrication and MPF. Fabrication collects more metrics, and makes them more accessible than any other part of the organization. This data has become the primary source for the author's analysis. Fuselage, although sure of the impact of shortages, had little data prior to the author's analysis to support their assertion of the magnitude Fabrication's impact on Fuselage operations. This leads to management based on the substantial experience of Fuselage leadership team. The Wichita site is currently transitioning to SAP, and this may significantly improve the consistency of measurement.

7.1.2. Political Lens Analysis

The political lens assesses the positional power held by different parts of the organization, or by individuals. The sources of this strength are many, including access to scarce resources, relations to the customer, or personal charisma. In many regards, the political lens can expose the difference between "how it's supposed to work" and "the way things get done".

Spirit's organizational structure has been profoundly influenced by the cumulative actions of individual leaders. For example, Strut/Nacelle manages a capacity called "Blue Streak". Blue Streak is a rapid manufacturing capacity, originally designed to mitigate supply chain disruptions. Now, 80% of its capacity is dedicated to standard production of Strut/Nacelle parts. Fabrication still spends a significant portion of its efforts on Strut/Nacelle requirements, although the majority of the work serves Fuselage. Blue Streak's original charter, supporting the vendor base, is now primarily used for reducing dependence from the Fabrication organization.

Fabrication was compelled by Corporate to outsource parts associated with certain production assets, which were determined to be non-core at the spin-off of the company. Fabrication has developed a plan to utilize this equipment to create a process parallel to Blue Streak for its own uses, rather than sell the assets as expected.

This forced off-load has had a profound impact on the management of Fabrication. As the number of parts they supply erodes, so does their primary base of political power. In the face of this decline, Fabrication is defensive of its remaining power structure. As the off-load schedule has slid significantly in the face of difficulty in finding suitable suppliers, Fabrication has shown in several cases that they are cost competitive, and lobbied to keep certain processes in house. This is neither good nor bad, but simply blurs the original core vs. non-core strategic decision.

A cost center structure frequently leads to defensive behavior. This is especially the case where the price charged is based on the standard production costs, and management emphasizes the absolute value of the variance between actual and standard costs. (Eccles & White, 1988) This is certainly the case in Fabrication, and has been so for long before the spin-off. There are additional contributors to the perception of Fabrication's behavior. The most frequently cited example of this behavior is the leadership of the organization. The leadership is known across the company for her passionate and vocal support of their organization, and tight control of their personnel.

The Fabrication organization mirrors the attitude of its leadership. During meetings to discuss preliminary findings, they dismissed information from several support organizations, and declared data from those groups suspect. While it is true in many cases that data quality was questionable, even directional value of the information provided was dismissed at the time. However, once the utility of the analysis was demonstrated, Fabrication also proved its willingness to develop strategic visibility.

Fuselage shipments to Spirit's customers accounts for nearly two-thirds of company revenue. Consequently, it enjoys tremendous political power. As an example, Fuselage, with cost savings opportunities in flow-time and safety inventory, initially declined to make cuts in either until they receive on-time deliveries. While this has allowed the author to access resources from the staffed and funded Inventory Reduction Initiative, it has effectively slowed the progress of a Corporate initiative. Eventually, however, Fuselage went on to improve their inventory turns, in support of the company's needs.

Fabrication believes that Fuselage maximizes the benefits of its larger size and has some tension with their own customer. On occasions, this can lead to the impression in Fabrication that projects to improve overall performance, are actually aimed primarily at Fuselage performance. An example of this was the author's project, which was initially viewed as a Fuselage initiative, rather than an effort to improve the overall process. This resistance creates an extra hurdle to be overcome when introducing operational improvements into the overall process. Although many performance initiatives may well be sourced in Fuselage, it is important the entire organization embrace opportunities to improve.

7.1.3. Cultural Lens Analysis

The cultural lens investigates the closely held assumptions of the organization, and the differences arising in different parts of the whole. Where the strategic lens shows "how it's supposed to work" and the political lens highlights "how it really gets done", the cultural lens investigates "why we see it the way we do." Spirit is a company in the midst of a fascinating cultural transition.

Although Spirit as a company is only two years old, the culture dominating the Wichita site stems from the "Boeing DNA" that Spirit was born. Arriving in the parking lot demonstrates the respect for experience over all else. There are special, prime parking spaces for employees with more than 20 years experience. There are no reserved spaces for special recognition (employee of the month, etc).

Spirit is aware that change is needed to meet new business realities as it transitions into an independent company, rather than a cost center for a larger corporation. The Corporate function is made up of many new faces and potential change agents. These recent hires seem to be aware that greater attention is necessary to the overall corporate mission to properly align business units. This contrasts with the general culture in the operating areas, which tends to dislike "interference" from Corporate, in favor of being left to focus on "getting the job done". This rift can slow the diffusion of radically different operating paradigms, and to a lesser extent operating best practices. As a company however, Spirit has made the strategic decision to provide greater flexibility to the operating units. Therefore, this direct operational influence of corporate will wane in favor of increased operational strategy-setting responsibility by the business units.

Fuselage also has a distinctive culture. It delivers to Boeing 100% on time, every time, regardless of the overtime and expense required. One Fuselage leader proudly claimed "Fuselage has never missed a delivery to Washington (the Boeing customer) since we've been Spirit AeroSystems."[8] Fuselage has been known to send operators with the shipment to finish work and ensure on time arrival. While Boeing's expectations can assess influence this behavior, it has become a cultural artifact as well. This contributes to a "firefighting" mentality in Fuselage, focused on major tactical issues rather than process improvement. This approach pervades much of the organization. The culture in Fuselage in turn exacerbates the negative view of late deliveries from Fabrication.

Fabrication has a defensive culture to outsiders, as described earlier. According to others in the organization, this culture has been part of Fabrication for a long period of time, since well before the spin-off of Spirit, and beyond the span of any one leader. This is in contrast to Fabrication's protective treatment of insiders. This is evident in the long tenure in Fabrication of many of the senior leaders, and in the author's experience during this analysis. Once the author's analysis was found useful, and was brought "inside" the organization, the members of Fabrication became profoundly supportive.

An NDA was required for the project of outsourcing of non-core elements of Fabrication. While normally this sensitivity would be understandable for an outsourcing project, the company has made significant efforts to avoid layoffs as a result of this project. Some elements of this outsourcing are in an advanced stage, with vendors touring current operations, measurements

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[8] Interview, Director of Support Services – Fuselage, 28 Nov 2007

being made of areas to be freed, and capacity planners being reassigned away from areas to be eliminated. One can only surmise that operators have drawn their own conclusions from these events, and most likely fear the worst, given the lack of communication.

Other examples of unwillingness to share information exist. For example, Fabrication was not informed of the author's project prior to arrival, or given input to the project scope at the outset. As the project demonstrated the significant impact of Fuselage quality re-work on Fabrication operations, the Director of Fabrication said "I don't want to tell [the VP/GM Fuselage] about his quality issues. I shouldn't tell him how to run his organization".[9]

7.2. Culture and Maintaining the Existing System

This issue surrounding the legacy cultural differences between Fabrication and Fuselage argues strongly against maintaining the existing organizational structure, with Fabrication as a stand-alone cost center. In the words of the Director of Fabrication, the culture of Fabrication is cost conscious, and its mission is to "keep in house the things we're competitive at, and help offload the stuff we're not competitive at." The Director also stated "My customer would say the single most important criteria (for Fab) is... on time delivery. My bosses would care more about cost."[10] Conversely, Fuselage feels that its customer demands cost, quality and delivery in equal quantities ("they speak about [the three metrics] like its one thing") but noted that "[Fuselage] tends to overspend to protect delivery." [11]

This cultural schism has led to poor communication in the past. For example, Fuselage chose to offload assembly work for capacity reasons, and these assemblies incorporated parts from Fabrication. SCM and Fuselage chose to have the new supplier fabricate and assemble all portions of the package, while Fabrication only learned of the offload as the parts were transferred to Procurement. This delayed communication makes it difficult for Fabrication to plan its work, which in turn is unproductive for Fuselage.

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[9] Conversation, Director of Fabrication 23 October 2007

[10] Interview, Director of Fabrication, 4 December 2007

[11] Interview, Director of Support Services – Fuselage, 30 Nov 2007

The existing structure of the organization fosters this culture of workaround communication as well. Fabrication is mandated to supply its goods to Fuselage and Propulsion, whereas Fuselage is free to approach the market as a whole, through SCM. This gives Fuselage the option to leave conflict with Fabrication unresolved, which prevents extracting the benefits of conflict, i.e., resolution. By receiving no benefits of conflict, both parties are then incented to monitor each other less closely and evoke less conflict. This ultimately results in less process improvement and less information available to top management regarding significant issues in the production environment. (Eccles & White, 1988)

This lack of communication engenders a lack of trust between the two organizations. During the author's analysis, some members of Fuselage were uncomfortable with supporting an increase in Fabrication's resources to avoid costs in fuselage, as they doubted the benefits would be achieved. As certainty increased, and additional evidence was gathered, Fuselage went on to support this change. Nonetheless, any technical solution depends on a certain level of trust on behalf of each party in the raw data involved, and the actions that the other party will take based on the analysis. Absent this level of trust, the most robust technical solution will simply become additional labor, and change will be difficult to institute or maintain.

This possibility may be untenable based on the current reinforcing negative cultural interaction between Fabrication and Fuselage. On the other hand, this same reinforcing interaction may reduce the amount of productive discussion that takes place, allowing this "as-is" solution to persist for a longer than an outsider might expect.

7.3. Culture and Fabrication as a Profit Center

One of the apparent benefits from a cultural perspective of converting Fabrication to a profit center is to increase the distance at which Fuselage and Fabrication interact. This would seemingly mitigate the disparities of culture that affect the previous option. Additionally, this extra distance would automate and internalize conflict resolution, as "conflict" would now be communicated through the transfer prices.

This more modular approach requires certain prerequisites be or become satisfied in order to operate effectively. Firstly, the downstream organization and supplier must work closely to ensure that the interests of each party are being fulfilled. Secondly, the modular organization must ensure that the right competencies remain under its control. (Dess, 1995) Ensuring the second requirement is adequately accounted for could be mandated by the corporate level of Spirit. This would be culturally acceptable in the short term, but mandates from above will not help foster an entrepreneurial spirit within the new Fabrication B/U.

The first requirement is the same fundamental issue as the first scenario. Currently Fabrication and Fuselage do not carry significant organizational trust. This organizational structure, by distancing the two parties, will not foster a new more trusting culture. At least, unlike the current organizational structure, it is less likely to create a self-reinforcing behavior, but that still leaves the existing culture in place.

The reason this existing culture is important is the initial setting of the transfer pricing. Prices in this case would not be offered up by a market. Instead they would be constructed by the actors involved in the transaction, ultimately binding these prices with the explication of the social relationship between the actors and the form, content context and language of the negotiation itself. Ultimately then, the transfer pricing policy will be set by managers in a manner defined by the social relationship represented in the exchange. (Eccles & White, 1988)

Because of these effects, the exchange pricing can then lead to significant conflict over unproductive content. Parties involved will become increasingly attuned to gamesmanship, even though is in some measure inevitable in any system of controls. Some even suggest that transfer price based models lead to an increased level of conflict overall. (Eccles & White, 1988) In an overall culture that favors consensus, this may well prove to have the appearance of destructive behavior, even if it is not.

7.4. Culture and Forward Integration

Of all the options, integration with the Assembly areas is a solution that will be most encouraged under the existing culture. Direct control is a very acceptable solution under the legacy command

and control culture. In and of itself, this makes the option desirable, since an option that cannot be successfully implemented is no option at all.

The cultural issues affecting the option of leaving the existing structure in place weigh significantly on this option as well. These local cultural issues could become a barrier to creating the coordination necessary to solving the fundamental problems of information fragmentation in this more vertically integrated structure. (Robertson & Langlois, 1995) Although a leader ultimately responsible for Fabrication and Assembly can drive directional changes quickly, a culture of open communication and data flow will not spring forward immediately. This is very likely to be the case under this option.

However, it would also foster a culture of improvement in many respects. By tying Fabrication more directly into the Fuselage decision making process, conflicts are more likely to result in resolution. As conflicts become more likely to result in process improvement, more open and complete communication will be fostered, and the exchange will become self-reinforcing over time.

7.5. Culture and Aligning with Supply Chain

The relationship of SCM with Fuselage is quite a bit different that of Fabrication, even though market conditions have yielded similar levels of performance from both organizations. SCM and Fuselage have meetings and communication at multiple levels, intense team integration and even a soft line reporting structure to Fuselage. SCM personnel are collocated in the Fuselage management offices. This support and more open support structure has helped enable process improvements, such as the integration of Contracting and Ordering & Scheduling functions within SCM. This process change required a significant learning curve, and went awry after a short period of time.[12] Ultimately SCM chose to reverse that action. Although not every experiment succeeds, they are imperative to creating process improvements. The key to working

[12] Interview, SCM Procurement Director - Fuselage, 12 December 07

through this particular experiment was "the relationship that was there – it just requires communication."[13]

By comparison, recall the examples of Fabrication not being able gain approval for equipment with a two year payback, or being left out of the communication cycle for Fuselage capacity offloads. A more open communication model in SCM has enabled more productive communication and experimentation. As a consequence, the cooperation and trust in the existing culture is reinforcing itself as results are achieved.

The combination of Fabrication and SCM would allow the cross-pollination of culture. By seeding SCM culture, and creating a more compatible culture with Fuselage, it is much more likely that the tighter integration will achieve the expected results. (Weber & Camerer, 2003) This could place the relationship on a positive reinforcing trend much sooner than other options.

7.6. Recommendations

No technical model can thrive absent trust in its inputs, and confidence in action based on its outputs. Conversely, no organizational realignment and cultural shift can be managed effectively in the absence of good data. The above explorations seek to highlight the intersections of strategic needs, culture and the incorporation of data in the balancing of operational needs. No observation is intended as a critique, but seeks to bring to the surface the way the company would truly be expected to operate. This realistic appreciation for the company is a prerequisite to considering any option.

Cultural reasons dominate the option of leaving the current structure intact. The customer has concerns about the performance it is receiving, and to date has not been satisfied with the corrective actions. This customer has more positional power than the supplier. A cultural/structural mechanism that provides an alternative to resolving the existing conflicts has fostered a culture that allows this behavior to exist, and it continues to survive in the face of

[13] Interview, SCM Procurement Director - Fuselage, 12 December 07

efforts to highlight the operational costs through analysis. These factors dictate that a change will happen, and that a change should be made.

Cultural and strategic reasons are equally of concern in considering the conversion of Fabrication to a profit center. Although operational needs could be balanced directly, Spirit's strategic needs could be unmet by profit maximizing efforts in Fabrication, and this could lead to an uncertain strategic position in the future. Although the structure could lead to reduced unproductive cultural conflict in the future, the establishment of a system considered to be mutually reliable will be very difficult under the existing cultural interactions. Some of these issues could be solved by strong centralized direction, but this could be directly counterproductive to the entrepreneurial spirit that this arrangement would require.

Integration of Fabrication under the Fuselage umbrella would potentially foster a more collaborative culture over time, although it could well be a long time in the making. In the meantime, the command and control culture that would dominate the interaction between the two organizations may well spur counterbalancing mechanisms. However, as a culturally implementable, acceptable solution, many of these strategic concerns can be addressed by consistent and conscientious management attention, and make this a workable possibility.

The merging of Fabrication and supply chain is a riskier, but potentially more rewarding strategy. There is significant distance between the cultures and processes of the two organizations. This will make a strategic vision to unite these organizations more difficult to drive across all levels. Conversely, this will increase the productivity of conflict in the organization by requiring resolutions, and by seeding Fabrication with a culture compatible with Fuselage. This would also centralize and illuminate critical strategic choices for the company with respect to Make/Buy.

In the balance, a solution that can be implemented is most of the distance to being a good solution. However, these options are not necessarily binary, on/off choices. Although the status quo, and profit center models seem untenable, the supply chain or assembly integrations have highly desirable elements. If there were a way to blend these two options to capture the ease of implementation, the cultural seeding, and the strategic benefits of centralizing Make/Buy decision making, this would be the optimal path for the organization.

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8. Conclusion

The aerospace industry is a unique and complex business environment. Massive bets are made on new aircraft programs. After a very long period of incremental changes, new technologies are fundamentally changing the production processes of commercial aerospace. Like many manufacturing industries, aerospace is creating more modular production designs. New business models are being employed to capitalize on this modularity, and creating companies like Spirit AeroSystems.

Companies like Spirit are in a fascinating phase. They move from being large cost centers to multi-billion dollar startups, they must understand their business on a completely new level than they have before. They must understand the legacy cultures that have pervaded their organizations for years, and meld these differences into a universal entrepreneurial culture that works to maximize the profitability of the entire company.

Quality data systems can highlight areas for improvement, and help show how to bring balance to the production process. But these data systems cannot be established or used without an appropriate culture of communication between the affected parties. With effort and management attention, analysis can make the first steps in this cultural transition. This was certainly the case in the author's work. As the author's analysis proved informative, it must be noted that Fabrication became profoundly supportive. Fabrication took great lengths to further the analysis, and discuss findings with immediate customers. Although reluctant at first to consider alternate strategic assessments, Fabrication is capable of and willing to change when a path forward is determined.

Many options are available to Spirit and companies in similar situations with regards to the alignment of their organization. The culture within those groups is quite unique to Spirit, and the best path forward will be unique as a consequence. This culture will interact with the strategic decisions made, by either reinforcing the options taken, or by undoing the progress attempted. For any company, understanding and appreciating the existing culture amongst the various organizations that comprise them is key to designing new organizations and implementing them successfully. Conversely, ignoring cultural factors in determining structural alignments can lead to unexpected, undesirable results, and ultimately failure. (Weber & Camerer, 2003)

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