

# Change Management, Production Ramp Up and the Sustainable Supply Chain in the Transportation Industry

by

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Sc.B., Mechanical Engineering  
Brown University, 2005

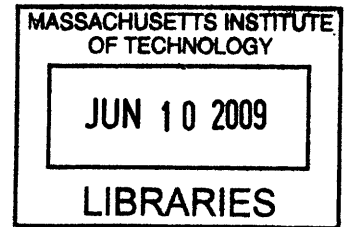
Submitted to the MIT Sloan School of Management and the  
Engineering Systems Division in  
Partial Fulfillment of the Requirements for the Degrees of

**Master of Business Administration**

and

**Master of Science in Engineering Systems**

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# **Change Management, Production Ramp Up and the Sustainable Supply Chain in the Transportation Industry**

By  
Sean Fortin

Submitted to the MIT Sloan School of Management and the Engineering Systems Division on May 8, 2009 in Partial Fulfillment of the Requirements for the Degrees of Master of Business Administration and Master of Science in Engineering Systems

## **ABSTRACT**

The ramp up phase is always the most risky part of any project, especially with a product material the company and its partners have very little experience with. One result of this lack of experience is frequent engineering changes to address design corrections and improvements. High levels of change create uncertainty within both the supply chain and the engineering change management systems. Just as a supplier may not be able to meet production requirements, elements of the change process may not be sufficiently flexible to account for the level of change the project experiences during production ramp up. A study of Bus Solution Systems' (BSS) Super Hotel Coach (SHC) program change management system will show that unsuitable change management system processes can cause downstream delays just as unsuitable supply chain strategy can cause the same.

This thesis details a situation where the SHC program's Materials Management Department (MMD) was having difficulty with visibility into the change management system. As a result of the situation, SHC MMD did not have the ability to order parts on time. The effect was that there were an increased number of parts needed for manufacturing jobs but were not in stock, and sometimes yet to be ordered. The ultimate result of this problem, and the multitude of other problems impacting the SHC not investigated in this thesis, was a bus program that was 2 years behind schedule in early 2009.

This thesis aims to correct the SHC MMD engineering change visibility issue by examining the current state of the engineering change process through a shortage part case study and by applying supply chain management strategy principles to extract part ordering information from the SHC General Engineering Change Process earlier. This thesis also proposes a long term systematic solution that would help prevent shortages from occurring in the future. The intent of the recommendation is to reduce the chance of shortage occurrences so as to prevent further delay of the SHC program.

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I would also like to thank the LFM program for giving me the opportunity to be a part of this awesome community. And, closely related to the LFM program, I would like to thank my thesis advisors, Professors Daniel Whitney and Sebastian Fixson. They both provided significant insight throughout the internship and really shaped the outcome of my internship. I would also like to thank Professor Donald Rosenfield for reading this thesis and signing the cover.

I would like to thank the people I worked with for helping me throughout the internship. Specifically, I would like to thank following people, who I could only put their initials: RR, ML, MS, TJ, TP, SD, TD, RH, JI, SS, SM, KE, CH, MD, and all the others who took time out of their busy days to work and speak with me.

I would also like to thank my friends, from Barrington, Brown, MIT, and where ever else they came from. Without them, my life would be incredibly boring.

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## Biographical Note

Sean Fortin was born just outside of Boston but spent the majority of his life in Barrington, Rhode Island. In 1994, Sean was drafted by the Orioles in the fourth round of the Barrington Little League Major League draft. He played two years for the Orioles and led them to the American League Championship, where they lost to the Rangers.

He attended Barrington High School, excelling in both academics and athletics. He played three years of varsity football, starting in all three seasons as a defensive tackle and offensive lineman. He also played two years of high school baseball as a catcher.

Following graduation from BHS in 2001, he matriculated to Brown University in Providence, Rhode Island. There, Sean earned a Sc.B. with a concentration in Mechanical Engineering with Aerospace Applications. In his senior year, he was elected an associate member of the scientific research society Sigma Xi. He was also awarded the George H. Main '45 Award. This award is awarded annually "to the Brown engineering senior who distinguished him or herself by diligence and devotion to studies rather than high grades."

While at Brown, he was a member of the varsity football team for three years, starting at the center position for all ten games during each of the final two seasons of his varsity career. As a self described "Ironman of the Gridiron," Sean missed only a single play over the two seasons. In a 2004 interview, Sean said the following about his experience walking onto the Brown football team as an unrecruited athlete: "In the beginning, I wanted to quit every day...[but] I didn't quit because I didn't want to quit."<sup>1</sup> During the 2004 season, Sean led the offensive line (11<sup>th</sup> on the team) with 1 catch for 3 yards. Following his final season, he became "pretty much a badass" and was awarded the Class of 1910 Award, an award given annually to the senior on the varsity football team with the highest academic standing.

Following graduation from Brown in 2005, he accepted a position as a system engineer at General Dynamics Electric Boat in Groton, Connecticut. He was a member of the steam plant piping systems group and had cognizance of the lubricating oil systems. His major contribution to the company was a cost reduction project which he proposed, managed, and executed that saved an estimated \$2.4 million per ship.

In the summer of 2006, Sean rode his bicycle from Arlington, VA to Providence, RI to raise money in memory of his late friend Lawrence Rubida. This 532 mile trip took 8 days and went through 7 states and Washington DC. This ride raised over \$12,000 for Ewing's Sarcoma research.

After approximately two years at Electric Boat, Sean was somehow admitted to MIT's Leaders for Manufacturing Program. While at MIT he worked toward his MBA and MS in Systems Engineering with System Architecture focus.

Aside from work and school, Sean enjoys athletic activities, specifically softball, intramural hockey, football, weight lifting, cycling, and deep knee bends. Sean also enjoys watching movies and regularly quotes Will Ferrell's character Ron Burgundy in Anchorman.

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<sup>1</sup> Reynolds, Bill. "Fortin finds game, not glory, fulfilling." Providence Journal, 19 November 2004. Accessed: 30 April 2009, <<http://www.brownbears.com/sports/m-footbl/spec-rel/111904aab.html>>

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# **1 Introduction**

## **1.1 Coach Bus Transportation Industry**

The bus industry across the board has always had difficulty maintaining profitability. Bus lines are always trying to reduce cost in order to remain competitive in a commodity industry where low ticket price is the key to winning customers. In mid to late 2008, the bus industry was in a fuel crisis where all bus lines had to adjust to account for fuel costs which had more than doubled in a short time span. In order to offset such a dramatic increase in operating expense, many in the bus industry introduced fuel surcharges, baggage charges, and increased many other existing charges to improve marginal revenue from passengers to keep ticket prices low. The industry needed a bus which consumed less of their biggest expense: fuel.

Another substantial cost the bus industry has faced is noise taxes. These are taxes levied by bus stations and federal governments on bus lines (and ultimately passengers) associated with the noise the internal combustion engine creates during acceleration. According to an unnamed article on the bus industry, of the passenger facility charges collected by the US Department of Transportation (DOT) during 2008, \$3 billion was earmarked for noise abatement programs around bus stations. Individual bus stations have also levied additional noise taxes on the bus lines. For example, it was reported that the bus station in Sydney, Australia levies an A\$3.58 noise tax on every departure.

The coach bus industry is dominated by two suppliers in the large passenger bus (i.e., greater than 50 passengers) segment: Bus Solution Systems (BSS) and Groundbus, a subsidiary of the European company Lithuanian Autobus and Transportation Conglomerate (LATC). In recent years, Groundbus has eroded BSS's market share, leaving essentially a market split. In 2008, BSS delivered 3,475 coach busses while Groundbus delivered 4,483 with coach bus revenues of \$58.25 billion and Lt65.0 billion, respectively, according to each company's annual reports.

All of the busses that BSS delivered and the majority of the busses that Groundbus delivered in 2008 were from their legacy programs (any program currently in stable production). However, both companies have undertaken programs aimed at producing new busses to address the gaps in the existing market and the changing preferences of the bus

lines. For Groundbus, their new bus models are the AAA triple deck bus and the single deck carbon fiber Ultra. For BSS, their new program is the carbon fiber Super Hotel Coach (SHC). Both companies are attempting to fill market niches, by addressing the unmet needs of the bus line industry.

## **1.2 BSS and the SHC Program**

BSS, headquartered in Nimrod, Minnesota, is one of the major coach/school bus design and manufacturing companies and the premiere coach bus manufacturer in the United States. The BSS Company consists of two major lines of business. The first is Yellow School Bus Systems (YSBS). YSBS accounted for \$30.9 billion, or 53%, of BSS's 2008 revenue. The second line of business is BSS Coach Busses (BCB), accounting for \$27.4 billion (46%) of BSS's 2008 revenue, according to their 2008 annual report.

BCB currently has four active legacy coach bus programs (as of 2009): the Super Charlie Coach (SCC), Super Delta Coach (SDC), Super Foxtrot Coach (SFC), and Super Golf Coach (SGC). In 2008, BSS delivered a total of 3,475 coach busses including 2687 SCCs, 130 SDCs, 93 SFCs, and 565 SGCs, according to the company website. Concurrently, BSS is also in the developmental phases of the SHC.

In 2003, BCB wanted to design and build a bus to address their customers' specific unmet needs. Their response was the SHC. The SHC was to be designed to attempt to lower bus line operating costs through decreased fuel consumption and reduced noise footprint during acceleration. These design improvements made the SHC one of the most desirable busses on the market. Following the official announcement of the development of the SHC program, over 8,108 firm orders from bus lines around the world were placed in the 5 years following, making the SHC BSS's most successful coach program launch in the company's history. The one downside to date: the SHC program has been marred by significant delays in engineering and manufacturing which has resulted in delayed delivery of the first bus to a customer.

## **1.3 Problem Addressed in this Thesis**

To date, the SHC program has been delayed by almost 2 years from its original published schedule. According to newspaper articles, the first SHC delivery was originally scheduled in May of 2008. Further schedule slippage has been reported, resulting in first test drive in the second quarter of 2009 and first delivery sometime in the first quarter of 2010.

There are several reasons why this delay has occurred, including the introduction of a revolutionary material (and associated new manufacturing techniques) and a supply chain design that placed unprecedented responsibilities on first tier partners (suppliers on legacy programs). One of the other causes of this delay, one which is less publicized, is from what are known as part shortages. A part shortage occurs when a manufacturing job is scheduled to commence but one or more of the parts required to complete the job are not in stock at the time of request. Throughout the developmental phases of the program, part shortages could be caused by several situations: late baseline engineering release (both design engineering and manufacturing engineering), traveled work,<sup>2</sup> quality rejection, engineering change, etc.

The most recent cause of part shortages has been engineering change. The SHC program has had a significant number of engineering changes known as engineering change notices, or ECNs. BSS had planned for a certain number of ECNs during initial planning phases, but the actual number of ECNs that the program experienced has been greater. The unanticipated number of changes has caused significant delays in certain areas of the company, some of these areas may not have had the necessary resources to perform the duties required to work these ECNs. The ultimate result of this situation has been part shortages.

In the SHC program, an internal company known as the Materials Management Department (MMD) is responsible for purchasing all parts required at SHC Final Integration to Delivery (FID). When a part shortage occurs, MMD is accountable for that part and is measured on how many SHC part shortages are outstanding at any given time. In order to avoid these situations, MMD needs as much advanced notice as possible because of the long lead time of certain parts and the delays upstream in the change process. The question is: how does MMD get the information needed from the change process as early as possible in order to avoid part shortages? This is what is termed as the ECN visibility problem for the SHC.

#### **1.4 Research Approach for this Thesis**

In order to provide MMD with a solution to the ECN visibility problem, several things were done. First, the SHC engineering change process was mapped in order to understand how the current change process is actually operating. This included detailing the specific steps, specific individual responsibilities in the process, and what step created any information

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<sup>2</sup> Traveled work is a job (or jobs) that was scheduled to be completed at a partner but is not completed at the partner. The assembly is shipped to BSS containing the unfinished work. BSS installs these “traveled work” jobs upon receipt of the assembly.

needed to order parts. Subsequently, a more detailed study of the change process was completed, including change process actual flow time calculation and individual step timing through a parts case study. In order to create a full picture of the problem, interviews of the different stakeholder groups were completed along with procedural reviews of the SHC change process and adjacent processes. Furthermore, a comparison between SHC and SGC management and change processes was completed. This may be used to show how and why the SHC has strayed from the baseline schedule.

From the information gathered, a proposed short term solution was developed. This short term solution attempts to address the part shortage issue immediately, sacrificing usability for immediate results. This short term solution was then piloted across SHC MMD to determine if there was any improvement in part shortages. A longer term solution was also developed, which can be implemented at a future point in the program.

### **1.5 Summary**

BSS's newest coach bus program, the SHC, has been hailed as one of the most revolutionary coach busses in the industry. However, to date the program has been marred by delays totaling almost two years. This delay has been caused by a range of different variables from the use of a new material to a new supply chain paradigm. This thesis will explore one of the lesser known reasons for this delay: part shortages, specifically focusing on those shortages resulting from lack of visibility into engineering changes emerging from the engineering change process.

This thesis will document the steps taken in order to properly diagnose the problem. The first step was to map the current state of the engineering change process through document review and stakeholder interview. To further define the current state, a process flow time study was completed via parts case study. Secondly, a comparison study between the SHC and legacy SGC programs was completed. Once all relevant information was gathered, a short term solution was generated and piloted. A longer term solution was then generated using background information and results from the pilot program.

### **1.6 Thesis Roadmap**

This thesis is structured to first provide the background information on the legacy programs (specifically the SGC program) as a baseline for the past managerial structure and performance of BCB. In this same chapter, the SHC structure is presented and compared to

that of the SGC program. Chapter 2 also includes a literature review of relevant academic fields including supply chain strategy, supply chain processes and alignment, knowledge management, and change management.

Chapter 3 presents information regarding the problems with the SHC engineering change process. The majority of this chapter revolves around visibility into the engineering change process, but also touches on other problem causes (quantity of change, engineering resources, and new change types) and how the SHC program has a more difficult time managing change. This chapter also includes the parts case study.

Chapter 4 attempts to illustrate that the change process is essentially a supply chain. This chapter uses elements of the literature review to show this and how supply chain strategies may be used to create a proper engineering change process strategy.

Chapter 5 takes all the information from chapters 2, 3, and 4 and presents the temporary solution piloted during the internship. It provides the informational details provided to purchasing through the pilot, along with the risks and benefits of this temporary solution.

Chapter 6 presents potential long term improvements to the current situation. Chapter 7 uses some of these recommendations to generate a long term solution. It also provides reasoning why elements of potential long term improvements presented in chapter 6 should not be implemented.

Chapter 8 presents the summary and conclusion for this thesis.

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## **2 Background**

### **2.1 Legacy Programs**

The four active legacy programs at BCB include the SCC (world's bestselling coach bus), SDC (the world's second largest coach bus), SFC, and the SGC (BCB's last new program launch). All four of the legacy programs are manufactured at BSS's facilities in the greater Lancaster, PA area, with the full size coach busses (SDC, SFC, and SGC) manufactured at the Knauers site and the SCC at the Reamstown site.

Although all four legacy programs had derivative programs launched, the most recent program developed from the ground up is the SGC. The SGC program launched in the early 1990s and with the first delivery of a SGC to a customer five years later. This program differed from the three other legacy programs in several ways: it was the first BSS bus to be designed with computers, it employed new technologies, and engineering involved cross functional teams across BSS and supplier companies. However, there were several aspects which remained the same, including the make/buy strategy and majority of the processes.

#### **2.1.1 SGC Technology**

The technology on every new BCB coach bus program differs in some way from the previous due to advancements in the field of automotive technology. Each new bus program has some sort of technology incorporated into the design that BSS has no prior history with. These advancements typically come in the form of systematic improvements, as structural design remained relatively similar across all legacy programs. Two of the major systematic advancements in the SGC program were the addition of cruise control and in-service entertainment (ISE) systems.

There were production issues involved with both systems during the initial ramp up phase of the SGC program. Since a cruise control system and the associated software development were new to BSS, there were several problems with the system, including the driving management system and the associated coding, which reportedly caused non-crippling delays in the installation of the air conditioning system. Once the coding was completely debugged, the SGC had around 1 million lines of code newly written for the coach bus, which is approximately six times the number of lines reportedly produced for the SDC. ISE also had production issues due to the wiring complexity of the system. However, the first bus was delivered on schedule in 1995.

### **2.1.2 SGC Make/Buy Strategy**

The make/buy strategy is relatively constant across all legacy programs. Large sheet metal sections of the bus structure are provided by outside suppliers while the bumpers are fabricated by BSS internally. For example, Chattanooga Structures (a former BSS company headquartered in Chattanooga, Tennessee) supplies major sections for all four legacy coach bus programs. Chattanooga Structures supplies the forward cab assembly for the SDC, SFC, and SGC, while it supplies the entire bus structure (not including bumper) for the smaller SCC.

The structural sections arrive at BSS from structural suppliers little more than a sheet of metal fastened to the internal supports. Sections come in four pieces (left, top, right, and underside) and commonly arrive with some brackets installed to allow for future system installation, but no other system installation is completed by the suppliers.

Once the bus sections are fully assembled at BSS, they are joined with the bumpers manufactured by BSS. Concurrently, BSS installs all the systems that are needed to make the bus move (engine, suspension, electronics, etc.). There is a different level of make vs. buy for each system, but there is a level (i.e., BSS doesn't make everything). For example, the engines have always been sourced from an outside supplier while BSS has built the major supports that connect the engine to the bus structure. They typically source small parts for the engine support from companies like Chattanooga and source unbent fuel tubes from a tubing company which BSS then bends and installs them between the fuel tank and engine. There are situations where subsystems are fabricated by a supplier (i.e., aspects of the air conditioning) but they flow directly to BSS for installation in the bus.

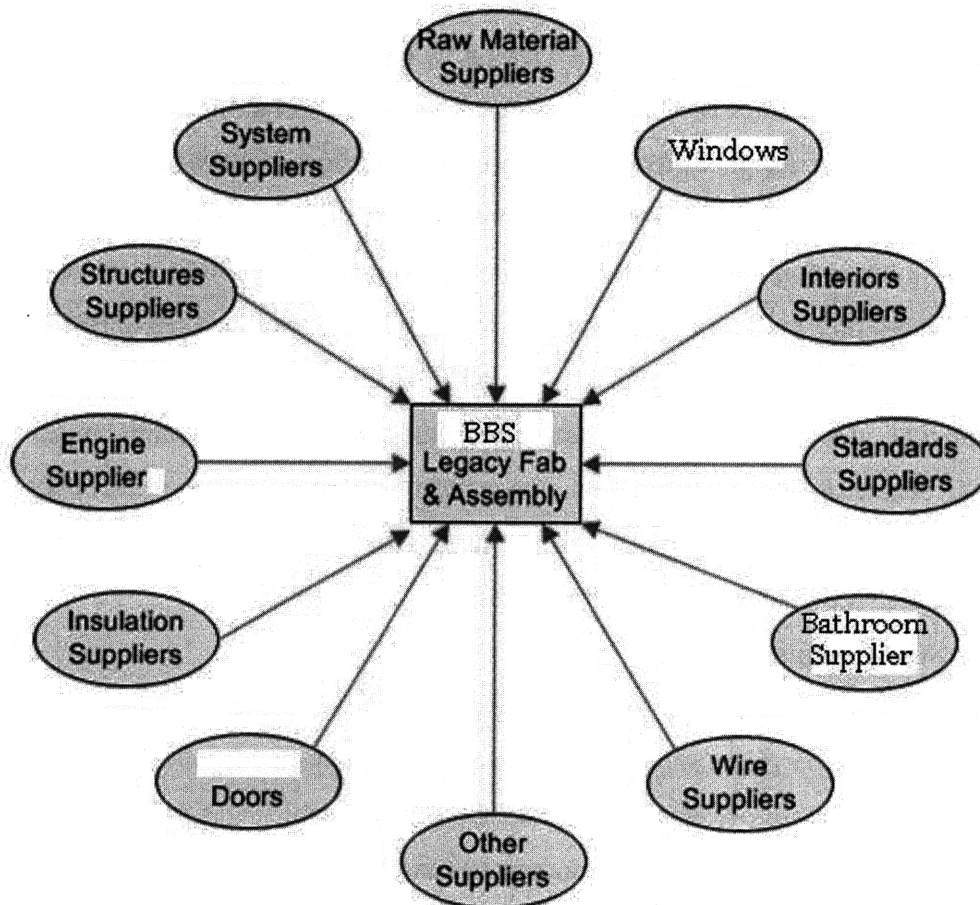
#### **2.1.2.1 SGC Traveled Work**

As with any bus production program, there are instances where uncompleted work moves from suppliers to BSS, or across the internal boundaries of BSS. This is called traveled work. Traveled work from structural suppliers is fairly easy to manage on the legacy programs due to its simplicity. The majority of the structural traveled work involves removing and replacing temporary fasteners that suppliers may have installed in the structure because they didn't have the proper fastener size. This type of traveled work is easy for BCB to manage because the work required to replace these fasteners is fairly straight forward and the area around the traveled work is relatively accessible. A

mechanic can easily identify and remove a temporary fastener through its markings and determine how to adjust the penetration to accommodate the permanent fastener.

### 2.1.3 Legacy Supply Chain

The legacy programs' supply chains did not differ drastically across programs because their make/buy strategies were mostly the same. BSS would receive everything from raw material to quarter sections directly from suppliers. The figure below shows a graphical representation of BSS's legacy supply chain structure.



*Figure 1: BSS legacy supply chain structure*

As can be seen from Figure 1, BSS was the central receiver of everything from raw material (such as aluminum or spools of wire) to system components (LCD screens, sensors) to structural components. This supply chain does not have very many levels as BSS suppliers do not supply incredibly complex parts to BSS. As a result, BSS does the majority of the manufacturing work to complete the bus.

#### **2.1.4 SGC Engineering**

The SGC program was BSS's first foray into cross functional and cross company design teams. Prior to the SGC program there was little input from suppliers regarding the design of the parts they produce. BSS would design these parts down to the detailed drawings and then hand them to the suppliers in order to fabricate the part. It was a build to print strategy.

The build to print strategy remained in the SGC program; however there was supplier input during the design phase which created a working together approach rather than an independent designing and manufacturing relationship. The SGC's design build teams were comprised of BSS design engineers, BSS manufacturing engineers and engineers from the supplier producing the part being designed. BSS did still maintain the clear leadership role in these groups. All three elements of the group were co-located in order to improve communication and collaboration amongst the group members.

The group members worked together to design the overall part using BSS owned processes and standards. This was ideal in that every cross functional team, regardless of the supplier on it, would work to the same processes and standards, maintaining consistency across the entire program. Once the overall piece was designed, BSS engineers would hand the part off to the supplier where their engineers would work the very detailed design (e.g., manufacturing design).

#### **2.1.5 SGC Computing**

On all programs prior to the SGC, the engineering drawings were completed by drafters by hand on velum sheets. The advent of computers made velum and drafters obsolete. The SGC program was the first BCB program which was fully designed in a computer aided design (CAD) environment. From the initial stages of SGC development through present day, 3D CAD was used extensively to design the SGC and its derivatives.

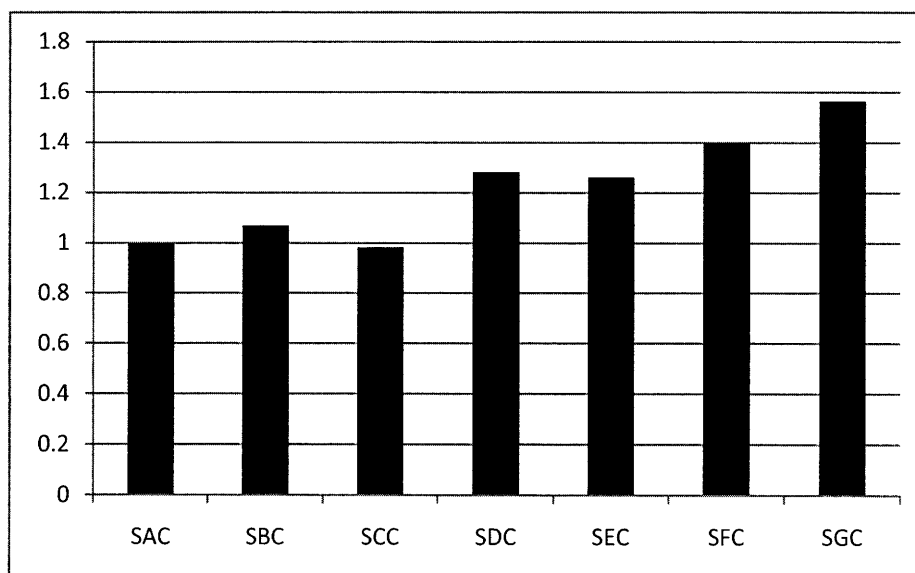
BSS received its first mainframe computers in the early 1990s and they were immediately put to use to design the SGC. They employed an early version of CATIA on these computers to design the majority of the bus. Once the design was nearing completion, the design build teams would hold design reviews where they would do virtual "fly throughs" of a 3D version of the bus. These fly throughs were intended to identify any areas of interference between the different system arrangements. If interferences were

observed, the design build teams would go back and compromise on an arrangement suiting both systems. The ability to fly through the virtual bus was incredibly beneficial. As a result of the fly throughs, there was a reduction in the number of times each drawing needed to be revised. As a result, the SGC's drawings were revised fewer (about half as many) times than its predecessor's (the SFC) drawings.

Aside from CATIA, the majority of the computing programs that the legacy programs currently use were internally written by BSS. BSS tailored these programs to address their specific needs for these programs.

### 2.1.6 SGC Scheduling

The SGC program was scheduled based on BSS's previous experience designing and manufacturing a brand new bus. The figure below shows a normalized view of the time duration between bus program go ahead and delivery of the first bus to a customer for all programs up to the SFC. The SGC series reflected in Figure 2 is schedule as proposed for the SGC at the beginning of the program.



*Figure 2: Time duration between go ahead and delivery for SAC through SFC programs. Planned schedule duration for SGC. Note: data normalized, SAC through SFC durations account for any schedule slip from the baseline schedule (if applicable)*

BSS delivered the first SGC to Greyhound Lines, Inc. in accordance with the schedule reflected in Figure 2.

### 2.1.7 SGC Processes

The majority of processes across the legacy programs are very similar. Processes such as first article inspection and assembly processes remain more or less the constant

across legacy programs. Of course there are subtle differences from program to program, but the differences are negligible. One of the major processes that remains consistent across legacy programs is the engineering change process.

#### **2.1.7.1 Engineering Change Process**

The engineering change process in the legacy programs is fairly complicated as there are several different types of change in the legacy programs. These different types of changes are associated with specific revised engineering design report (REDR) numbers (essentially a classification of the type of change). REDR numbers correspond to typical change types such as basic release, engineering errors, drawing updates, and committed changes. There are numerous different REDR numbers, so many that BSS had to design and distribute a slide ruler type tool in order to aid engineers when trying to determine the proper REDR number to use.

Following the determination of the correct REDR number and the approval of the change, a single SGC change board would meet. The change board would include all the stakeholders involved in the change. The change board acted as a forum for all parties to discuss the change and, ultimately, agree to a project plan for the change. The project plan is known as the engineering/design commitment schedule (EDCS) for legacy programs. This schedule is a graphical plan of each step required to incorporate a change in bus design. The schedule is based on quotes from each stakeholder for each job needed to implement the change on the bus. It includes the milestones needed to incorporate the change configurations. If there are any disconnects in quotes that would prevent on time completion, the change board will bring the affected parties together to determine a resolution that would satisfy the needs of the affected parties without delaying manufacturing activities. The EDCS must include the implementation plan for all events requiring date commitment such as new/revised parts, design reviews, engineering release events, order by date, part rework, etc. This implementation plan needs to be complete prior to the release of any engineering supporting the change.

As the name suggests, an EDCS is a commitment by each party to this agreed upon schedule. It can be considered akin to a contract as it is signed by all parties impacted by the change. Once this schedule is agreed upon by all the stakeholders, stakeholders are accountable for meeting each of the dates they are responsible for. If

any stakeholder should need to change any date in an EDCS, that individual must provide the proper evidence that shows there is a valid reason for the delay. If there is no valid reason, the request to change is rejected. BSS intentionally designed the EDCS revision process to be difficult because they wanted to dissuade individuals from delaying or missing milestones for arbitrary reasons.

A report was published internally to BSS summarizing the contents of the many SGC EDCS documents. This report detailed all parts which were scheduled to have engineering release within a set time period. This would provide all parties downstream (contracts, purchasing, quality, etc.) notice of the work that would soon be coming at them.

The change processes in all the legacy programs began as a paper based system because those programs were started before computers were widely used across the company. Even with this paper based system, changes were typically completed rather quickly as the SGC program's liaison engineering team was considered incredibly competent by those inside the company.

Changes could also be proposed by suppliers. If a supplier identified an opportunity to improve manufacturability through a design change, they could propose the change to BSS engineers (every change to design would have to flow through BSS for approval). If the change was approved, BSS would open the drawing and change the engineering drawings to reflect this improvement. One of the issues that resulted from this business arrangement was that, when a change was proposed by a supplier it made their job easier (e.g., a change to improve manufacturability), it reduced supplier costs while BSS paid to make the change (in other words, BSS had to foot the bill for this change while the supplier received all the cost savings). There could be contract negotiations that would transfer some of the savings to BSS, but the savings did not always outweigh BSS's cost of making the change.

## **2.2 SHC**

The SHC was formally announced by BSS in 2004 based on the order of 463 SHC coaches from Boston/New York based Fung Wah Bus Transportation Inc., the biggest launch order of any in BSS's history. Following this announcement, the SHC continued making

history for BSS. By September 2007, BSS reportedly had over 6487 orders for the SHC from 48 different bus lines which made it the most successful coach launch in bus history.

### **2.2.1 What makes the SHC technologically different?**

The SHC's popularity is due to several technological improvements which made it vastly different from any other coach bus in the world. First, the primary bus structure is mainly made of a composite material while every other coach bus in the world uses aluminum and other metals as the primary structural material. BSS sources estimate that as much of 60% of the primary structure will be composite material. The chief benefit of the use of composite material is that it is significantly lighter than any suitable metal, which results in significant fuel savings. Additionally, since the composite primary structure is a single barrel, the number of fasteners has been reduced significantly, further reducing the weight of the bus.

Weight reductions are also seen in areas where BSS has replaced mechanical systems with electronic systems. For example, BSS has replaced many of the mechanical switches used to turn systems on and off with digital switches. Instead of physically flipping a switch, the pilot will flip a digital switch on an LCD screen. As a result, the SHC will include 2.6 million lines of computing code to run this system, its air conditioning, and other onboard support systems, which is more than 2.5 times more code than the SGC, as reported by a trade journal in the industry.

In addition to the reduction in weight, the jet engines make the bus more efficient. BSS partnered with Broad Power (BP) and Spins-Harrelson to develop brand new internal combustion engines for the SHC. Industry experts estimated that the improvement in engine design will result in 8% better fuel efficiency and will be 50% quieter than predecessors. The quieter engines will also help bus lines avoid noise fines associated with operation in highly populated areas.

BSS has been able to increase fuel efficiency through other improvements to aerodynamics and systems. With all of the efficiency improvements, the SHC is reported to be at least 20% more fuel efficient than other busses present in today's coach bus market. It is estimated to be 65% more fuel efficient than BSS's first coach jet, the SAC.

There are also improvements which make the SHC one of the most passenger friendly busses. BSS has designed the windows with a digital dimming shade, where the

window itself becomes opaque. This will allow passengers to dim or brighten their area of the window as desired, making the ride more enjoyable.

Other improvements to the passenger experience include the use of LED lights to allow the coach lighting to be more passenger friendly. Also, state of the art air filters will make the cabin air the cleanest of any bus, eliminating even small viruses from the air. The passengers will also be able to control the temperature in their area of the coach to make the ride more comfortable.

### **2.2.2 Make/Buy Strategy**

Not only does the technology of the SHC differ greatly from the legacy programs, but the make/buy strategy also differs greatly from the legacy programs'. As stated above, the legacy programs have a more vertically aligned manufacturing strategy where BSS receives a lot of the low level parts and installs them on the coach bus. At the outset of the SHC program, BSS made the decision to make the SHC program a more horizontally integrated program where BSS performs the final integration to delivery (FID) role.

As a result of the decreased manufacturing statement of work, BSS entered into a partnership with several different companies for the SHC program. There are 28 top-tier partners which work closely with BSS to produce the SHC, 4 of these will manufacture the major bus structures. Most of these partners, like Tokyo Bus Construction (TBC) of Japan, Chattanooga Structures, and Venice Bus Solutions (VBS) of Italy, have worked as suppliers on the legacy programs. Therefore, most of these top suppliers should know how BSS works through their experience on legacy programs.

The main difference in the make buy strategy is that the structural suppliers will manufacture larger sections of the bus. In legacy programs (except the SCC), structural suppliers supply BSS with ¼ bus section pieces (top, bottom, left, and right sides) which would then be manufactured into a full size section at BSS's Knauers site. With the SHC, BSS will receive entire rectangular sections approximately twenty five feet in length from the partners. These full sections will have the supports and brackets installed inside just as in legacy.

In addition to structural partners supplying full sections, partners now supply the full bumpers to BSS. The bumper has historically been the pride of BSS's work. However, on

this bus, BSS decided to outsource the bumper engineering and manufacturing to Seoul Collision Protection (SCP) of Korea.

The structural partners will also receive semi-complete systems from other partners (e.g., Lester Wiring, Inc. of Luxemburg for system wiring, Pedroia Cooling of the USA for air conditioning, Ellsbury Tubing of Austria for fuel tubes, etc.) and install them into the bus sections and bumpers. The structural sections are intended to be provided to FID with the systems fully installed in each section.

Once system installation is complete, insulation is installed into the coach bus sections by the structural partners. These coach bus sections are ultimately transferred to BSS (some bus section integration work is transferred to another partner, Papelbon Integration (PI), where further integration work is completed before being shipped to FID).

Once BSS ultimately receives these sections, BSS will integrate the sections together. In the original business case, BSS would receive each coach bus section and the bumper and essentially “snap together” each of the pieces to form the full bus. In an ideal world, each one of the sections would match up perfectly where systems are easily spliced together. BSS would do much less of the actual manufacturing and assembly work than it did before. Therefore, the final integration role would be just as it sounds: final integration only, no “real” manufacturing. The original BSS plan was to be able to do final integration work in 2 days from the day the structural pieces entered the plant to roll out of a complete, unpainted bus. Whether BSS will ultimately be able to meet this goal is unknown.

It is useful to note that BSS has completely outsourced the entire bus. BSS Companies still manufacture and integrate the steering column, spoiler, and interiors.<sup>3</sup>

#### **2.2.2.1 Traveled Work**

With the change in make/buy strategy, there is also a change in the type of traveled work that BSS receives from partners. Traveled work occurs for various reasons, all to do with not having the proper parts in stock. It typically occurs when a manufacturing job cannot be installed before the bus section is shipped to BSS. The causes can occur because engineering may not be released to support manufacturing and

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<sup>3</sup> “SHC: International Team Facts.” Accessed: 10 February 2009, <[http://www.BSS.com/coach/SHCfamily/dev\\_team.html](http://www.BSS.com/coach/SHCfamily/dev_team.html)>

the section is due to BSS before either the engineering is released or before manufacturing can install the parts. It can also occur because suppliers cannot support the need dates of partner manufacturing (i.e., they cannot provide the parts to the partner as promised due to internal supplier problems).

On the SHC, no longer is the traveled work just structural in nature. Traveled work can now range from replacing temporary fasteners (just as in legacy programs) to installing complicated wire bundles or other systems. The traveled work of the SHC differs greatly from that of the SGC. There are few similarities between traveled work between the two different programs.

As stated earlier, legacy traveled work was mainly limited to jobs that required removal of temporary fasteners and installation of permanent fasteners. The traveled work that the SHC has experienced has been significantly more complicated. When the first SHC bus sections were delivered to BSS in Knauers, PA, it was reported that there were boxes filled with brackets, clips, wires, and other parts which were supposed to be installed in the delivered section. In addition to having different parts to install, BSS also needed the expertise to complete traveled work jobs. The manufacturing technicians would require the proper direction to install these brackets, clips, and wires, whereas in the SGC, it was well known, tacit knowledge how to replace the temporary fastener with a permanent fastener.

Other situations do exist where BSS is given traveled work which is characterized as “out-of-sequence” work. These situations occur when a partner cannot supply a bus section with some parts, but has provided the section with all the other parts installed. Out of sequence work occurs when a partner installs the follow on jobs because it is easier for the partner to ship the bus section with these parts installed rather than shipping them separate, where they could be damaged. BSS would then have to install the missing parts “out-of-sequence” which could require the manufacturing technician to remove significant sections of ducting, insulation, and other parts in order to install the missing part(s). This makes the traveled work (from suppliers) on the SHC that much more complicated than BSS has ever experienced. It is anticipated that the amount of out-of-sequence work will diminish as the program ages because program production will become more stable.

### 2.2.3 SHC Supply Chain

The supply chain of the SHC differs greatly from the supply chain of the legacy programs. This stems from BSS's choice of a new make/buy strategy whereby the major partners install systems rather than provide subassemblies for BSS to install. Figure 3 shows the new supply chain structure for the SHC.

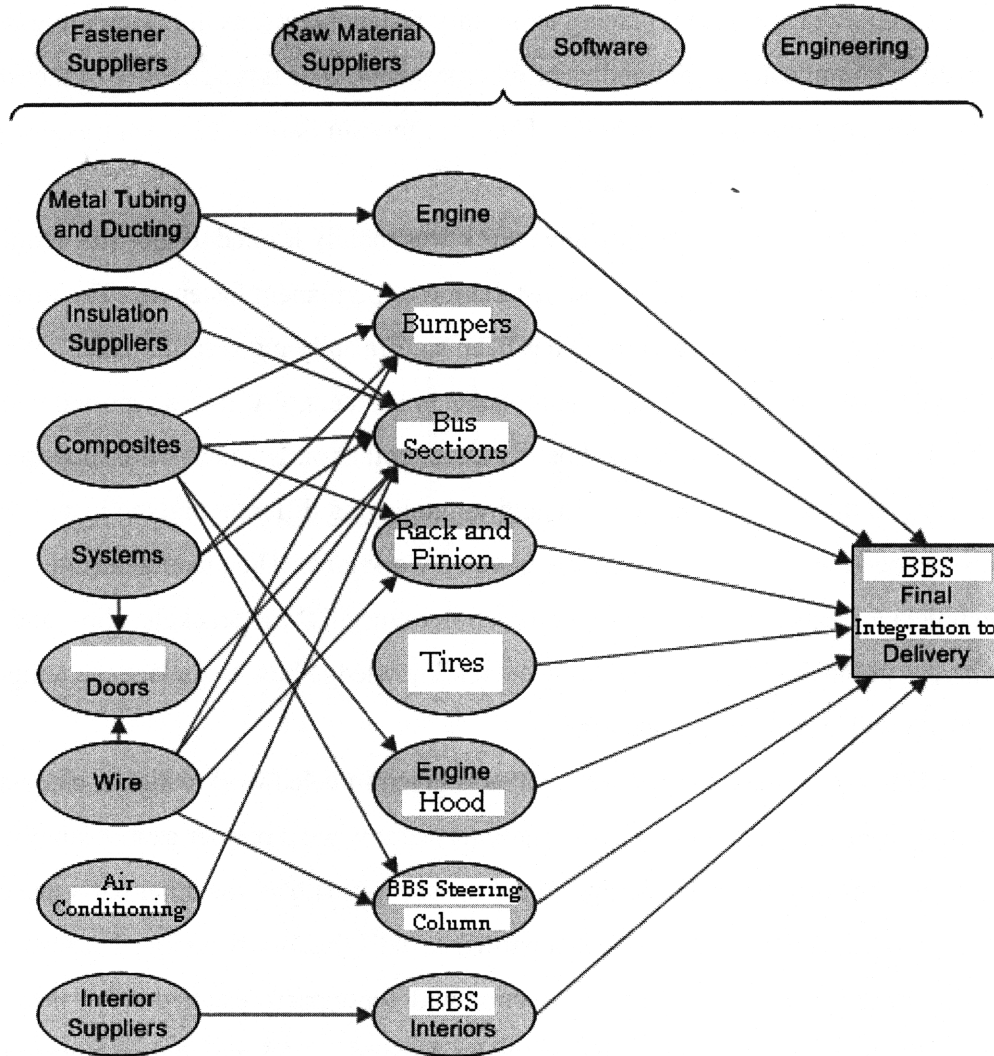


Figure 3: Graphical representation of the SHC supply chain. Items across top are common to all levels of the supply chain

When compared to the supply chain of the legacy programs (see Figure 1), it can be seen that the new SHC supply chain is much more complicated. Where BSS was the central recipient of almost every part in the legacy programs, BSS now only receives parts from top-tier partners. The top-tier suppliers receive the less complex (but still complex) parts from a wide variety of suppliers (some of which supply to several top-tier partners)

and integrate them into the very complex bus sections which are delivered to BSS. BSS has, therefore, reduced the number of suppliers they have to work directly with by adopting this model for the SHC program, and has created a much more horizontally integrated program.

However, BSS's experience this supply chain structure has not been all good to date. The structure that BSS has created is, in essence, a series of individual supply chains lumped together. The top-tier partners manage their own supply chain with little BSS oversight. Furthermore, these supply chains intersect in multiple areas because multiple partners require the same parts, causing the jumble which can be seen on the left side of Figure 3, which causes competition across the sub supply chains. With this structure, BSS does not have direct control over the larger supply chain since each mini supply chain is managed by individual partners with their own processes (i.e., there are no standard processes across the entire supply chain). It, therefore, takes a much longer time for issues lower in the supply chain to get to BSS whereas, in legacy programs, BSS had direct contact with all suppliers on a regular basis.

#### **2.2.4 SHC Engineering**

Manufacturing was not the only aspect of BSS's business to be outsourced for the SHC. Engineering was also outsourced for the first time on the SHC. Where BSS used to do the majority of the engineering, BSS now owns little of the engineering. BSS entrusted the same manufacturing partners, like VBS, TBC, and Chattanooga Structures, with the bulk of the engineering of those parts of the bus they manufacture. BSS gave the partners a taste of engineering with the design/build teams of the SGC, but full engineering of the SHC product definition is completed by the partners with little BSS input and oversight.

The partners employ their own engineers to complete engineering, and in some cases, outsource that engineering to sub tier companies. For example, Varitek Autobus's (Ireland) statement of work was the rear section of the bus. Instead of designing and building the floor for their section, they outsourced it to Ortiz Floor Services, LTD of the Dominican Republic. However, outsourced SHC engineering cannot be approved for incorporation into the bus configuration unless it is subsequently approved by the applicable first-tier partner (in this example, Varitek would have to approve Ortiz's

engineering). Outsourcing of engineering to sub tiers makes it that much harder further downstream (most especially for BSS) to determine engineering intent of the design.

### **2.2.5 Engineering and Program Management Computing Systems**

The majority of the engineering and program management computing systems used on the SHC is off-the-shelf systems rather than the designed and built in-house systems of the legacy programs. Like many in the engineering and design industry, the main computing programs consist of the product lifecycle management suite supplied by the firm The CAD/CAM People (TCCP). Other off the shelf software is used for tracking, purchasing, and manufacturing.

### **2.2.6 Processes**

The vast majority of the processes used on the SHC program were created specifically for the program. Very few of the processes were rolled over from previous programs because the thought was that this was such a radically new program (both technologically as well as systematically) that the existing processes could not be applied to the new architecture.

#### **2.2.6.1 Engineering Change Process**

The SHC engineering change process is one of the completely new processes for the SHC program. BSS initially tried to simplify the change process by eliminating the REDR process and replacing it with the General Engineering Change Process (GECP). No longer do engineers have to determine the correct REDR number in order to properly commit changes. Furthermore, the GECP has been simplified from the REDR so that every change has the same general flow through the process. There are some instances where the GECP process has been simplified for common change types (e.g. an electrical wiring change that impacts only wiring) which don't need the level of review as average changes.

Even though the process itself has been simplified, execution of the engineering change process has now become more complex in that BSS no longer owns the engineering. There are two different types of engineering change: a change that impacts BSS FID's statement of work, known as an A type change, and a change that only impacts a partner's statement of work, known as a B type change.

B type changes are changes that only impact a partner statement of work. These changes include situations where the change is internal to the partner design but has no effect on any other partner including BSS FID. An example of such a change would be a change in design of a bracket on the inside of the bumper that will be installed by SCP from the first bus the change is committed for. Type B changes are not governed by the GECP.

In contrast, type A changes are governed by the GECP and are the focus of this thesis. Type A changes are considered most important to the BSS Company because they directly impact their statement of work. Changes to work that BSS would ordinarily complete (both engineering and manufacturing) when the program is sustaining would be considered A type changes. These changes would be internal to BSS, provided the change does not impact any partner's statement of work. All type A changes are managed by the SHC program.

Type A changes become more complicated if the change impacts both BSS and partners (the most common Type A change). The coordination is more complex because communication is needed between companies which may be in different countries, where the local language may not be English. Examples of A type changes of this variety are:

- If a change is made to a BSS job, but it impacts a partner job. For example, BSS decides to make a piece bigger, and in turn needs a stronger bracket. The existing bracket is supplied and installed by Chattanooga Structures in the bus front section. BSS and Chattanooga must work together on this change to determine a proper solution, and implement the change together.
- A change is retroactive to any bus, including those which are currently under BSS ownership and/or delivered. For example, assume there is a defective wiring design in a partner work package that impacts all busses and BSS has busses one, two, and three at FID. BSS is not going to ship this piece back to the supplier for retrofitting; BSS will retrofit it themselves. Since this change is to a partner work package, the partner will complete the design engineering for the change and BSS (potentially another partner in certain circumstances) will create installation instructions and retrofit the busses under their cognizance. These busses and other busses outside of

BSS's current cognizance may need to have this change incorporated by BSS as an out-of-sequence installation when they arrive at FID. As part of the change process, BSS and the supplier negotiate an in-sequence installation bus where the change will be incorporated by the supplier into the supplied bus section.

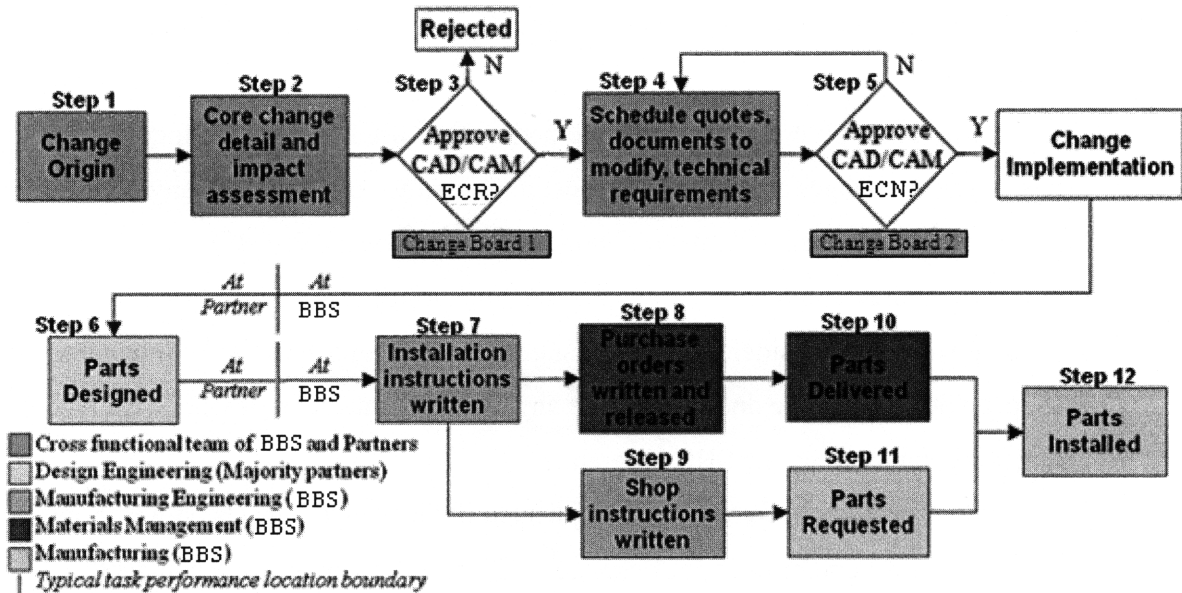


Figure 4: BSS Engineering Change Process for A type changes

Figure 4 details the typical flow through the SHC's GECP. The GECP, as designed, was intended to be used throughout all phases of the program: production ramp up, stable production, and derivative development and production. The changes originate from various documents such as nonconformance reports, traveled work, or design improvements from engineers (step 1). These documents are then analyzed by design engineers (DEs) from the responsible companies to determine if the change is actually necessary. If the change is necessary, they assess the potential impacts of the change, document principal requirements of the change, and build a business case justifying the change (if necessary) in a document called a Engineering Change Request (ECR) in step 2. The principal requirements are a high level description of the solution to the problem or improvement in design. It typically includes a series of renderings of the new part or assembly and what it takes to integrate the change into the bus. It would also document any improvements in design over the previous design.

Once this is complete, the design engineer presents the ECR to at least one change board for approval in step 3. There are several change boards, one for each functional

area in the SHC program (e.g., propulsion, electrical, structural, etc.). All change boards that a change impacts have to approve the ECR. The change boards meet at the BSS facility; with any partner DEs meeting virtually. Following the presentation, the change board either rejects the change and it dies right there or it approves the change for further development. Following approval by the first change board, the ECR goes to any other change board it impacts. Once all applicable change boards approve of the ECR, the ECR goes to step 4 where a document called an Engineering Change Notice (ECN) is written. This document is intended to organize the change and include all the necessary schedule information to complete the change. The ECN document is used to:

- Document the detailed technical requirements of the change
- Identify the documents and data (including part numbers) that will be created/changed/eliminated by the change
- Document schedule quotes
- Document the implementation plan for the change

The ECN document is supposed to include all the information necessary to cover the above aspects, but sometimes it doesn't.

During the construction of the ECN document, it is reviewed by a second series of change incorporation boards (CIBs). There are several of these, just as with the ECR change boards (CB). The main function of these CIBs is to act as a forum for stakeholders to negotiate the requirements of the change (e.g. a partner's implementation schedule) and to review the ECN to ensure that it includes all the required information. Once all the details have been ironed out and the ECN document is complete, each of the CIBs impacted will authorize the change for implementation in step 5. Once approved, a revision request is required to make a change to an authorized ECN document. These revision requests are submitted to the change board(s) for approval.

After the ECN is approved for implementation, the technical work required to implement the change is started (step 6). At this point, DEs from applicable partners, and potentially BSS, change their CATIA models to reflect the change. The part numbers and part geometry are digitally defined at this step. Once design is complete, the parts are reviewed and approved by the various group leads.

The parts that comprise an ECN may make up several different manufacturing jobs. Once all parts required to do a specific manufacturing job are completed and approved, Manufacturing Engineering (ME) can now proceed with their work (step 7). The ME writes their installation procedure in their Computer Aided Manufacturing (CAM) program, which takes all of the information from the DE and formats it into 1) lists of parts added, removed and reworked, and 2) the steps necessary to install the job shipside.

Once the instructions are complete, the ME lead in the group approves the work in the CAM system and the ME submits the job. Once the job is submitted, the process becomes parallel in steps 8 and 9. There is a digital connection between the CAM system and both the purchasing system (Enterprise Resource Planning, ERP, system) and the Manufacturing Execution System (MES). While the job instructions are being written in MES, SHC MMD can purchase parts as needed in the ERP system.

Once the purchase order (PO) is written by MMD, the supplier is notified of the need for the part and then, in turn, produces it. Ideally, the PO is written with enough time so that the lead time for the part is less than the difference between the PO issue date and the manufacturing need date. If the difference is greater than the lead time, the part should be in BSS's possession before the part is needed for installation in the bus. If the difference is less than the lead time, BSS may have to expedite the part or delay the manufacturing job in step 12. A delayed job because of a missing part creates a "part shortage" condition which is closely tracked by MMD and SHC upper management.

### **2.3 Summary**

The SHC program is fundamentally different from the legacy programs across the board. The following figure shows the fundamental differences between the SGC program and the SHC program.

	SGC Program	SHC Program
Technology	New: ISE, air conditioning, 1 million lines of computer code	New: Carbon fiber structure, mechanical systems replaced with electronic equivalents, efficient engine, 2.6 million lines of computer code
Make/buy strategy	Supplier relationship, BSS responsible for most of manufacturing Structural: quarter bus sections supplied to BSS, BSS completely manufactures both bumpers System: integrated and installed by BSS	Partnership, BSS responsible for final assembly (minimal manufacturing) Structural: full, four sided sections supplied to BSS, bumpers outsourced System: majority installed by partners
Traveled work	Insignificant, commonly limited to replacing temporary fasteners	Complex. Traveled work frequently involves significant part removal to access the work area. More steps involved
Supply Chain	Essentially vertical. Suppliers typically deal directly with BSS	Essentially horizontal.
Engineering	Design/Build Teams. BSS owned engineering	Partners complete most of engineering. BSS completes minimal final assembly engineering
Computing	CATIA for CAD. Internally developed systems for much of the other programs	CATIA for CAD. Off the shelf software used commonly across the program (rather than in-house)
Scheduling	On-time delivery of the first bus	Close to two years behind original schedule
Processes	Many rolled over from previous legacy programs. REDR process for engineering change, EDCS ensures accountability	Brand new for SHC program. Minimal roll over from legacy programs. Engineering change process (GECP) lacks accountability

*Figure 5: Comparison between the SGC and SHC programs*

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### 3 Literature Review

This chapter provides background information on supply chain strategy, supply chain processes and process alignment, knowledge management, and change management as gathered from relevant literature and research. The information presented in this chapter will be used later in the thesis to provide useful insights into the SHC shortage problem.

#### 3.1 Supply Chain Strategy

In the last 100 years, worldwide manufacturing industry underwent an incredible transformation. Up until the early 1900s, the majority of companies provided products and services to the local populace with resources coming from the surrounding area. With the advent of such technological advances as the train, bus, automobile, and internet, communication and transportation have become much faster and easier. As a result, companies have had the opportunities to become more global through importing/exporting and outsourcing. Hence the global supply chain was born. Proper supply chain strategy and management is, therefore, much more important to a company than ever before because the supply chain is exponentially more complex and is an opportunity for a competitive advantage.

In order to properly cope with this increasingly globalized supply chain system, companies have become reliant on the principles of supply chain management. The University of Tennessee's Supply Chain Research Group has defined supply chain management as:

the systematic, strategic coordination of the traditional business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole.<sup>4</sup>

The supply chain must be aligned with the proper supply chain strategy in order to improve the long-term performance that the definition puts forth.

Supply chain strategy has been researched heavily in the recent years as companies themselves have become more global and their supply chains have become more complex. Accordingly, the strategic choices required emerge "from an enterprise's assessment of

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<sup>4</sup> Mentzer, John T; Stank, Theodore P; Myers, Matthew B. "Global Supply Chain Management Strategy." Handbook of Global Supply Chain Management. Eds. John T. Mentzer, et. al. Thousand Oaks: Sage Publications, 2007. p 19.

externally based opportunities” which typically include aspects such as condition of global markets, regulatory conditions, or potential supply chain partner characteristics like management style, values (shared vs. unshared), and culture, where culture plays a very important role.<sup>5</sup> The key component of culture which influences supply chain strategy is support from top management throughout the supply chain. Upper management is essential because they have the ability to shape the strategic direction of the entire organization. Furthermore, organizations where top management supports behavior consistent with the supply chain strategy have the opportunity to be more successful managing their supply chain than those that do not.<sup>6</sup>

The supply chain strategy must also be determined with respect to the product itself. As Peter Kraljic writes in his article, “Purchasing Must Become Supply Management,”<sup>7</sup> a company’s supply chain strategy is contingent on two different factors which can be used by management to determine the type of supply chain strategy needed to minimize risk and identify important suppliers. Managers must first explore the supply chain strategy’s strategic impact with respect to: value added to each product, percentage of total cost derived from raw materials, impact of raw material purchase on profitability, impact of outsourcing subassembly on profitability, etc. Kraljic writes:

By assessing the company’s situation in terms of these two variables, top management and senior purchasing executives can determine the type of supply strategy the company needs both to exploit its purchasing power vis-à-vis important suppliers and to reduce its risk to an acceptable minimum. Attractive new options, or serious vulnerabilities, or both, may come to light as the assessment explores questions like these:

1. Is the company making good use of opportunities among different divisions and/or subsidiaries? Combining the supply requirements of different divisions can increase the corporation’s total buying clout...
2. Can the company avoid anticipated supply bottlenecks and interruptions?
3. How much risk is acceptable? Vendor mix, extent of contractual coverage, regional spread of supply sources, and availability of scarce materials all contribute to the

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<sup>5</sup> Mentzer, John T; Stank, Theodore P; Myers, Matthew B. “Global Supply Chain Management Strategy.” Handbook of Global Supply Chain Management. Eds. John T. Mentzer, et. al. Thousand Oaks: Sage Publications, 2007. p 22.

Mentzer, John T; Stank, Theodore P; Myers, Matthew B. “Global Supply Chain Management Strategy.” Handbook of Global Supply Chain Management. Eds. John T. Mentzer, et. al. Thousand Oaks: Sage Publications, 2007. p 25.

<sup>7</sup> Kraljic, Peter. "Purchasing must become supply management." *Harvard Business Review* 61, no. 5 (September 1983): 109-117. Business Source Complete, EBSCOhost (accessed February 18, 2009)

company's supply risk profile. A company can often take action to lessen unacceptable risk...

4. What make-or-buy policies will give the best balance between cost and flexibility? If the company covers a large percentage of supplies from sources it owns, it will be in a much better negotiating position to cover the remainder of its outside requirements than its less-integrated competitors.
5. To what extent might cooperation with suppliers or even competitors strengthen long-term supply relationships or capitalize on shared resources? ...[certain companies are] increasingly involving suppliers early in the design process in order to ensure better quality, lower cost, and "just in time" production.

Once the strategy is selected and implemented, Kraljic continues down a path focusing on strengthening the organization. One of the key points he makes is that managing purchasing in isolation from the rest of the company is impossible in today's industrial environment and problems result from isolation:

Greater integration, stronger cross-functional relations, and more top-management involvement are all necessary. Every facet of the purchasing organization, from systems support to top-management style, will ultimately need to adapt to these requirements. Concrete changes in the organization will be required to establish effective organizational relations, provide adequate systems support, and meet new staff and skill requirements... Too often the purchasing department receives information on the company's business plans and objectives that is incomplete or improperly geared to the tasks and time horizons of strategic supply management. Purchasing executives... often lack adequate operating information with a three- to six-month time horizon, which would provide early warning of short- to medium-term demand fluctuations. The purchasing department needs these data for negotiating prices, rescheduling supply quantities... In the absence of such data, supply bottlenecks, short-term demand fluctuations, and ad hoc purchasing decisions are inevitable. In turn, the company incurs higher time and money costs...

Complex companies with numerous products, multiple plants, and substantial production for stock... are more vulnerable than are companies with a single product line and/or considerable job order production... In either case, tailor-made systems support will be called for. Such support might include: improvement of operational flexibility through a rolling demand forecast system with a three- to six- month time horizon... Improved systems support frees buyers and management from preoccupation with day-to-day problems and enables them to focus on long term analytic work and planning. Additional benefits include price reduction or savings, inventory reduction, reduced clerical work, and better delivery and service.

The company will realize these benefits only if it uses the systems effectively. It must foster consistent, cross-functional information flows and demands and induce line managers to supply the required data for the purchasing information system. (One way is to show them that most of the "new" data already exist and need only to be recast in

an appropriate format.) Finally, management must make certain that any major new systems are user friendly.

A similar, but more recent, article appearing in Harvard Business Review details a separate process to determine a supply chain strategy. This article, written by Marshall Fisher and titled "What Is the Right Supply Chain for Your Product?",<sup>8</sup> focuses on how individual products define the type of supply chain needed. The article first speaks to two different categories of product: functional vs. innovative products. A functional product is considered akin to a standard product, similar to a commodity, where product differentiation between competitors is minimal or non-existent. Functional products are characterized by predictable demand, stable design, address an established long term market need, satisfy basic needs (e.g., pencils, hammers, shovels), and have low margin. An innovative product is as the name suggests: a product which has differentiated itself from the competition through design improvement. Innovative products are characterized by unpredictable demand, short life cycle, and higher margins.

These two different types of products, functional and innovative, need fundamentally different supply chains. The most important difference between the two supply chains is that innovative product supply chains need to be flexible, while functional product supply chains do not need to be flexible (but can be), but do need to be efficient. The primary reason for this is the demand for innovative products is inherently unstable while demand for functional products is typically stable because the demand forecasts are typically based on historical data which results in a relatively accurate prediction. Functional product supply chains need to be efficient to ensure lowest cost in a commodity market.

An innovative supply chain needs to be flexible so that it can react to the realized market demand for that product in order to fulfill customer needs. If the supply chain is inflexible, producers will either manufacture too much (creating excess inventory) or too little (creating shortages). Similarly, partners or suppliers in an innovative product's supply chain should be chosen based on partner/supplier speed and flexibility with respect to production capacity and inventory positioning, not on low cost (although this variable should be considered), in order to hedge against this unknown demand.

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<sup>8</sup> Fisher, Marshall L. "What Is the Right Supply Chain for Your Product?" Harvard Business Review 75, no. 2 (March 1997): 105-116. Business Source Complete, EBSCOhost (accessed February 19, 2009).

Once the supply chain structure is chosen, the company must constantly reassess the state of the supply chain and improve when necessary. Fisher continues by stating that companies with innovative products should invest in improving flexibility in supply chain when hiccups occur because the return on the resulting increase in supply chain responsiveness from a flexibility improvement is much greater than the return on an improvement in supply chain efficiency. Furthermore, continuous improvement must be focused on creating more value for the customer. Value management must always be considered throughout the life of the supply chain in order to ensure that the organization at least meets, if not exceeds, the needs of the customer.

Value management can be broken down into two specific subgroups: value creation and value appropriation. “Value creation addresses the global supply chain’s ability to offer a better value proposition to customers than that offered by competitors. Value appropriation addresses firms’ abilities to extract value from the market at a sufficient level to meet earnings and profitability targets.” Furthermore, the supply chain strategy must be continually managed and realigned to meet the value demands of the marketplace.<sup>9</sup> If the organization lacks the proper value management, there is risk that the organization will lose market share to its competitors. It is the task of every process and task in the value chain to help attain the goal of delivering the highest value to the end customer.<sup>10</sup>

### **3.2 Supply Chain Processes and Process Alignment**

The primary challenge of any company is to create processes that align with the product. A process is defined as a “repetitively used network of activities linked in an orderly manner using information and resources for transforming ‘object in’ into ‘object out,’ extending from the point of identification to that of satisfaction of a customer’s needs.” The organization’s management must properly design, establish, and develop the suitable infrastructure in order to align all supply chain processes with the organization’s objectives.<sup>11</sup>

Fisher contends that there are “four tools” for aligning these processes to the innovative product. The first tool is to ensure acceptance of demand uncertainty. The company needs to

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<sup>9</sup> Mentzer, John T; Stank, Theodore P; Myers, Matthew B. “Global Supply Chain Management Strategy.” Handbook of Global Supply Chain Management. Eds. John T. Mentzer, et. al. Thousand Oaks: Sage Publications, 2007. pps. 26-27.

<sup>10</sup> Flint, Daniel J; Gammelgaard, Britta. “Value and Customer Service Management.” Handbook of Global Supply Chain Management. Eds. John T. Mentzer, et. al. Thousand Oaks: Sage Publications, 2007. p 52.

<sup>11</sup> Larson, Everth. Ljungberg, Anders. “Process Orientation.” Handbook of Global Supply Chain Management. Eds. John T. Mentzer, et. al. Thousand Oaks: Sage Publications, 2007. pps. 103-104.

accept that there is uncertainty in the product which will put the company in the right mindset for transformation of the supply chain, helping it look for ways to improve the supply chain to hedge against this uncertainty. Fisher specifically cites an example from industries which are oligopolies. In these situations, companies with less competition tend to find it difficult to accept the inherent demand uncertainty because of the environment the company was exposed to: low competition, weak retailers, and less demanding customers who have a tendency to accept the actions of the company.

The second tool is alignment of processes to reduce uncertainty. Uncertainty in the supply chain can be reduced by finding and employing new data sources into processes. By finding and adding additional *useful* demand information to the supply chain processes, supply chain analysts can be more confident that orders are correct. This additional information can reduce uncertainty by providing more complete information to supply chain analysts earlier so that they can make purchases according to the best information available, rather than doing it with partial blindness.

The third tool avoids uncertainty in processes by reducing lead time in production and increasing flexibility in the supply chain. This allows the supply chain analyst to use additional information to make purchases that more accurately match demand.

The fourth tool is to hedge against any additional uncertainty not eliminated by the previous tools. An example would be to change processes to require additional inventory buffers or excess capacity at strategic points throughout the supply chain.

Fisher ends the article with the following statement focusing on how common supply chain problems are in industry and how improvement rewards can be large:

Managers at many companies continue to lament that although they know their supply chains are riddled with waste and generate great dissatisfaction among customers, they don't know what to do about the problem. The root cause could very well be a misalignment of their supply and product strategies. Realigning the two is hardly easy. But the reward – a remarkable competitive advantage that generates high growth in sales and profits – makes the effort worth it.

Any supply chain processes need to be continually monitored and improved to suit customer needs and values just as the supply chain strategy itself should be. In order to continually improve the supply chain processes, management needs to be able to measure the performance of these processes. Performance measures of every supply chain process are needed, both across firms and between firms. A holistic view of the process performance can

show the health of the entire process while between firm performance measures will show how the firms in the process are reacting to the adjacent firms in the process. Performance measure of the entire process will be able to show if a process needs significant improvement across the board while firm to firm performance can be used to pinpoint any underperforming firms or any issues associated with intercompany linkages at each step in the processes.<sup>12</sup>

### **3.3 Knowledge Management<sup>13</sup>**

Knowledge management is defined in chapter 6 of the Handbook of Global Supply Chain Management as “a business process that promotes organizational learning by integrating a firm’s approach to creating, sharing, and using its knowledge resources [where] knowledge resources make up a firm’s intellectual capital.”<sup>14</sup>

There are two major types of knowledge which need to be managed in any company, explicit and tacit knowledge. Explicit knowledge is knowledge which can be separated from the individual employees that make up the firm, and is typically easily defined and documented. For example, explicit knowledge can be historical purchasing trends, demand trends, engineering design changes, etc. Explicit knowledge is typically fairly easy to transfer across employees and partnering firms. Tacit knowledge is knowledge that is not easily documented because it is not easily separated from individuals. Tacit knowledge is in the minds of the employees but cannot be easily defined on paper, but can be transferred by employee to employee interaction (e.g., observation). An example of tacit knowledge is when an individual knows the best practice for engineering a bracket on an bus. This is not easily defined but can be learned through experience.

A competitive advantage can be created when a firm takes advantage of the knowledge it creates. The more a company knows the better and faster they can react to the constantly changing competitive environment. However, knowledge must be properly managed in order to realize this competitive advantage. Knowledge management requires engagement of the entire organization in the commitment to learning and, in order to succeed, competent

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<sup>12</sup> Mentzer, John T; Stank, Theodore P; Myers, Matthew B. “Global Supply Chain Management Strategy.” Handbook of Global Supply Chain Management. Eds. John T. Mentzer, et. al. Thousand Oaks: Sage Publications, 2007. p 22.

<sup>13</sup> Davis, Donna F; Chenneveau, Didier. “Knowledge Management.” Handbook of Global Supply Chain Management. Eds. John T. Mentzer, et. al. Thousand Oaks: Sage Publications, 2007. pps. 87-102.

<sup>14</sup> Davis, Donna F; Chenneveau, Didier. “Knowledge Management.” Handbook of Global Supply Chain Management. Eds. John T. Mentzer, et. al. Thousand Oaks: Sage Publications, 2007. p 90.

knowledge management must rely equally on three foundations: climate, processes and infrastructure.

There must be a climate for knowledge management (similar to organizational culture) that encourages knowledge management. This climate is important because knowledge will not be effectively managed if employees are against knowledge management. Employees must be willing to manage their knowledge in order for the system to work.

Knowledge management processes must support knowledge creation, knowledge sharing and knowledge use. Knowledge is useless if it is not shared or used after it's created. Knowledge management processes must therefore be aligned to encourage sharing of knowledge across the company so that the company can take advantage of any and all knowledge that is created by its employees. An example of a knowledge management process would be the requirement for cross functional teams. This allows each member of a different background to share their knowledge with other group members. Together, the group can use their combined knowledge to complete their project with the best possible outcome.

Similar to the knowledge sharing in a cross functional team, knowledge infrastructure must be aligned to support the sharing of knowledge across the company. Knowledge infrastructure allows communication of knowledge through different channels, like computing systems, phone systems, and social networks. Knowledge infrastructure is usually considered akin to knowledge IT but is not effective unless the IT systems are filled with relevant knowledge:

For IT to be an efficient communication channel, a firm must have standards for collecting, storing, and sharing information using compatible platforms and centralized databases. In firms that do not have an integrated IT infrastructure, workers routinely manipulate data as it passes between functions. Data are downloaded from one database, reformatted, and uploaded into the next application. This not only takes up valuable time; it also raises the risk of introducing errors, thereby reducing the credibility of the information. As a result, departments resort to collecting and storing their own versions of critical information, isolating it on fragmented systems or "islands of information." A user-friendly, integrated IT infrastructure ensures the standardization, compatibility, and interoperability of systems and data required to build knowledge management competence.<sup>15</sup>

With proper alignment of knowledge management climate, processes, and infrastructure, a company can benefit the most from the knowledge it has created and,

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<sup>15</sup> Davis, Donna F; Cheneveau, Didier. "Knowledge Management." Handbook of Global Supply Chain Management. Eds. John T. Mentzer, et. al. Thousand Oaks: Sage Publications, 2007. p 100.

therefore, create a competitive advantage. With the proper alignment of these three characteristics of knowledge management, the company can more efficiently operate across the entire enterprise. Specifically, it can help a company operate more effectively with their partners in the supply chain because the information supporting the knowledge will be more readily available to any partner who needs it. However,

Building knowledge management competence is not an easy task. It is far easier for managers to focus on projects that promise short-term results than to take on the mission of positioning a firm to compete over the long term in a global supply chain. It is a complex, never-ending process.<sup>16</sup>

### **3.4 Change Management**

#### **3.4.1 Organizational Change Management<sup>17</sup>**

This section focuses on organizational change management. However, the principles of organizational change management can and will be applied to engineering change management later in the thesis.

Change management is those strategies and action plans which are used to transition from a current state to a future state (whether it be a technical engineering change or an organizational change). There are two different change management critical processes: gaining buy-in of the change throughout the organization and executing the change. These two processes are related when proposing a technical engineering change in that buy-in (more commonly known as approval for implementation in engineering change situations) of the change is required to execute the change. Buy-in of a technical change is garnered by providing the technical data supporting the need for the change to those who will approve or reject the change. Provided that this data is sufficient for the decision makers to approve a change, the change management process will continue to executing the change.

In order to successfully execute any change, a detailed execution plan is needed. This execution plan is a project in itself and should be managed as a project, following all of the prudent project management principles. Accordingly, the change management should be structured into a “disciplined set of tasks” in the execution plan. The elements

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<sup>16</sup> Davis, Donna F; Cheneveau, Didier. “Knowledge Management.” Handbook of Global Supply Chain Management. Eds. John T. Mentzer, et. al. Thousand Oaks: Sage Publications, 2007. p. 102.

<sup>17</sup>Dittmann, J. Paul; Mello, John E. “Change Management.” Handbook of Global Supply Chain Management. Eds. John T. Mentzer, et. al. Thousand Oaks: Sage Publications, 2007. pps. 523-529.

of a complete change management plan require complete and detailed written description of the objective, scope, responsibilities, communication plan, and detailed completion steps of each task.

The most critical plan component is the communication plan because, without the proper communication plan, task details, responsibilities, timelines, etc. can go unheard. This can prove fatal to any change management plan as the required work must be completed but won't be if not received by those who are to take action. There are two key steps in creating a proper change management plan. The first is to identify the key stakeholders in the change implementation plan. Once these individuals and groups are identified, the proper communication method to each stakeholder has to be determined. As each stakeholder has different values and priorities, the communication to each has to be appropriate to that individual or group so that each properly understands what is required of them.

In order to properly execute the change management plan, there are several roles which need to be filled. They are as follows:

1. Sponsor – the individual who submits the change for approval. This person provides the justification for the change and proposes the solution for the change.
2. Change Owners – those individuals who manage the whole change process across all groups.
3. Change Managers – individuals in each affected functional area who ensure the individual steps in the change process are completed and completed on time. If any step were to fall behind, the responsible change manager would be required to determine and implement the required corrective action to get the step back on track.
4. Process Owners – individuals tasked with the responsibility to complete the details of the steps (e.g., technical document update) required to fully execute the change.

The communication to each of these roles in the change management process must include all relevant data needed to complete their responsibilities including, but not limited to:

- Clearly defined tasks
- Responsibilities
- Schedules with clear completion dates

“It is critical that everyone understand and buy in to the critical component in the change process; without successful execution of each person’s role, the change [implementation] will fail. In the final analysis, everyone is a leader in a successful change process.”

### **3.4.2 Engineering Change Management**<sup>18 19</sup>

Engineering change management is similar to organizational change management in that it attempts to manage a change that hopes to improve the design of the entity. In organizational change management, that entity is the firm while in engineering change management, the entity is a product.

Engineering change occurs for several reasons ranging from correcting design errors to improving design. Engineering changes are inherent to the design process because engineering “is an iterative rather than a purely linear process and traditionally are targeted toward correcting mistakes, integrating components, or the fine tuning of a product,” therefore, resulting in design improvement. Studies have shown that engineering changes “consume one-third to one-half of engineering capacity and represent 20% to 50% of tool costs, which can easily account for over US \$100 million in large development projects.”

Engineering change is managed through an engineering change process and its supporting sub processes. The engineering change process consists of a sequence of several events involving handoffs to and from several different stakeholders from a wide variety of organizations. These stakeholders include, but are not limited to, engineers, project managers, departmental managers, purchasing, quality, and planning. The processing engineering change through the change process is typically “a rather complicated endeavor” resulting from the multitude of stakeholder input and the complex managerial approval sub process which may exist. In studies of the automotive industry, depending on the complexity of the change, the engineering change process can require from several weeks to over a year’s time to complete a change. However, the actual processing time (value added time) of changes is typically no longer than 2 weeks.

In their article “Accelerating the Process of Engineering Change Orders: Capacity and Congestion Effects,” Loch and Terwiesch identify three components that drive the

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<sup>18</sup> Terwiesch, Christian. Loch, Christoph H. “Managing the Process of Engineering Change Orders: The Case of the Climate Control System in Automobile Development.” *Journal of Product Innovation Management*, 1999. Volume 16, pps. 160-172.

<sup>19</sup> Loch, Cristoph H. Terwiesch, Christian. “Accelerating the Process of Engineering Change Orders: Capacity and Congestion Effects.” *Journal of Product Innovation Management*, 1999. Volume 16, pps. 145-159.

length of the change process. The first driver is processing time. This is the time that it takes to complete the content of the change. This includes, but is not limited to, such value added activities as updating CAD, creating manufacturing instructions, and writing purchase orders. The second driver is batch waiting. This occurs when waiting for other changes of the same type to be completed so a group can be processed simultaneously. The third driver is waiting time, aside from batch waiting. This occurs when a change sits on an individual's desk in between change process steps or when the engineer does not work on a change in order to work on his or her responsibilities. Essentially, it is the time that the change remains in a state of pending.

Waiting time is typically a significant portion of the process completion time. A studies of an airframe manufacturer and mechanical controls company showed that the value-added time for an engineering change was shown to be 1.75 days over three weeks and five days over five weeks, respectively. Therefore, only 8.5% and 21%, respectively, of the total processing time was value added. Further results of the study across all white collar processes show that value added time can be lower than 5% of total processing time.<sup>20</sup>

In their other article "Managing the Process of Engineering Change Orders: The Case of the Climate Control System in Automobile Development," Terwiesch and Loch identify five key contributors to the long processing times through the change process: complex approval process, snowballing changes, scarce capacity/congestion, setups/batching, and organizational issues. They describe these contributors as follows:

1. Complex approval process: multiple decisions, approvals and handoffs can take up to 10 days in the study completed by Terwiesch and Loch.
2. Capacity/Congestion: lack of proper engineering capacity for a department will cause a queue in engineering change work for the department. Congestion can occur due to the fact that arrivals of engineering change for a department are stochastic. Backlogs can occur when a "large wave" of engineering changes flows to a department even when the department has an acceptable capacity.

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<sup>20</sup> Blackburn, Joseph D. 1992. "Time-based competition: White-collar activities." *Business Horizons* 35, no. 4: 96. *Business Source Complete*, EBSCOhost (accessed April 30, 2009).

3. Setups/Batching: “mental” setups occur when an engineer picks up an engineering change that he or she has not worked on recently (e.g., over a day). He or she must get themselves back “up to speed” on the details of the engineering change.  
Batching occurs in situation where similar changes are grouped together in order to realize economies of scale. In certain situations it is cheaper to process two similar changes at once. An example of this is when it is cheaper to process two changes that impact the same CAD model. By grouping these two changes together, the CAD model has to be opened only once. Delays can occur when the first change is waiting for the second change to complete upstream sub processes.
4. Snowball effect: by changing a part, the couplings between the interfacing parts may need to also be changed. If these couplings are not initially considered, future delays in the engineering change process could occur.
5. Organizational issues: the culture of the company can create delays in the change process. Terwiesch and Loch point to an example where a company had a culture for cost management, and the company’s metrics and incentives reflected this culture. There was not a culture for time management. This resulted in delays because, even though slight cost overruns were heavily scrutinized, two week delays were overlooked even if it was a time sensitive project

Terwiesch and Loch conclude that the complex approval process, capacity/congestion, and setups/batching result from issues with business process management. The other two, snowballing and organizational issues, result from the responsiveness and culture of the organization. As a result, they present potential improvement activities attempting to improve or eliminate these delays through process improvements or cultural changes. These are as follows:

1. Eliminate unnecessary steps: eliminate unnecessary oversight, bureaucracy, data reconciliation, etc. A process stream mapping exercise can be completed to identify unnecessary elements of the engineering change process. This will also reduce the number of handoffs in the process.
2. Reduce utilization and variability: reduce utilization through hiring, if possible. Utilization can also be decreased by increasing the flexible capacity, better IT, and pooling of resources. Increasing flexible capacity through use of overtime helps when

engineers are overloaded. Better IT will help employees work more efficiently.

Pooling of resources can allow individuals to assist others when there is slack in their work.

3. Ensure fast feedback and turnaround: requiring fast turnaround of issues involving key couplings and interfaces will help minimize snowballing. The theory is that a fast turnaround time and resulting quick finish of the change. This will minimize the chance that other changes are created that may impact the same parts as the first engineering change. It makes change execution less complex.

### **3.5 Summary**

This chapter presents the literature review on supply chain strategy, processes and alignment, knowledge management, and change management. The literature review will ultimately be applied to the SHC program and its change process further into this thesis.

## **4 Problems with the SHC Engineering Change Process**

The SHC General Engineering Change Process (GECP) was built from the ground up specifically for the SHC with little roll over from the engineering change processes of the legacy programs. The intent was to produce a process which was a simpler change process than the legacy change processes (the REDR process). In addition, BSS management felt that a newly designed change process was required as the legacy change processes would be unsuitable for the new supply chain strategy of the SHC. However, there have been many problems in the SHC program with respect to the GECP.

This chapter presents some of the problems with the SHC program that have caused the delays the program faces. The production delays are significant and have been caused by several things including the current state of the SHC engineering change process. This problem impacts the purchasing department (MMD) greatly because they do not have proper visibility into the change process that would allow them to determine which parts will need to be ordered in the future.

Furthermore, this chapter will look examine one of SHC purchasing's major metric: the part shortage metric (a part shortage is when a part needed by manufacturing is not in stock to support a manufacturing activity). In order to diagnose the root cause of the shortages created by engineering change, a parts case study was completed to map the average development timeline. After discussion of the parts case study, the root causes of the case study results are discussed.

### **4.1 Delays**

There have been delays in the engineering change process (the GECP) throughout the history of the SHC program. Specifically, there have been delays in processing both ECRs and ECNs due to the volume of these documents passing through the engineering groups and change boards. BSS predicted that it should take no longer than 8 days to complete an ECR and 17 days to complete an ECN. However, the actual completion times for each ECR and ECN average 33 days and 67 days (all numbers normalized for the actual flow through ECR and ECN stages to add up to 100. Predicted flow multiplied by same factor), respectively, a factor of four times what was originally expected. The current state of the GECP could be due to several reasons including, but not limited to: the quantity of engineering changes, BSS's available manpower, and the focus of the changes.

#### **4.1.1 Quantity of Change**

As with any forecasting, BSS's initial change forecasts for the SHC had a wide range. This is expected as the new supply chain and engineering structures had not been used in BSS coach or at the partners, so there was no precedence to base any forecast on. Many people in management interviewed feel that the number of changes that have been approved for implementation by the SHC program has been on the high end of the forecasts, if not greater. There is little data which shows average number of changes for legacy buses due to their change processes being paper based during ramp up. However, many managers feel that the number of changes to date through the SHC program has been greater than the number of changes impacting any other legacy program during their respective ramp up. What is known is that legacy programs' change notices focused on design improvement situations, correcting engineering mistakes, and weight reduction during ramp up. The SHC program has the same three causes of change but there are two additional causes for ECNs: traveled work and out of sequence installation changes.

#### **4.1.2 Engineering Resources**

A second potential cause for the current change flow time may be due to the fact that there may not be sufficient resources to properly manage and work the quantity of engineering changes. In a situation where management predicted that 600 parts would be received into BSS FID for SHC manufacturing number (M/N)<sup>21</sup> 1 but 15,000 parts were actually reportedly received from the partners, it can be assumed that management did not have the necessary manpower at hand to tackle this situation. Although this situation occurred significantly before the writing of this thesis, BSS may not have been able to successfully pull itself completely out of the hole created by M/N 1 because of the continuous addition of other traveled work from delivery of successive busses (i.e., M/N 2+) and sufficient engineering talent may not have been available to fully address this problem.

#### **4.1.3 Additional Change Types: Traveled Work and Out of Sequence**

A third potential cause is the nature of the changes. Both traveled and out of sequence work are accounted for on ECNs because the change process is used to manage

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<sup>21</sup> Manufacturing number (M/N) refers to the number in the order of bus production. SHC M/N 1 would be the first bus built and tested (not necessarily delivered due to the first 3 busses being for lengthy test programs).

all work statement transfers (i.e., manufacturing responsibility transfers from a partner to BSS FID). This includes transfers that may be permanent or may be temporary (i.e., a certain range of busses – say M/N 4-10 – may have the same traveled work jobs transferred from a partner to BSS FID).

With the addition of traveled work and out of sequence installation as prominent engineering change causes in a new supply chain paradigm, BSS may not have the experience dealing with these new types of changes (on legacy programs, major traveled work occurred when the bus moved from one place in the BSS factory to the next step, making traveled work easy because the teams were collocated). Adding to the problem, they also may not have had all the engineering information necessary to rapidly correct the situation. They may not have had the necessary engineering information because BSS does not own a lot of the SHC's engineering and, therefore, lack the product life cycle data to determine the engineering intent of the traveled and out of sequence work. Without the engineering intent, BSS engineers would either have to contact the partner engineer responsible for the design of the part(s) or potentially need to reengineer the parts to gain the required information in order to disposition the ECN. This situation would tend to increase the performance time of any ECR or ECN.

A specific example of this situation reported in the press occurred when the VBS section of M/N 1 was delivered to the Everett site. Along with the large bus section also came dozens of crates filled with parts which were supposed to be installed by VBS but were not. The crates did come with instructions on how to install some of the parts, but they were either insufficient installation instructions or were written in a language other than English. There were some parts that were supplied without any installation instruction at all. This is the environment the SHC program faces because engineering has been outsourced to partners, an environment which BCB had never experienced.

#### **4.2 Engineering Change Part Visibility**

One of the major problems that the SHC program has been facing is visibility into the change process. Some of the stakeholder groups, namely MMD, have found it difficult to timely determine which parts are required for purchase from ECNs. Continually, there were instances where ECN part purchasing information did not flow downstream to MMD for purchase until it was too late to purchase the part outside of lead time. There have been

extreme instances where MMD was informed of the part need the same day that manufacturing requested the part for installation on the bus. However, the most common situations have been where MMD is not informed of the need to purchase a part until within lead time.<sup>22</sup> Any delay in steps 1-7 of Figure 4 (e.g., late engineering release) can be a cause of an impingement on the part's lead time.

When situations occur that cause BSS to order within lead time, BSS must either pay expediting fees to receive the part on time or delay manufacturing activities. BSS often chooses to delay the manufacturing activity and, when this happens, it creates a part shortage. Part shortages occur when a part is needed for a manufacturing job but one or more of the required parts are not in stock. One shortage occurs for each unique part number that is not available to complete the manufacturing job. Hence, if a single manufacturing job for a single M/N is short seven parts, but four of the parts are one unique part number, two of a second and one of a third, the total shortage count will be three with a quantity of seven. Change is not the only cause for a part shortage as shortages occur for a myriad of reasons. Other reasons that cause a part shortage include supplier delays, rejection tags, and shipped short orders (i.e., installation kits shipped missing a part or parts).

#### **4.2.1 Shortage Metric**

The total number of active shortages is one of the major metrics which SHC MMD is judged on. When shortages are inordinately high, upper management looks to MMD leadership to correct this problem. An extreme example of an inordinately high shortage count occurred in 2007 when the SHC program was short over 5,000 fasteners, as reported in the local media. Figure 6 shows this metric which MMD is judged on. It is a graphical representation of shortages on the SHC program over a period of time.

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<sup>22</sup> BSS is within lead time if the lead time is greater than the number of days between purchase date and manufacturing need date

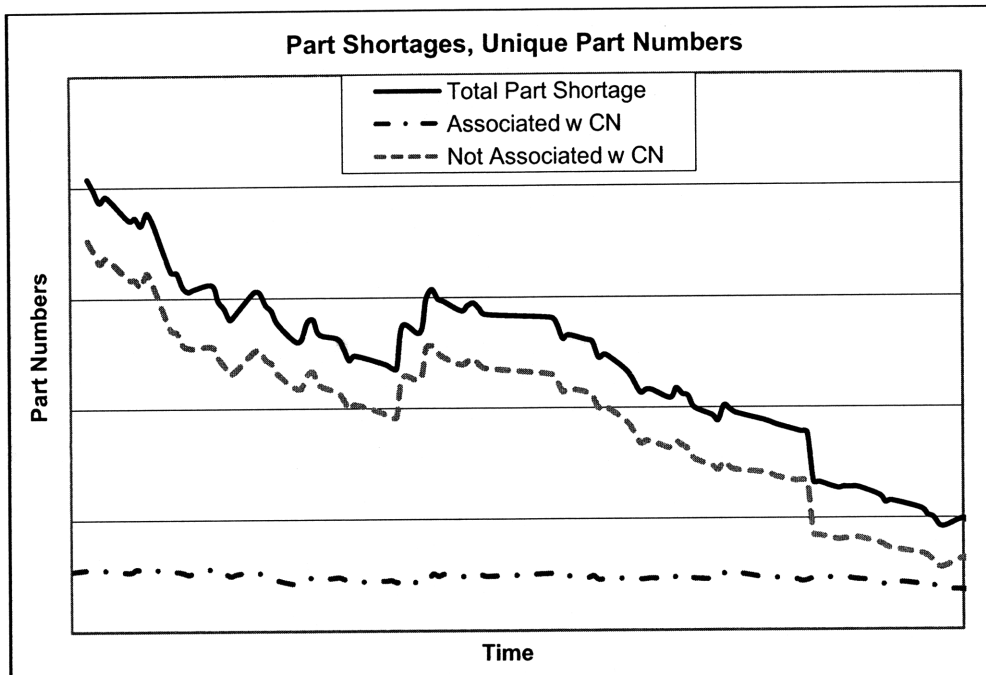


Figure 6: SHC part shortages broken out by engineering change associated and no engineering change association

The three lines on Figure 6 represent the total number of shortages, number of shortages associated with an engineering change (change shortages), and the number of shortages not associated with an engineering change (non-change shortages). Essentially, a change shortage is a shortage that is associated with a part number that was added to the bus definition by an engineering change (i.e., it wasn't in the baseline design). A non-change shortage is associated with a part that was part of the baseline design.

As can be seen, the total number of shortages has substantially decreased over this time period. The number of non-change shortages seems to mirror the decrease of overall shortages. This would suggest that the SHC program is doing an effective job improving their shortage position with respect to non-change shortages. This is what is expected at the end of the ramp phase of any product design and development project: gradual improvement. As the design becomes closer and closer to the final configuration, issues resulting from the original design (whether they are due to part shortages, engineering changes, etc.) decrease over time as the wrinkles are ironed out and more knowledge is gained on the product.

However, as can be seen in Figure 6, change shortages do not seem to improve. This data series remains relatively flat, with only a negligible downward trend. This would suggest that parts associated with engineering change are not responsive to the current

initiatives aimed at reducing these shortages and that these shortages are still at the beginning stages of the ramp up phase because there is not a downward trend (a horizontal curve means that as soon as shortage is cleared, there is another new shortage to take the place of the cleared shortage. At the end of the ramp up phase, there should be a downward trend as more shortages should clear than should open. This, therefore, suggests that the change process has not reached the end of the ramp up phase). In order to reduce change associated shortages, something else is needed in order to improve these shortages associated with engineering change in order to see the same trends as the non-change parts. A graph of the number of manufacturing jobs affected by shortages has similar trends as those in Figure 7.

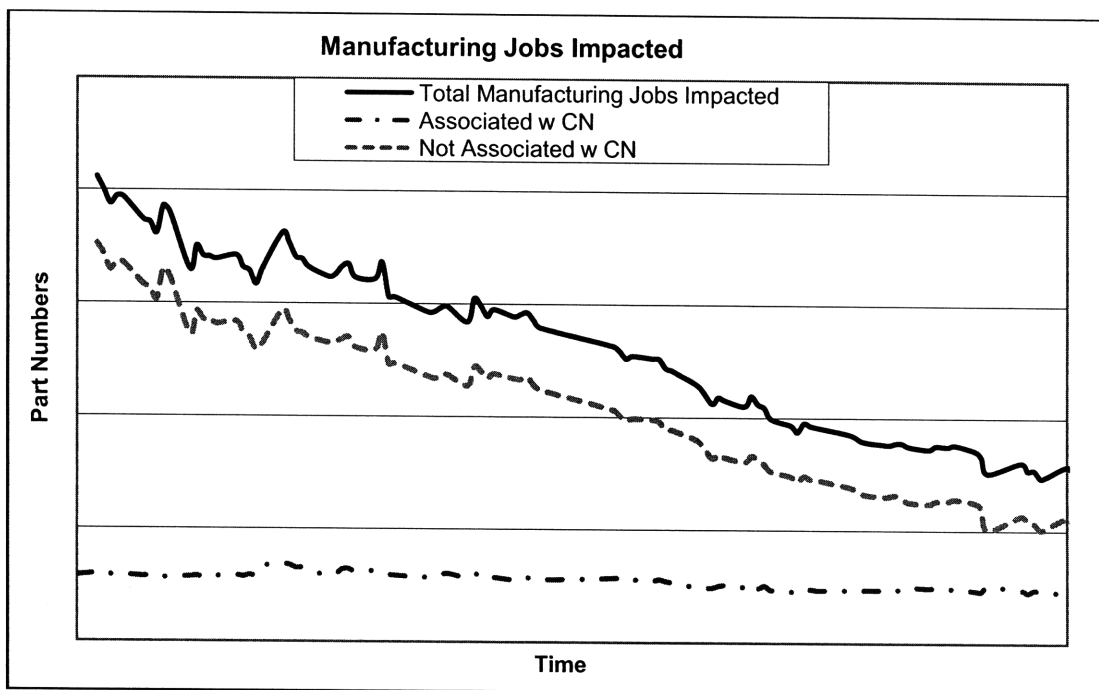


Figure 7: SHC manufacturing job delay breakdown for jobs affected by shortages

As can be seen in Figure 7, there is an improvement in the number of manufacturing jobs delayed by non ECN issues while the number of jobs affected by ECNs has remained relatively, flat just as Figure 6. Figure 6 and Figure 7 would suggest that, even if ECN shortages are being cleared, there are new ECN shortages occurring affecting just as many manufacturing jobs as there are being cleared, creating a cyclic effect in the system. If the non ECN shortages continue to improve at the rate reflected in Figure 6, ECN shortages will soon dominate the shortage metric and will be the deciding factor in driving further schedule delays. In order to improve the ECN part situation, these shortages must be

prevented from ever happening. This can be accomplished by ordering earlier in the process.

### **4.3 Engineering Change Parts Case Study**

A case study was completed in order to understand the root cause of the part shortages associated with engineering change. A sample was taken on a random day during the internship and studied for average flow times through the GECP.

#### **4.3.1 Engineering Change Parts Case Study Procedure**

##### **4.3.1.1 Sample Generation and Criteria**

The BSS shortage tracking program (referred to as STRACK) was used to determine the part numbers considered a shortage on the randomly chosen day. The criteria used to determine which parts are impacted by engineering change are as follows: a field in STRACK known as installation instruction contained the letter combination ECN (typically FIDECN) and/or a change notice number was associated with a given shortage record. Once all part shortages associated with engineering changes were determined, flow times through the engineering change process had to be determined.

##### **4.3.1.2 Determining Associated ECRs and ECNs**

In order to determine flow time, the first step was to determine the ECRs and ECNs associated with each shortage record. This was completed by using the CAD and CAM systems to locate the ECN(s) associated with the shortage record. The CAD system was used with the part number associated with the given shortage record to determine what ECN created the part. The CAM system would be used with the installation instruction number to determine the ECN associated with the creation of that installation instruction. Commonly, the ECN that created the part did not match the ECN that created the installation instruction. This is reasonable because parts can be used in several different locations throughout the bus, but the part may have been initially created for another installation instruction but was found to be useful in another application later in program development.

In order to determine the ECR associated with the ECN, each ECN document was opened from the SHC ECN database. Each ECN must have a referenced ECR in its contents as an authority to proceed with the ECN.

#### **4.3.1.3 Determining Step Flow Times**

In order to determine the flow times in each step of the change process, the document created at each step was opened and the start/finish data mined out. The ECR duration for each ECR impacted by the shortage record (one from each the CAD and CAM data, or one for both the CAD and CAM data, if ECN number matched) was calculated by accessing the ECR in the ECR database. The duration of the ECR step was calculated by taking the change board approval date of ECR and subtracting the ECR open date, both in the ECR document.

The ECN duration was calculated in the same fashion as the ECR duration. ECN duration was calculated taking the authorization (approval to proceed with change implementation) date and subtracting the ECN open date. In certain situations, ECNs had yet to be fully authorized but had been partially authorized at some point in the history of the ECN. In these situations, it was assumed that the partial authorization date was the date that approved the part or installation instruction for implementation. If the ECN had both a partial authorization and full authorization event in the history, the part or installation instruction ECN approval date was investigated to determine if the part or installation instruction was authorized through the partial or full authorization event, then the duration calculated accordingly.

The CAD system was used to determine the duration of part design. Creation and approval date were available in the CAD data for each part. Duration was calculated by subtracting the creation date from the approval date.

The CAM system was used to determine the approval date of the installation instruction. The remarks section of the installation number data file provided the approval date for each revision of the installation instruction. Revisions typically were used to change (typically add) effectivity of the installation instruction (i.e., if the installation instruction was initially assigned to M/Ns 1-3, but needed to be extended to include M/N 4, a revision of the installation instruction would be completed to extend effectivity to M/N 4). The revision data would be used to determine which revision of the installation instruction impacted the respective shortage record (each shortage record included M/N data).

The duration of installation instruction writing could not be determined from the information given in the CAM system. However, there is a standard completion time for installation instruction writing and approval on the SHC program. This time was used as the average duration for all installation instruction writing to approval. Although various interviews did yield a range for actual completion times, this information was qualitative and did not provide a distribution across this range. And since sufficient quantitative data could not be found in order to properly calculate an average installation instruction writing duration, the standard completion time was therefore assumed to be a sufficient estimate of average completion time.

Data from the STRACK program was used to determine when the shortage record was created. Data about purchase order date was not provided in the shortage records and, therefore, purchase order date could not be determined. Each shortage record was then tracked on a daily basis in order to determine if and when the record had cleared (i.e., the parts were received). Once the record had cleared, the duration of the shortage could be calculated.

Once all data was accumulated, records with insufficient information were eliminated. Situations where records were eliminated due to insufficient information include, but are not limited to:

- Installation instructions did not contain the necessary approval information
- Shortage records did not contain an installation number (i.e., the field could be filled with a temporary value which would include the letter combination ECN)
- CAD and CAM data did not provide ECN numbers
- CAD and CAM ECN data was incorrectly referenced in documents (typically associated with incorrectly inputted numbering)

For the remaining shortages with sufficient information, the data was then averaged across different groupings of the sample. Groupings were generated by comparing commonalities across the different records' data sets. The different groups were formed because the data behind each grouping is fundamentally different and the groupings were formed in order to avoid skewing the data due to differing circumstances. The different, mutually exclusive groupings are as follows:

- All records with committed ECNs and installation instructions (considered “normal” parts in the case study)
- All records with uncommitted ECNs in either the CAD, CAM, or both databases (essentially, they are changes that have yet to be authorized for incorporation on an bus but work has started)
- All records without an installation instruction currently approved against either the installation instruction number or line number associated with the record. The first occurs when an installation instruction number has been determined but it has yet to be approved. The second happens when an installation instruction is approved for certain line numbers, but has not been extended to the line number reported by the shortage record.
- All records that are associated with standard parts (parts which are widely used throughout the bus – examples would include standard fasteners)

#### 4.3.2 Sample Defining Data

There are several ways to characterize the data to show the true picture of what the sample consists of. Firstly, of the total shortage records which conformed to the search criteria, 42% had sufficient data to provide a full picture of the current state of the change process. Of this 42%, Figure 8 below shows the breakdown of ECR data.

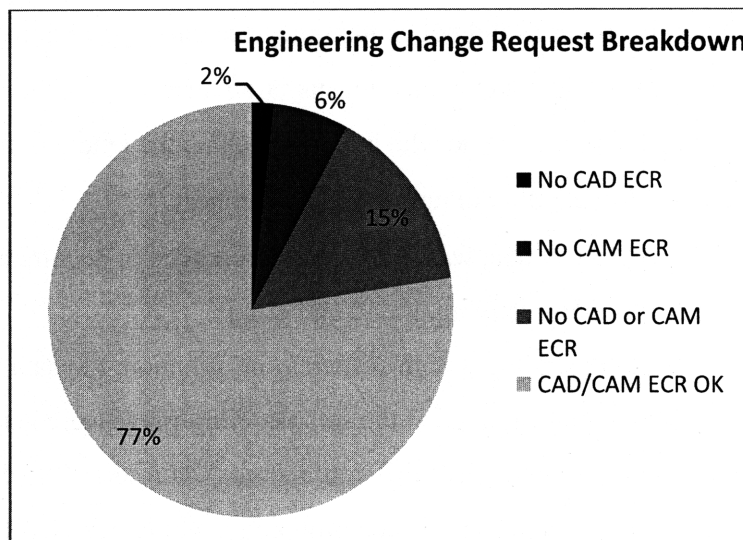


Figure 8: ECR data breakdown for the 42% sample

Figure 8 shows that a percentage of the records did not have useful ECR data (i.e., dates were missing from the ECR report) or the ECR data could not be found. These

records were still considered as part of the sample because the ECR step is not a defining step and is relatively minor when executing the actual change. However, these nonexistent ECR date values were omitted from the averages across the sample (i.e., there were no unnecessary values of zero included in the sample averages). This is significant because the data related to the ECR duration reflected in the parts case study results do not go across the entire sample. Should the ECR data exist for all parts in the sample, then the results could potentially be different. However, this effect is considered negligible. It is important to note this because the steps downstream from the ECR step have been included in the final sample averages for the parts case study, even if they didn't have the necessary ECR data.

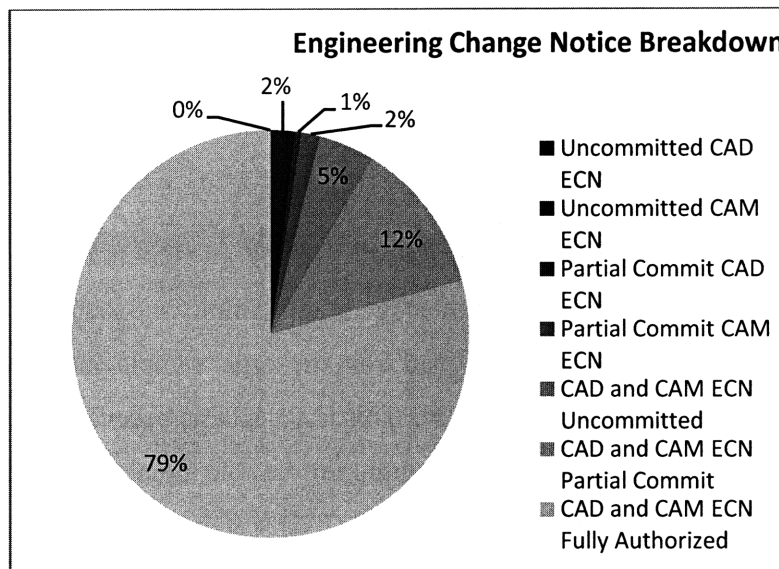
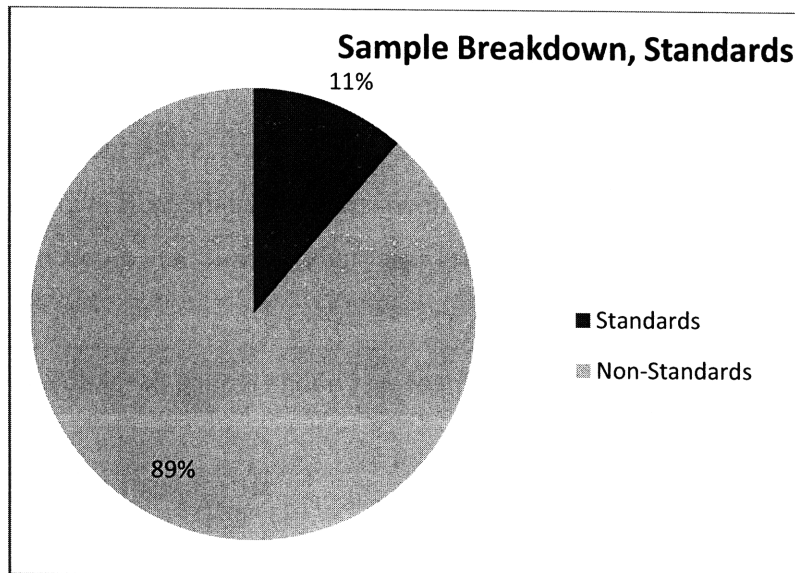


Figure 9: ECN breakdown for 42% sample

Figure 9 shows the breakdown of the ECN status for the sample. It is interesting to note that a small percentage of the shortage records are associated in some way with an uncommitted ECN, either in the CAD, CAM, or both. This is important to note because, by FAA regulation, parts associated with these changes cannot be installed on the bus until the ECN is authorized.

There is a larger percentage of the sample that is associated with partially committed ECNs. This is considered acceptable because parts of the ECN are authorized for incorporation. As stated before, it is assumed that all parts associated with a partially committed ECN are related to the sections of that ECN which are committed. This is significant because it is a big assumption. There are typically several revisions in the

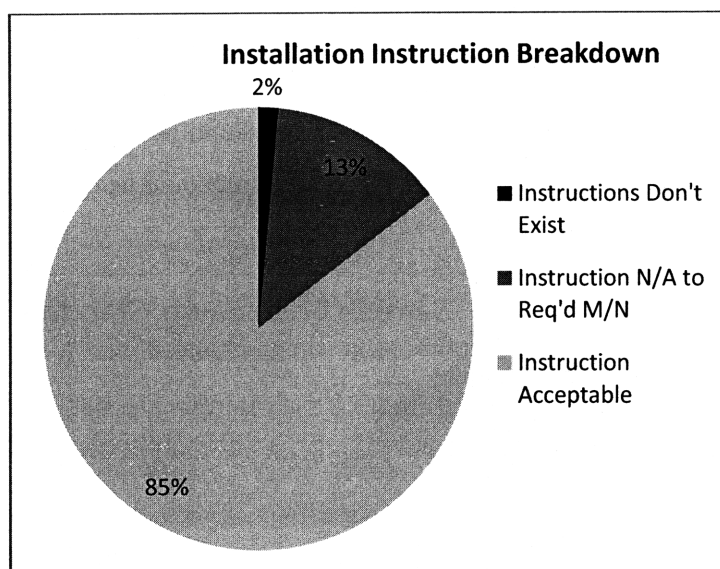
ECNs life where the ECN is at a state of partially committed. There is a chance that parts would be approved in a partially committed revision other than the first one (i.e., the start date is reflected as earlier than it actually was). This assumption has the potential to skew the data, making the average ECN step shorter than actually reflected.



*Figure 10: Standard vs. Non-Standard breakdown for 42% sample*

Figure 10 shows that a small percentage of the sample is associated with shortages of standard parts. These items were removed from the larger sample because the CAD data typically does not associate with an ECN. This is acceptable because these parts are typically designed much earlier in the program for the sole intent of using many times across the bus. The lack of ECN data from the CAD system is, therefore, expected and accepted as normal.

This is a significant variable because these parts are inherently different from the other 89% of the parts because they are used commonly throughout the bus. Since they are so common (i.e., they may have a standard stock level with a reorder point), the cause for these shortages could be significantly different than the cause for any of the other parts groups (e.g., improper ordering rather than late engineering release).



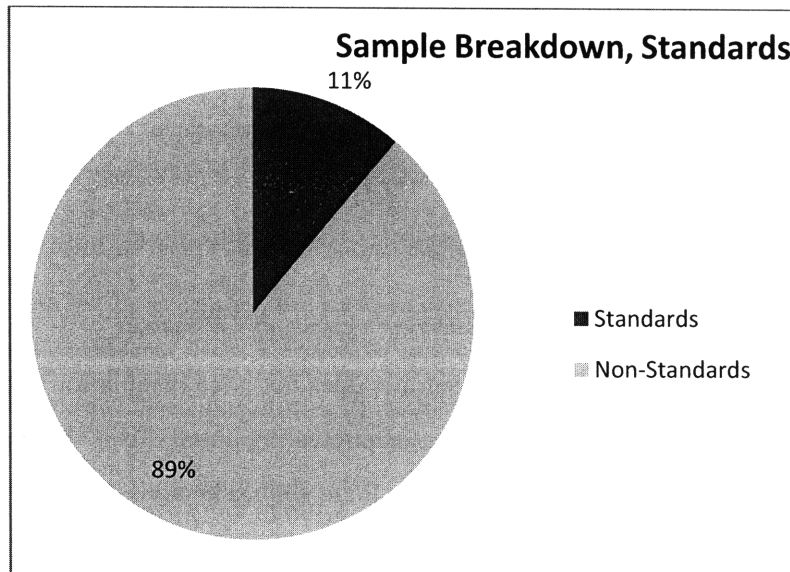
*Figure 11: Installation instruction breakdown for 42% sample*

Figure 11 shows that 15% of the sample does not have installation instructions written to cover the shortage record. What is interesting about this is that, without the installation instruction written and approved, there should be no demand in the BSS ERP system, and there is nothing driving the issue of a PO. Essentially, this means that there is a manufacturing need for a part that does not have the installation instruction written to install the part and no demand in the ERP system telling MMD to purchase.

Aside from characterizing the breakdown of ECN data, there is another aspect which needs to be examined. Following the completion of the study, there were several shortage records which remained open for the duration. Figure 12 shows the breakdown of the records closed vs. the records which remained open at the conclusion of the study.

To properly explain the significance of the data in Figure 12, in a hypothetical situation, say the randomly chosen day was July 1. On July 1, the sample was taken of all the parts which were considered “short” in the STRACK program, totaling 100 parts. Of this 100 parts, 42 of the parts had sufficient information for the parts case study (i.e., the 42% defining the parts case study). These 42 parts were the focus of the study throughout the duration of the study (i.e., no more were added as new shortage reports were created in the days following). If the study ended on August 1, of the 42 shortage records in the sample, 81% (or 34) of the part shortage records had been closed (i.e., the parts for these 34 records were received by BSS FID, therefore satisfying manufacturing need). However, at the end of the study there were still 8 parts which had not been received.

These 8 parts were split out from the 34 because their shortage duration is unknown because there is no way to tell when the close date for these will be. This will hopefully prevent significant skewing of the data. However, it should be noted that if the study was of a sufficient length, the true average shortage duration could be calculated and would be a better gage of the duration.



*Figure 12: Shortage record status at the conclusion of the study*

Figure 8 through Figure 12 each have the ability to skew data slightly. In order to minimize the impact of the data in Figure 8 through Figure 12 on the results of the parts case study, the data from the sample was split up into four different categories, two with sub groups, for proper analyzing.

#### **4.3.3 Study Results**

Each shortage record was characterized based on the data that could be gathered for the engineering change parts case study. These four groupings are as follows:

1. Normal Parts – parts which provide sufficient data that are not standard parts, do not have uncommitted ECNs against them, and do have an applicable installation instruction. New parts are broken down into two subcategories as follows:
  - a. Parts with closed shortage record at end of study
  - b. Parts with open shortage record at end of study
2. Parts with an installation instruction (termed IP in Figure 13) which either doesn't exist or is not yet applicable to the M/N reflected in the shortage record. Parts without installation instructions are broken down into two subcategories as follows:

- a. Parts with closed shortage record at end of study
- b. Parts with open shortage record at end of study
3. Parts with an uncommitted ECN against the CAD and/or CAM records (no open shortage at end of study)
4. Standard Parts (no open shortage at end of study)

Figure 13 below shows just how each one of these groups is reflected in the sample used for this study.

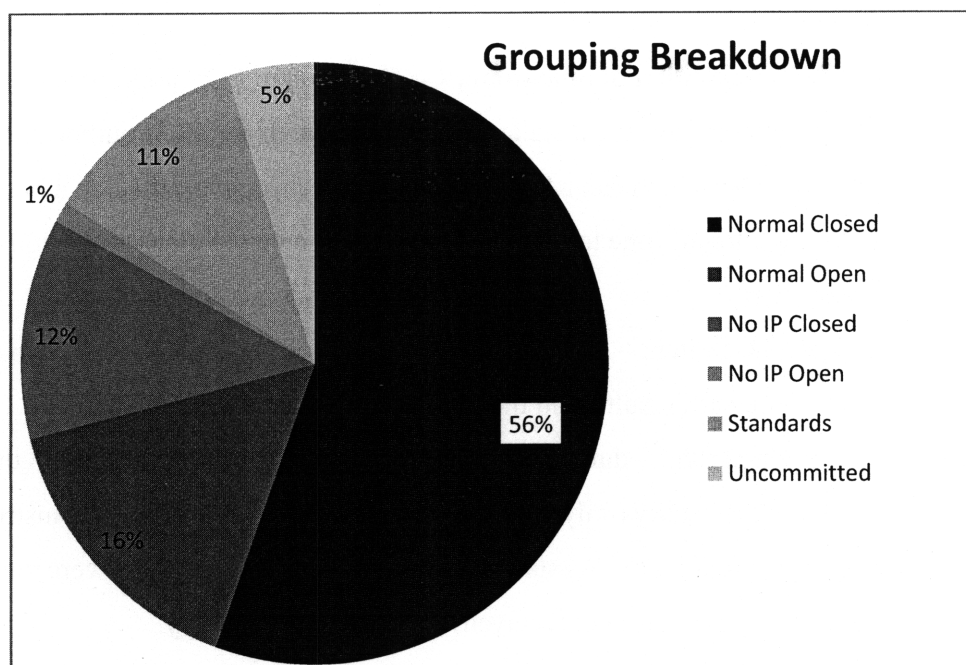


Figure 13: Breakdown of the sample into the individual four groups (two with subgroups)

Once each record is characterized as a member of one of the four groups, the groups are taken as a whole and averaged to create a “change map.” The change map shows the flow characteristics of that group. A change map used in this study is a Gantt chart representation of the durations of each step in the change process, where activity durations are represented by a black bar. Queues (i.e., time between steps that products are not in work) are represented by the white areas between successive steps. The change map represents the change process steps in the following order:

1. CAD ECR – duration of time from ECR begin writing to ECR approval by change boards. This ECR is responsible for part creation.

2. CAD ECN – duration of time from ECN initiation to ECN authorization to schedule the part creation and approval in CAD. Upon authorization of the ECN, the CAD can be officially approved.
3. CAD – duration of time to create the part in CAD, from part creation to part approval.
4. CAM ECR – duration of time from ECR writing to ECR approval by change boards. This ECR is responsible for creation and approval of the installation instruction.
5. CAM ECN – duration of time from ECN initiation to ECN authorization to schedule authoring of the installation instructions. Upon ECN authorization, the installation instruction can be approved, and the change installed on a bus.
6. CAM – duration of time to create and approve the installation instruction in the CAM system.
7. Shortage Closed Item – duration of time from shortage record creation to the receipt of the part, resulting in the closing of the shortage record.
8. Shortage Open Item – duration of time from shortage record creation to the end of the parts case study (only applicable to normal and no installation instruction written part groupings). As stated earlier, these shortage records were not cleared (i.e., parts were not received) by the end of the study.

#### **4.3.3.1 Normal Parts**

Figure 14 shows the results of the parts case study for normal parts during the ramp up phases of the SHC program. Note that the total duration has been normalized to 100 in order to protect the sensitivity of the data.

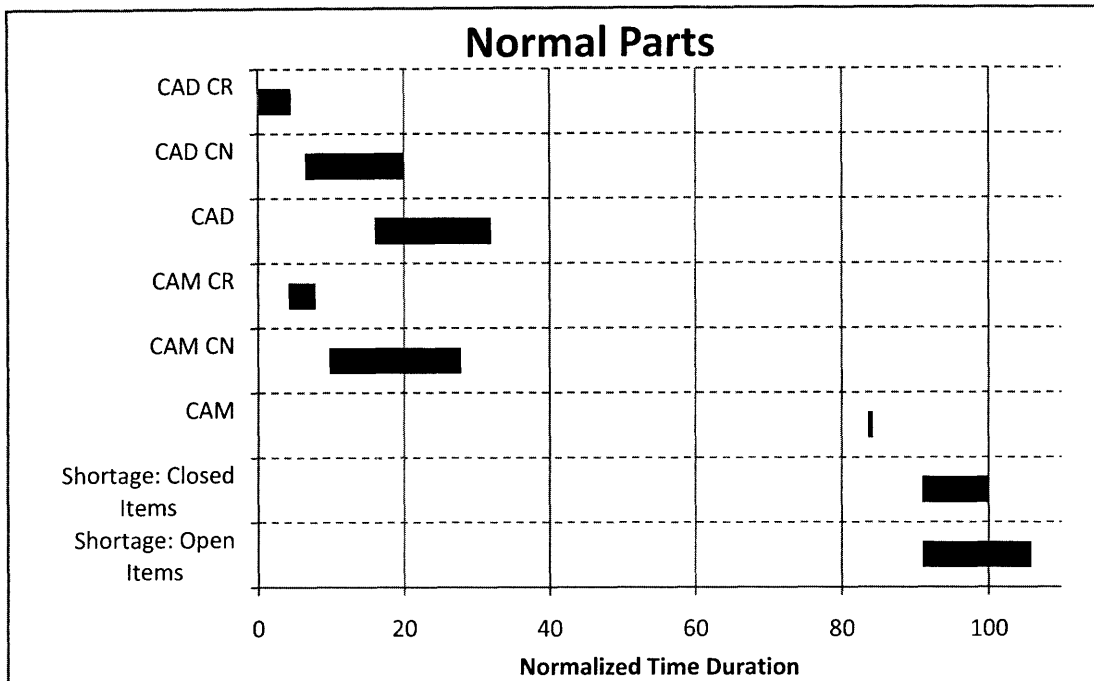


Figure 14: Parts case study normalized results for normal parts during SHC ramp up

The Gantt chart in Figure 14 shows that there is a significant delay between the completion of the CAM ECN and the start of installation instruction writing (for simplicity, termed CAM in Figures 14 through Figure 17), accounting for 52% of the overall total flow time. There is also a significant duration in time between the completion of the installation instruction (end of CAM) and the opening of the shortage record (5-10% of the total flow time). This would suggest that there was a duration of time between when the purchase order was placed and the need date by manufacturing. Accordingly, the amount of space between installation instruction approval (end of the CAM bar) and shortage report start date (beginning of the shortage bar) could have been increased by moving the installation instruction writing to the left. It would be anticipated that a PO would be placed earlier resulting in a decreased duration of the shortage record bar.

In addition, there were a small number of shortage records which remained open at the end of the study (in Figure 14, these are termed "Shortage: Open Items"). These items were split from the remainder of the data for the shortage step only in order to more properly reflect the shortage duration. Since the closing date of the open shortage records is unknown, it would not be prudent to leave this data in the same category as those shortages which have a known closing date. The data in Figure 14 was

normalized to the average end date of the closed records, which is why the data for open items extends past 100. All other data (e.g., ECN, ECR, CAD, and CAM data) for open shortage record items were aggregated with the data from the closed shortage record items. This is acceptable because the only aspect that is truly different between these two groups is the closing date of the shortage record. If these records had closed a day before the study had ended, there would be absolutely no difference from the closed items. The end date of the study cannot define the data or the grouping.

It is also interesting to note is that there is significant overlap between the CAD ECN and the CAM ECN. This would suggest that a significant number of the parts in this sample are governed by the same ECN for both the creation of the CAD part and the creation of the CAM installation instructions. However, if all the parts were governed by the same ECN for both CAD and CAM work, the two bars would match perfectly. Since there is a significant overlap, it is reasonably valid to assume that over half of the parts are governed by the ECN for both the CAD and CAM work (this is an acceptable assumption because averages were used for this study). It will be seen in the following sections (see Figure 15 through Figure 17) that the other groups do not have the same tendency across CAD and CAM ECNs.

#### **4.3.3.2 No Installation Instructions Applicable**

Figure 15 below shows the parts case study results for any part shortage reports associated with an installation instruction number that is either not written (or approved) or the existing installation instruction number has yet to be extended to the M/N reported in the shortage record. This figure reflects changes during the ramp up phases of the SHC program.

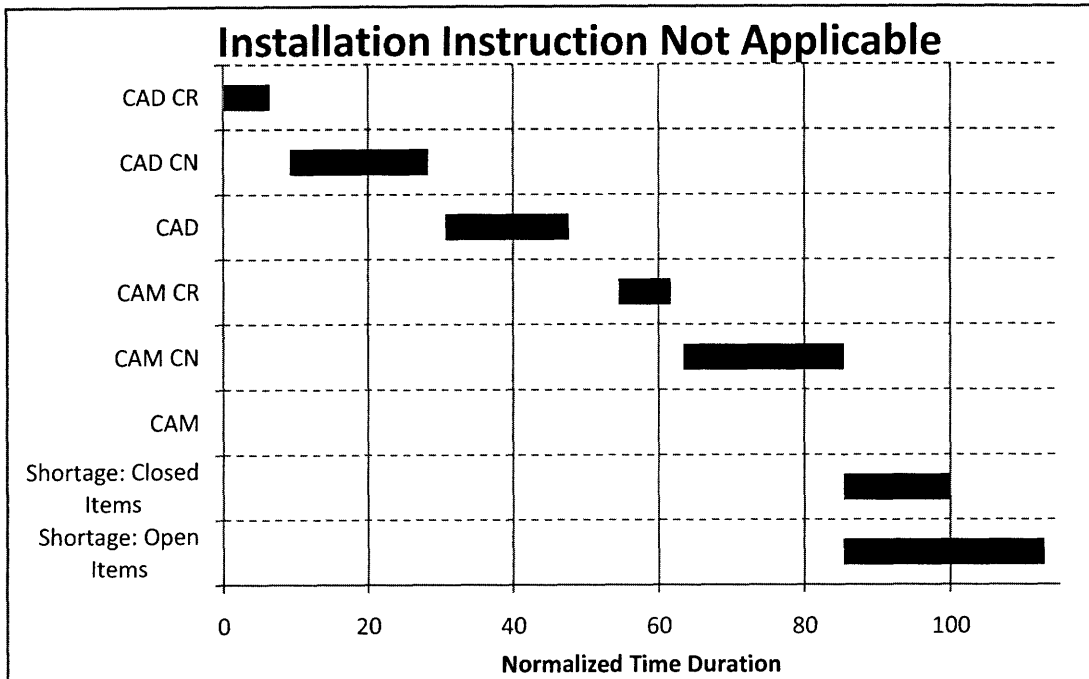


Figure 15: Parts case study results for items without an applicable installation number during SHC ramp up

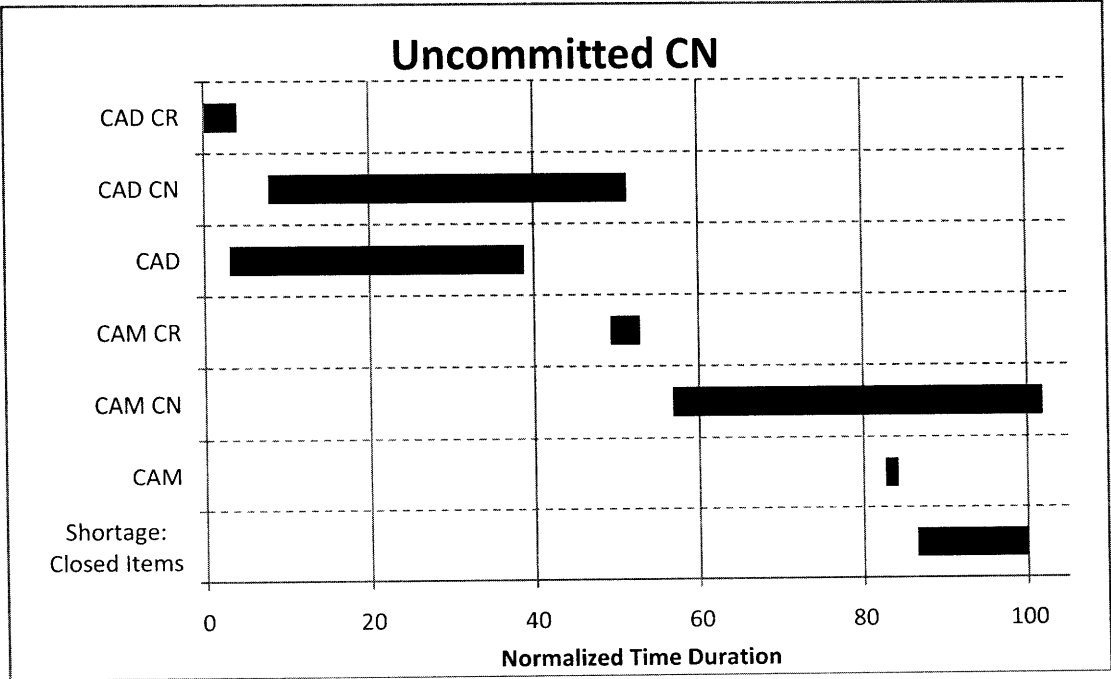
The CAM step has been left blank in the above figure due to the fact that data does not exist representing the CAM step. Shortage records that exist in this state are odd in that they should “technically” not exist. In order for a shortage to exist, there should usually be demand in the system. However, it is known that there is no demand in the system for these parts because the demand is created by an approved installation instruction and, since there is no approved installation instruction, there cannot be demand in the ERP system.

In normal situations, once an installation instruction parts list is approved, the CAM system then feeds the information to the ERP system, which creates a need, or demand, for the given parts. This tells the purchasing individual that the SHC program needs a number of parts X, Y, and Z. The purchasing individual then places purchase orders with the supplier for the given part (if on contract, if not contracting will put a supplier on contract for the given part) with a need date of delivery to BSS. In the circumstances of Figure 15, without this demand in the ERP system, there must be something informing the purchasing individual that a purchase order is needed for the part. There are paper based workarounds of the automatic system such as advanced ordering procedures and engineering memos. This is what is assumed to be driving the shortage records here, potentially due to urgency of the ECNs behind the data.

It is interesting to note in Figure 15 that the shortage records were created immediately following the commitment of the CAM ECN. This would suggest that the ECNs applicable to these shortage reports are either behind schedule with respect to the manufacturing need date, or are just “very hot” ECNs. These ECNs may be important ECNs that are needed to support critical milestones and the turnaround time for the change needs to be very quick (i.e., management wants to get the applicable parts onsite as quickly as possible rather than wait until the installation instructions are completed. To circumvent this step, management manually creates these shortage records as a driver to complete purchasing).

**4.3.3.3 Uncommitted ECN**

The parts characterized in this group have an ECN applicable to CAM data in the ECN database where the latest revision available at the end of the study is uncommitted. An uncommitted change has yet to be approved for implementation on any bus by the CB(s). However, sometimes partners get ahead of the work before full commitment so that engineering is ready for implementation once the ECN is approved. Figure 16 shows the parts case study results for the uncommitted ECN parts during the SHC ramp up phase.



*Figure 16: Change part case study results for parts without committed ECN during SHC ramp up*

This is a very small percentage of the parts as can be seen in Figure 9 (around 2% of the sample). These parts cannot technically be installed on the bus because DOT regulation does not allow an ECN to be incorporated shipside unless the ECN has been committed. However, these parts could be for other manufacturing jobs involving subassemblies in the shop (i.e., it is possible that the jobs reflected in Figure 16 are jobs done in the shop manufacturing subassemblies to be installed on the bus when the ECN is authorized). Even though these subassemblies cannot be installed on the bus until the ECN is committed, these shortages could ultimately have the potential to delay shipside manufacturing jobs if subassembly shop jobs are not completed on schedule, before the ECN is committed. In other words, shortages that occur in this situation may not delay shipside manufacturing activities immediately, but delays can cascade down over time, leading to a delay in shipside manufacturing activities in the future, once the ECN is committed.

It is interesting to note that the average CAD work reflected in Figure 16 starts before the ECN is ever opened and finished significantly before the CAD ECN is authorized. Additionally, there is overlap between the CAD work and the ECR work before the ECR is approved. This would suggest that the CAD work was started to support the ECR during the initial CB reviews. It also may be due to the fact that these changes are so critical to the manufacturing schedule that management wants to get ahead in order to mitigate the risk of missing important milestone requirements.

#### **4.3.3.4 Standard Parts**

Standard parts are used widely across the bus and include such parts as standard fasteners, shims, fillers, etc. What makes these parts different from the normal parts group is that they were designed early in the program and have been used widely throughout the bus. Figure 17 shows the change parts case study for the standard parts.

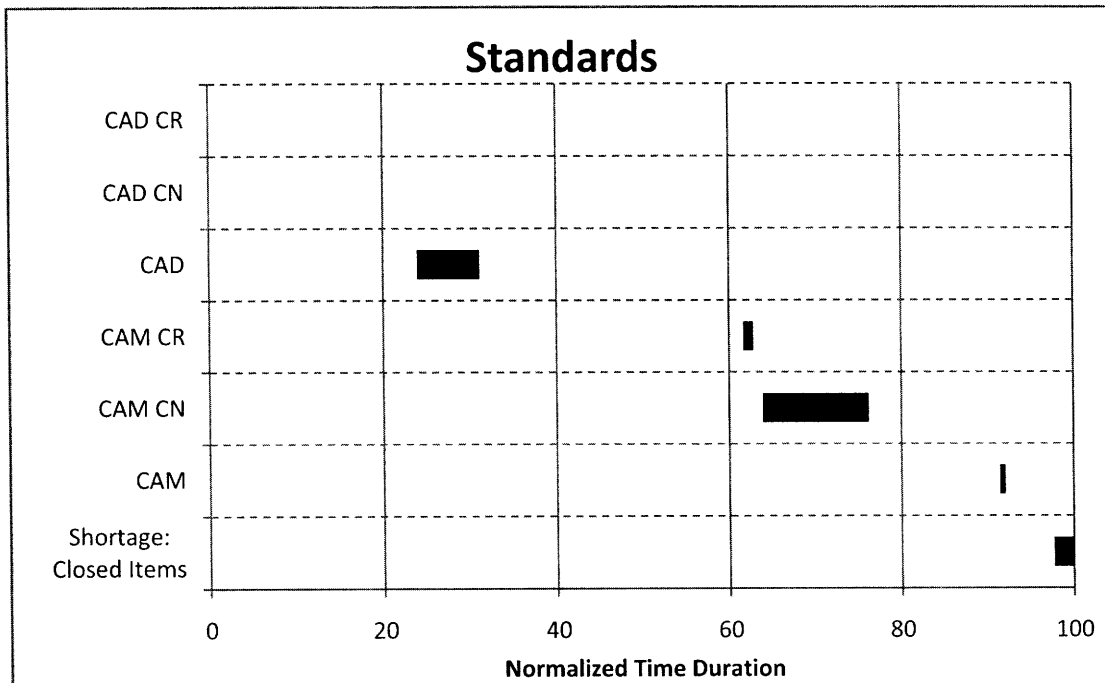


Figure 17: Part case study results for standard parts during SHC ramp up

Figure 17 reflects no duration for the CAD ECR or CAD ECN. This is because the authority to create these parts in CAD was not by a true ECN. The ECN typically referenced in the CAD history was the ECN that was an authority to begin and schedule the SHC program during the program's infant stages (they were part of the original configuration). These parts were designed for wide implementation and therefore did not address a change to the original bus configuration at the time of creation.

The CAM durations in Figure 17 are much more useful. Figure 17 shows that the CAM ECN is significantly after the creation of the part. This means that the shortages that the shortage record addresses were not part of the baseline design and the parts were added later in SHC development through engineering change. This is also verified through the search criteria used to generate the sample, which required an ECN letter combination in the installation instruction field.

The same situation exists in Figure 17 as does in Figure 14, a significant time delay between the end of the CAM ECNs and the start of the installation instruction writing in the CAM step.

There is no conclusive evidence from Figure 17 as to the cause of the standard parts shortages. There is significant uncertainty because of the nature of these parts.

#### 4.3.3.5 Part Case Study Conclusion

It can be concluded that the root cause of the majority of shortages is due to the large delay between the CAD work/CAM ECN authorization and the start of CAM work, which ultimately creates demand in the ERP system. With more prudent action from the ME department to complete the installation instructions earlier, these shortages could be reduced, or even avoided. Note that there is some CAD work that is involved in between the CAM ECN and CAM steps which is not reflected in the part case studies (due to lack of information), but this work is considered minimal. This work typically involves taking parts created in the CAD step (not actually creating the part in CAD), adding a unique part instance number (unique to that part usage on the bus) linked to the base part number and then incorporating it in a CAD document. Once this document is created, it is sent over to MEs for the CAM work (installation instruction writing).

Potential improvement to this large delay before installation writing (which ultimately delays part ordering) is to extract the information essentially at the end of the CAD step. As can be seen specifically in Figure 14, the CAD work is completed just after the CAM ECN is authorized. On average the CAD work is started just after the CAM ECN is opened and is finished soon after the CAM ECN is authorized, but the average CAD work is always finished significantly before the CAM work is started (i.e., installation instruction writing). The delay after CAD work completion (before starting CAM) allows a significant opportunity for purchasing to get ahead.

Similar conclusions can be made from Figure 15 through Figure 17 for those groupings. However, the large delay before CAM work is constrained by the end of the CAM ECN, rather than the CAD work. Strategies may have to be adjusted to account for these situations.

Note that in Figure 14, CAD work on average is finished after the CAM ECN is committed. However, the CAM ECN commit date and the CAD completion date seem to be relatively close in this figure. Therefore, there is a significant chance that, on occasion, the CAD work may be completed prior to committing the CAM ECN. This could be an issue because POs cannot be placed until all ECNs are committed. The only instances where purchasing is allowed to purchase before commitment is when there are extenuating circumstances and resulting manual workarounds create the

authority to purchase. This manual workaround seem to occur in Figure 15 through Figure 17. In contrast, bypassing the installation instruction step would allow for part information to flow to purchasing sooner, especially for the group of part shortages which did not yet have installation instructions written against them. With proper management of a bypass of the installation instruction writing, proper purchasing would occur sooner than it is currently is.

#### **4.4 Causes for Difficulties Managing Change**

BSS has had a significant problem managing change, which is evident through the significant number of shortages the SHC program has faced. There are several reasons why this is the case, ranging from the architecture of the supply chain to the engineering IT infrastructure to the change process itself. This section attempts to provide information regarding the different aspects of the SHC program management that may have defined the results of the parts case study in section 4.3.

##### **4.4.1 Supply Chain**

As stated earlier, the supply chain is much different on the SHC program than any legacy program. In the SHC supply chain, aside from the fact that partners supply large bus sections rather than small parts, partners now create and supply information in the form of engineering. Compared to legacy programs where suppliers only supplied relatively simple parts, the partners now supply both complex parts and information which both flow through the supply chain. This makes the SHC program much more complex, making it more difficult to track changes through the system because some changes are internal to partners. This complicates the current structure because BSS has very little information regarding the intent of engineering changes made internally by suppliers from one bus to another. This becomes an issue during installation instruction writing for partner engineered changes that must be installed at FID out of sequence work (the ECN is the vessel used to account for this work). If an ME has to write out of sequence installation instructions to incorporate an engineering change that requires removal and reinstallation of a partner engineered change, the ME will have to determine the engineering intent of the partners work in order to properly write the reinstallation instructions. This situation makes it more difficult for the BSS ME to determine the engineering intent of the work because BSS did not complete the engineering work for that

ECN and may not have been informed of the engineering change (and did not need to be informed due to SHC process requirements).

This situation could be a cause for shortages because MEs would need extra time to write installation instructions in order to properly determine engineering intent of every part and assembly. This problem is exacerbated by the fact that the DE works for another company which may be half way across the world and he or she may speak a different language, making communication more difficult than ever.

In changes where partners control the design engineering but the change will be implemented at SHC FID, the partners are required to engineer and approve the parts before BSS can write the installation instructions that currently drive purchasing. Without the proper approved engineered parts, BSS MEs cannot begin the installation instruction writing step. If the engineering is not approved in sufficient time for the BSS ME to complete installation instruction writing, this could cause part shortages by pushing the downstream schedule to the right earlier in the process, in turn delaying parts ordering. This was the case earlier on in the SHC program, but as can be seen in the part case studies, on average this is not the cause of the shortages that are currently reported.

#### **4.4.2 Change Process Accountability**

The change process itself is lacking the accountability required to ensure work is tracked, completed on time and, if late, tracked by a recovery plan. As stated in 2.1.7.1 Engineering Change Process, the legacy programs' change processes include a very detailed implementation schedule (called an EDCS) with a detailed description of every step required to implement the change. A deviation from the EDCS is only justified and approved if the delay is essential to completing the change. To dissuade people from making unjustified changes to the EDCS, the process to make a change is considered "very painful" by engineers on legacy programs. Furthermore, since this EDCS is a public document which can be accessed throughout the company, individual projects within individual changes are easily tracked and individuals are accountable.

The SHC GECP attempts to recreate a document similar to the EDCS, but falls very short. The ECN document is supposed to include all of the schedule quotes necessary to schedule the change. However, the output from the process has historically been very archaic and incredibly hard to follow for individuals not involved in the change itself.

Furthermore, commonly (especially early in the program) ECN documents omitted several of the sections required by the GECP procedure and there was no penalty for doing so. This makes tracking anything in ECNs impossible which, in turn, makes accountability nonexistent and accurate ECN metrics incredibly difficult to create.

Especially early in the program, it was very difficult to determine what parts were going to be replaced by new parts in an ECN. Either the parts were buried in or were omitted from the ECN. This makes it very difficult for anyone who needs replacement part information, specifically purchasing, to find the information. This does not provide sufficient part number visibility into the change process. If all replacement parts were laid out in an easy to read format in the ECN or, even better, combined into a single database with estimated completion dates, it would improve visibility. This information exists somewhere (either mentally or physically, as on a piece of paper) as someone involved in each change has to know (or at least be able to gather) all the part number information otherwise the full change would never be completed. The information needs to be in one place and easy to use in order to make it useful.

The lack of accountability makes change difficult because there is no easy way to extract the information from a central document. If the information was in a central document and everyone was made accountable to keep to their commitments, purchasing visibility may be able to significantly improve.

#### **4.4.3 IT Infrastructure Triggering**

The IT infrastructure lacks key triggers to automatically notify the next step that the previous step has been completed. Figure 4 in section 2.2.6.1 shows the process map for the SHC GECP. The only true automatic trigger which exists in the entire process is the trigger that notifies the ERP program that the ME has completed their job (the trigger between steps 7 and 9). There is no trigger between the ECR/ECN, ECN/CAD, and CAD/CAM steps; these steps rely on manual triggering. However, of these three connections, the only real issue to date is the lack of trigger between the CAD/CAM steps. The ECR/ECN exchange is not an issue because each the ECR and ECN steps typically involve the same individuals. This is also mostly true of the ECN/CAD steps. The individuals (or at least a representative) responsible for the CAD work are involved in the

ECR/ECN process and have probably started some of the work by the time the ECN is authorized. These steps, therefore, do not need a trigger to initiate the next step.

However, the CAD/CAM step does not have a trigger. An ME may not know the DE completing the CAD work or that the CAD work is completed. This is because information is transferred across company boundaries. Making this situation more complex, the transfer relies on emails or telephone calls which the DE may or may not have made. It also lacks incentive for the BSS ME to proactively obtain the information from a partner DE.

Automatic communication sent to the ME when each part is complete, it may allow the ME to do his work earlier and, in turn, provide purchasing the information through the automatic demand CAM notification earlier. This would allow purchasing to place a PO earlier and, therefore, mitigate the risk of the part becoming a shortage.

The lack of triggering makes change difficult because it complicates management of the change process. Without consistent triggering between the DE and ME when the CAD work to support the change is complete, the ME step will not begin. Someone must manage the process at this step to ensure the ME is informed that installation instruction writing can begin. It can also result in delay of all downstream steps in the change process.

#### **4.4.4 Change Process Information Availability**

Change process information is not as readily available as it needs to be. Purchasing is only informed of part needs following notification through the automatic CAM/ERP link. The question to ask is: where in the process is what information required to purchase parts actually available? Is it truly after this CAM step or is it earlier in the process? Are portions of part ordering information available at various steps or at one step? A study of the change process was completed through interviews, change process research, and IT infrastructure research. The following figure was created based on Figure 4 to show what necessary part ordering information is available at what step.

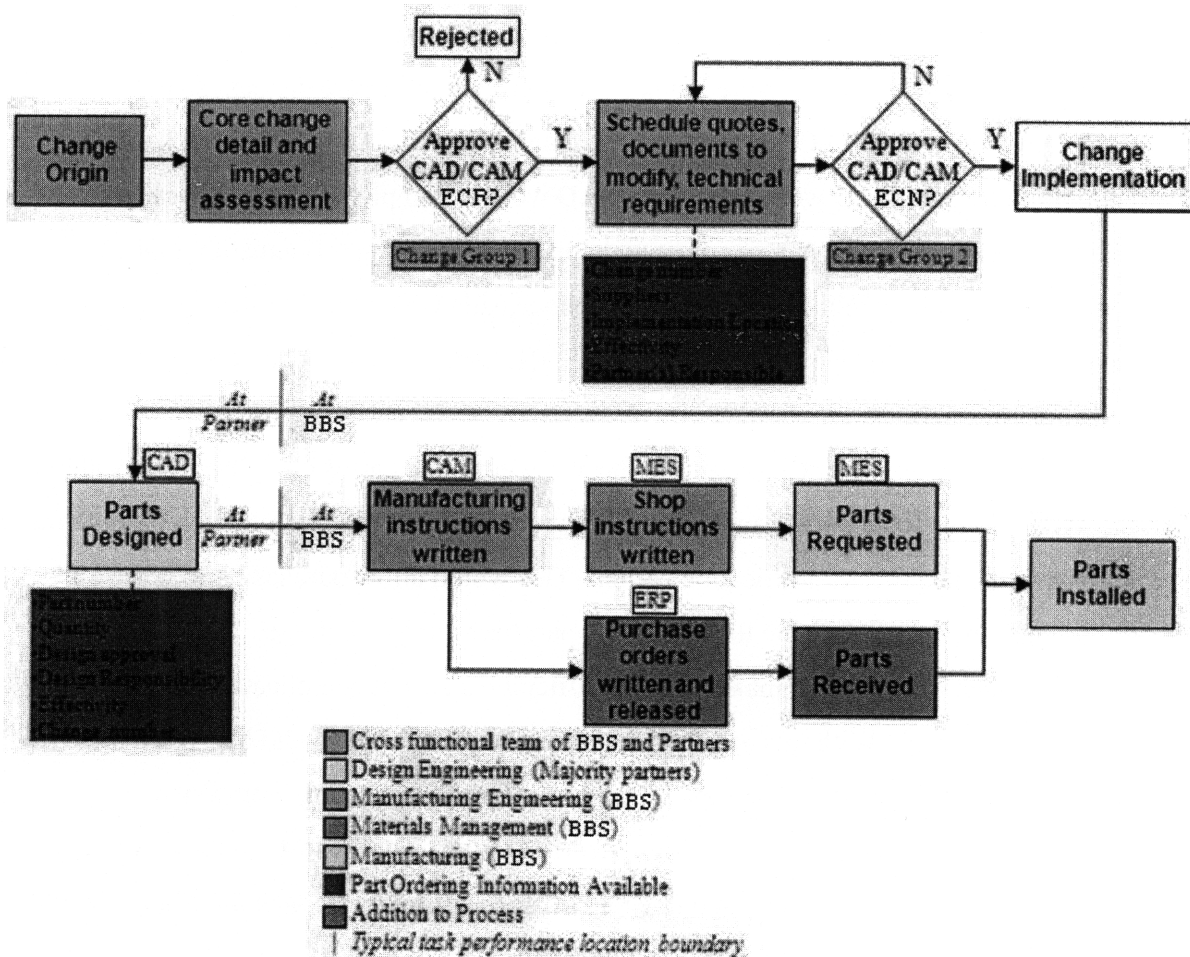


Figure 18: Change process information availability

As can be seen from Figure 18, it turns out that two steps output all of the necessary ordering information at the ECN and CAD, which both occur before the CAM step.

Therefore, there is no value added to part ordering by waiting for CAM step completion in order to purchase parts.

#### 4.5 Conclusions

The GECP is not operating to the needs of the SHC program for several reasons, but the root cause seems to be the time delay between the completion of the CAD and CAM work. As stated earlier, there is some CAD involved in between these two steps but it is considered minimal. In addition, all the necessary information to purchase the parts is available before the CAM step. It could prove prudent to connect the steps that create the ordering information with SHC purchasing in order to avoid these crippling shortages.

## 4.6 Summary

This chapter presented some of the problems with the SHC General Engineering Change Process. The problems included the high quantity of change, the lack of engineering resources, and the addition of additional change types, namely traveled and out of sequence work.

This chapter also addressed the issues with MMD's (purchasing's) visibility into the engineering change process. Historically, MMD has had limited visibility into the engineering change process. As a result, MMD did not know the engineering change parts that would soon be flowing into their statement of work. Without this information, they cannot properly react to the parts lead times (i.e., they don't know if a part is coming down the information flow late, which delays ordering and ultimately manufacturing). The result is part shortages, which are readily tracked by MMD and SHC upper management.

The parts shortage metric can be grouped in two different categories: change impacted parts (where an engineering change added the part to the bus definition) and non-change impacted parts (parts that are included in the baseline design). The non-change impacted part shortages have been steadily improving but the change impacted parts have not. A parts case study was completed to determine the root cause of these change part shortages.

A sample was taken on a random day which was used to diagnose the health of the current engineering change process. Each part in the sample was investigated to determine the flow time through the SHC's General Engineering Change Process. Parts that did not have sufficient information to create a full picture were eliminated from the sample. The remaining parts were split into four groupings based on the different characteristics of the parts. Each group was then averaged across each step in the change process. The result was Gantt charts that represented the flow times of the average part through the change process.

The Gantt charts showed that there was a significant time delay (which can be considered a queue) between finishing of the CAD work and the beginning of the CAM (installation instruction writing) work. This delay consumed the vast majority of the change development time and ultimately delayed parts ordering, resulting in shortages.

Possible causes for this large delay in the change process are: the supply chain is much more complex, there is a lack of accountability, there is a lack of IT infrastructure triggering,

and there is poor change process information availability. All these aspects can help to cause the shortage situation in the SHC program and the results reflected in the parts case study.

## 5 The Change Process as a Supply Chain

The SHC GECP is essentially a supply chain but instead of creating parts, it creates information. As can be seen from Figure 18, all of the information required to produce the output, in this case a purchase order (rather than a part), is available with a non-value added step in between, the installation instruction writing.<sup>23</sup> Assume the change process was a supply chain moving parts and there was a non-value added step in between manufacturing (creation of the information) and shipping (PO writing) that created a large delay in the entire process (including delays at the receiving customer) and could be completed in parallel with shipping. If this was the case, there would be a clamor by the downstream, receiving company (manufacturing) to make the supply chain more efficient and eliminate this step from the supply process if it has delayed their operations. This is especially true if these parts have a long shipping duration (lead time). However, this step exists for a reason and may be important to another group like final inspection (ME) because this is the step in which the final inspection criteria (installation instructions) are written. Therefore, this step could not be fully eliminated in general, just bypassed, making it a parallel process to shipping, to get the parts to the downstream company in a reasonable time. In other words, there is no reason to let the parts sit on the shipping dock while these procedures are written.

If a non-value added step like the installation instruction writing existed in the actual SHC supply chain, SHC upper management would not stand for this waste. Upper management would demand that this step be redesigned in the process. Since it is a necessary step in the big picture (i.e., it is value added somewhere in the program), it could not be removed, but should be completed in parallel with value added activities. SHC upper management should demand that the ME installation instruction writing be changed from in series to in parallel with the parts ordering process.

This chapter aims to use the information presented in the literature review (Chapter 3) and apply it to the current SHC change process. This section attempts to apply those supply chain strategy elements that focus on strategy evaluation, flexibility selection, and value management to determine where the current SHC change process may be flawed and, in turn, improved.

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<sup>23</sup>Note: Installation instruction writing is non-value added to the purchasing process but value added to the SHC program because it provides the direction necessary to install the parts necessary on the bus. Without these instructions, mechanics would lack direction on how to install these manufacturing jobs. However, it is not needed to place a PO.

## **5.1 Supply Chain Strategy and the Change Process**

### **5.1.1 Assessing Strategy through Evaluation**

Peter Kraljic proposes five questions for management to answer when determining their supply chain strategy (see section 3.1 Supply Chain Strategy). These five questions will be applied to the current SHC change process strategy.

#### **Question 1: Is the company making good use of opportunities among different divisions and/or subsidiaries?**

Instead of applying this to different divisions or subsidiaries, it should be applied to each group involved in each step of the SHC GECP. Is the SHC program making good use of opportunities among change boards, DEs, MEs, etc.?

It is very evident that the SHC program is leaving something on the table with the change boards and DEs. This is evident in Figure 18, which shows that the program has the information created by these two groups but fails to utilize the data as early as it can. Therefore, the SHC program is not utilizing these two groups as well as it could when it has the opportunity to extract this information and provide it to purchasing earlier. Maximum utilization would be use of the data as soon as it is available.

#### **Question 2: Can the company avoid anticipated supply bottlenecks and interruptions?**

Yes. The SHC program can avoid the CAM bottleneck by bypassing it and completing installation instruction writing in parallel with purchasing procedures.

#### **Question 3: How much risk is acceptable?**

At the current state in the program, with delays of over two years, risk needs to be mitigated. The current situation, where the program is waiting until installation instructions are written before purchasing, is creating an incredible risk of not receiving parts on time, resulting in shortages and bus delivery delays. This is unnecessary risk in the system and should be mitigated in any way possible.

#### **Question 4: What make-or-buy policies will give the best balance between cost and flexibility?**

This question does not really apply to the current situation because there is no way of changing the engineering responsibility to or from BSS and a partner due to contractual requirements. However, this could be reevaluated when establishing a future program. To evaluate the strategy for a new program, management needs to ask: in what situations are there issues with determining engineering intent or what types of parts to partners have

trouble engineering? In situations where there are issues determining engineering intent, the engineering of these parts should probably be taken back in-house because they increase the time for ME work. Taking these back in-house will, in turn, decrease the risk of shortage with the current change process structure.

Proper knowledge management of the experience on the SHC is required to prevent the same problems from occurring on any future program. The SHC learned that the program is flawed, but must manage this learning to ensure it is not lost after the ramp up phase. This knowledge is explicit knowledge, and should be documented in a form that is easily accessible to those who will be designing the next new bus design a decade down the road, who may have forgotten the troubles of the SHC's ramp up. Whatever forms knowledge is documented in, it must promote sharing and use of this knowledge in future programs. A ramp up lessons learned document could suffice, but must be accessible to the future programs and not lost in the sea of data that exists within BCB. BCB needs to ensure that they will be able to benefit the maximum possible from the knowledge gained through the SHC ramp up phase so that it can operate more effectively through any future ramp up.

**Question 5: To what extent might cooperation with suppliers or even competitors strengthen long-term supply relationships or capitalize on shared resources?**

Cooperation with partners is essential in the SHC GECP structure because the partners own much of the engineering. Without partner cooperation, the SHC program would have more problems than it has today. Partner cooperation is essential to get the ECNs committed and CAD work complete. If these steps are not finished or finished late, part shortages will result which will cripple the program.

These questions need to be reevaluated constantly with respect to the change process strategy in order to determine where the change process can be improved. Without constant improvement, the process will remain riddled with the problems. Just as supply chains can be the source of a competitive advantage, the change processes can also be a source of competitive advantage.

**5.1.2 Determining the Change Process Flexibility**

Marshall Fisher contended that there are two different types of products that require two different types of supply chains: the functional product which requires an efficient

supply chain and the innovative product which requires a flexible supply chain (see section 3.1).

When applied to the change process, it is easy to see that the information that flows through the change process is an innovative product created by the GECP. The number and focus of changes is inherently unstable just as the demand for innovative products is unstable, both because of inaccuracies in forecasting. The change process right now is not nearly as flexible as it needs to be because it created a significant number of shortages. By making the change process flexible, the SHC program can hedge against any bottlenecks due to unanticipated changes. The change process must be able react to an inherently unstable volume of changes, without that, a large backlog (a backlog as seen prior to the CAM step in the parts case studies) can occur delaying downstream processes.

The need for a flexible engineering change process is that much more important to the SHC program because it is currently in the ramp up phases. During initial ramp up of any cutting edge (i.e., innovative) product development program, the needs for the program are unknown, which has to be anticipated by management. In the SHC's case, BSS and partners are dealing with a material that has never been used as extensively in a coach bus program. As a result, it is inherently unknown how this material will behave when the bus is manufactured and flight tested. There is some shop testing that can be completed upfront, but there is no way of accounting for every potential issue prior to manufacturing the first bus. This fact, coupled with the new partner structure, is a very distinct signal that the change management processes must be flexible or the change management process will ultimately fail, creating the problems facing the SHC program. In order to minimize risk during the ramp up phase, the change management system must be flexible in order to account for increased numbers, increased focus (i.e., number of functional areas – bumper, bus structure, systems, etc. – impacted), and increased scope of changes during the ramp up phase of any bus production program.

### **5.1.3 Value Management**

In order to reassess the change process, SHC management must determine what the end customer values just as a supply chain managers would. Whereas some elements in a supply chain may value on time delivery or cheaper products, SHC FID values on time and correct delivery of parts because on time delivery allows them to complete their

manufacturing jobs on time. Ultimately, the end customer (the bus lines) need to get their purchased busses delivered when anticipated because they have scheduled a bus for retirement for when the new SHC is to be delivered. Therefore, bus lines value on time delivery of busses (and further upstream: parts) because huge delays can cripple a bus line.

In order to offer the customers the best value proposition, the SHC program needs a change process that ensures on time delivery of parts to manufacturing. This can be achieved by optimizing the process through continuous improvement by constantly evaluating and reevaluating, and by increasing the change process' flexibility.

The following statement by Kraljic sums up the SHC change process and what needs to be done to deliver the proper value proposition to the end customer:

Greater integration, stronger cross-functional relations, and more top-management involvement are all necessary. Every facet of the purchasing organization, from systems support to top-management style, will ultimately need to adapt to these requirements. Concrete changes in the organization will be required to establish effective organizational relations, provide adequate systems support, and meet new staff and skill requirements... Too often the purchasing department receives information on the company's business plans and objectives that is incomplete or improperly geared to the tasks and time horizons of strategic supply management. Purchasing executives... often lack adequate operating information with a three- to six-month time horizon... The purchasing department needs these data for negotiating prices, rescheduling supply quantities... In the absence of such data, supply bottlenecks, short-term demand fluctuations, and ad hoc purchasing decisions are inevitable. In turn, the company incurs higher time and money costs...<sup>24</sup>

## **5.2 Change Process Sub Process Alignment**

Internal change processes require sub processes just as a supply chain has sub processes. Two of the "tools" that Fisher (see section 3.2 for more information) contends are necessary to align processes are to reduce uncertainty in the future and to avoid uncertainty by reducing lead time. Both of these are important in each of the change process' sub processes. One sub process in the change process can be characterized as one step in the change process. That is, the ECN step is a sub process, the CAD work is a sub process, the writing of a PO is a sub process, etc.

The sub processes need to each be aligned to support the ultimate goal of delivering correct changes to manufacturing, on time, to support the production schedule. Each of these

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<sup>24</sup> Kraljic, Peter. "Purchasing must become supply management." Harvard Business Review 61, no. 5 (September 1983): 116. Business Source Complete, EBSCOhost (accessed February 18, 2009)

sub processes can be specifically aligned to support this goal by providing information to the subsequent sub processes in the most efficient way possible. This can be accomplished through automatic means such as electronic signals sent when a part is approved or through manual means such as the dissemination of an ECN document to the affected parties. Whatever the means of communication is, it must be effective with the most useful and correct information.

Proper communication is incredibly important. As stated by Dittmann and Mello in chapter 31 in the Handbook of Global Supply Chain Management, a proper communication plan is the most critical aspect of change management (for more details please refer to section 3.4.1). Without the proper communication method individually tailored to each individual or group, the message (i.e., relevant information that each group needs to act on) will be lost in the flood of information that employees receive every day. The result of ineffective communication can mean delays in the change process or, at worst, failure to complete the engineering change.

Dittmann and Mello continue to say that there are four roles which are incredibly important to implement any organizational change: the sponsor, change owner, change manager, and process owner. Although Dittmann and Mello are using these roles to describe implementing organizational changes, these same roles can be applied to engineering change. The SHC process currently has all four of these functional roles in the engineering change process. They are as follows:

- The sponsor – engineer leading the change, provides the engineering justification for the change
- Change Owner – the change board head, termed the change coordinator in the SHC change process
- Change Manager(s) – individual function leads. These would be the DE and ME managers who are managing the work completed to support the change by their direct reports
- Process leads – the individual contributors, either individual DEs or MEs, who complete the detailed work which support the implementation of the change

Some of the roles are not performed well enough, resulting in the current state of the SHC engineering change process. Specifically, the change owner and change manager

functions have not been performed to the level necessary for the SHC program to succeed. The change owner (i.e., change coordinator) is needed to ensure the engineering change as a whole is completed in a reasonable amount of time (i.e., within the schedule, without impinging on part lead time) which is definitely not happening, especially with respect to the installation instruction writing. Also, the change managers (individual ME and DE leads) are not ensuring their people are completing their work on time to support the change owner. This is very evident through the very large queue in Figure 14 before the CAM work and the resulting shortages.

In order to improve this situation, the change owner needs to work with the change managers and create tailored communications providing detailed requirements for the completion of the change's tasks. Dittmann and Mello contend that these communications should, at a minimum, include clearly defined tasks, individual responsibilities, and schedules with clear completion dates. This is very similar to the requirements of the EDCS employed in the legacy programs. Other details which may be useful in communications include contact information for the adjacent sub processes and a standard format for communication to each group across all changes.

### **5.3 Chapter Summary**

The SHC's General Engineering Change Process is essentially a supply chain of change information. As with true supply chains, the change process needs a strategy in order to ensure that the process fits with the company's product and industry. The fit of the change process should be evaluated by using some of the same evaluation methods used for supply chains. For example, BSS needs to question the current SHC engineering change process strategy using the questions posed by Peter Kraljic. The information provided by the answers will show where the holes in the process are and then can be used to correct the process.

It is evident that change information in the ramp up phases is essentially an innovative product flowing through the change process. Therefore, the change process needs to be inherently flexible to account for the unknown amount of change information that will flow through the system. Without a flexible change process, there is no way to properly react to high levels of change information which can occur during the ramp up phase.

BSS needs to evaluate the change process using these techniques for the SHC program. It is important to ensure alignment of the change process with the ramp up phase so that BSS

can accommodate the needs of the end-customer, the bus lines. Without taking into account the needs a customer that values on time delivery, the change processes goal needs to be aligned to deliver a value proposition that aligns to the customers' needs. These techniques will help BSS achieve the proper value proposition alignment with customers.

The lessons learned from the SHC ramp up need to be managed by BSS to ensure any new program in the future has change process alignment during the ramp up phase. Without proper knowledge management of the SHC problems and corrective actions, BSS is at risk for the same problems in future programs.

The sub processes of the SHC's General Engineering Change Process need to be aligned to support the ultimate goal of delivering engineering change parts to manufacturing, on time (i.e., before or on the manufacturing need date). Information throughout the change process must be transferred efficiently and correctly in an effective manner. The current reliance on manual triggers and change board meetings has not sufficed as proper communication methods because they are not tailored to effectively and efficiently transfer the information to each stakeholder. Manual transfer of information lacks the accountability while the change boards focus predominantly on the engineering, where the part ordering information is typically lost in the slew of engineering jargon used in these meetings. The communication of ECN requirements needs to be tailored to each stakeholder otherwise the process will remain ineffective.

## 6 Temporary Solution

A temporary solution was employed to immediately help improve this situation. This temporary solution gathered all the information necessary to purchase parts from the change process to create an advanced ordering report which purchasing can act on. The initial launch of the report was for the most critical M/Ns, M/Ns 1-6. The report was then expanded to also cover releases for M/Ns 7-25. This report was used by SHC purchasing to place POs for those part numbers included on the report. Figure 19 below shows how this advanced ordering report fit into the SHC's engineering change process and what data it extracted from which step.

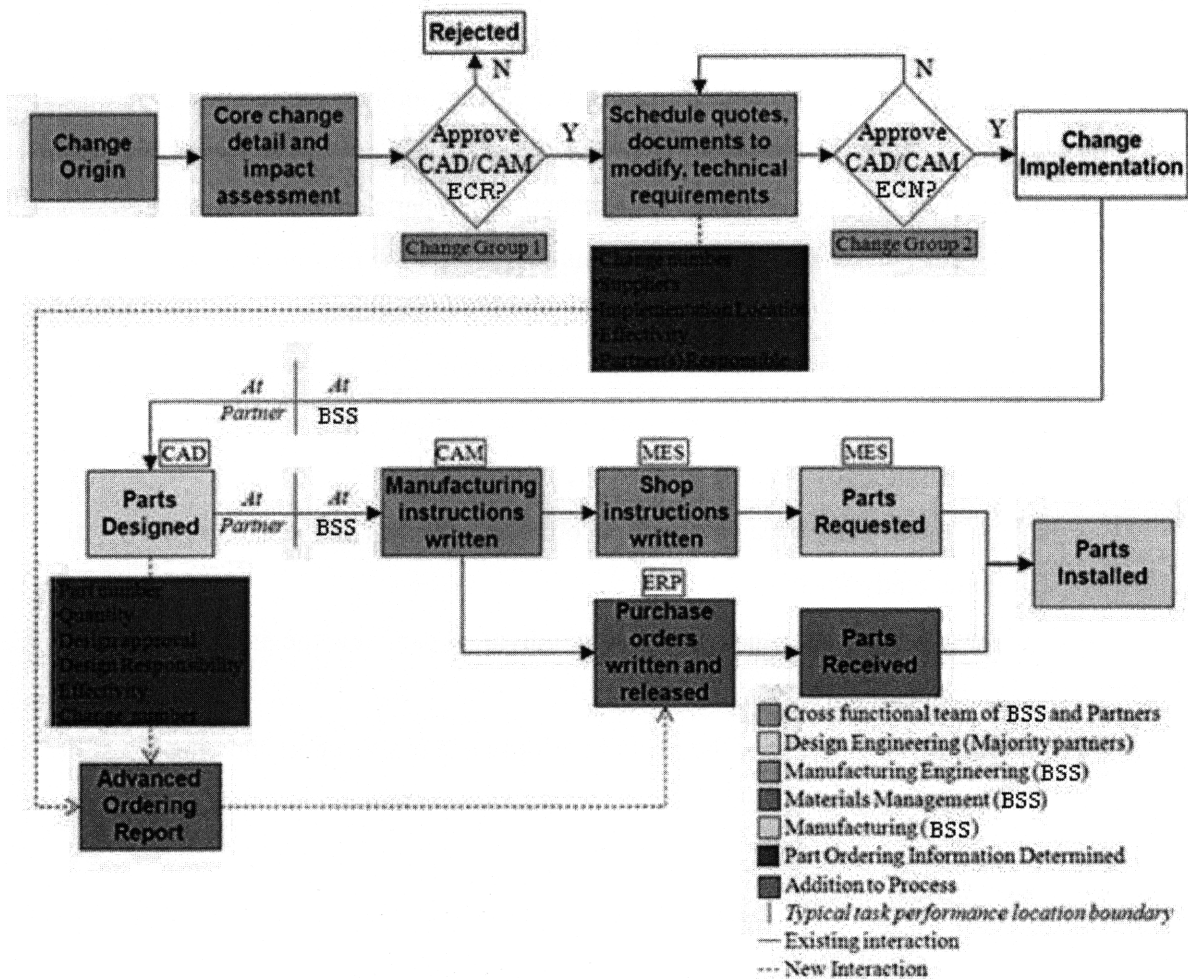


Figure 19: Change process representation with advanced ordering report

As can be seen, the advanced ordering report connects the information available at the ECN and CAD steps with purchasing so the purchase order can be written. Essentially, it puts purchase order writing in parallel with installation instruction writing. This allows purchasing to

get ahead and place the purchase orders before the ME writes and submits the installation instruction that creates the demand in the ERP system.

### **6.1 Details of the Report**

This report provides the following information to the purchasing individuals in a website format:

1. Part number quantity by design responsibility, including any part numbers which are suppressed (i.e., cannot be purchased for reasons such as it is a collector part number).  
This gives the user the quantity of parts against a given partner
2. A detailed breakdown of the parts which can and cannot be purchased. These part numbers are broken down into the following subcategories by design responsibility. These sub categories are intended to track where part numbers are in the pre-purchase process and to ensure accountability. Each one of the sub categories can be opened in excel format by clicking on a link to see exactly what parts are behind each metric.
  - a. Total items not ready (cannot be purchased because pre-purchase work is incomplete).
  - b. Items not ready because it has not been added to the ERP system.
  - c. Items not ready because the part is not on contract yet.
  - d. Items not ready because quality has yet to approve.
  - e. Items not ready because supplier coding in ERP has not been completed.
  - f. Items ready for PO.
3. A dropdown menu where each purchasing individual can view the part numbers that they are responsible for.
4. A graphical representation of the overall performance to the report showing lines for.
  - a. Total POs required.
  - b. Actual POs placed.

The spreadsheets linked to this website provide the following information for each part in the report:

1. Part number.
2. Design responsible company.
3. ECN(s) applicable to the part number.
4. Milestone parts needed to support (e.g., first drive).

5. The M/Ns the part number is applicable to.
6. Part class (high level description of what the part is).
7. Date added.
8. Quantity by M/N.
9. Total quantity.

This report is on the BSS intranet and can easily be accessed by any purchasing individual who is responsible for executing POs.

## **6.2 Benefits**

This report allows the SHC program to optimize the current change process by providing all the data to purchasing as soon as it is complete. This report gives SHC purchasing the advantage of not having to wait until ME has processed the installation instructions; it allows MMD to work in parallel with that step altogether. When compared to the change process case study results of Figure 14, half of the process flow can potentially be eliminated. This is essentially doing what Terwiesch and Loch said in their article “Managing the Process of Engineering Change Orders: The Case of the Climate Control System in Automobile Development”: it is eliminating congestion through eliminating an unnecessary step in the purchase order sub process.

Even if ME reduces its queue to a much lesser percentage of the process flow time in the future, this report will still allow purchasing to start the purchase order process (i.e., setting up ERP, putting the parts on contract, parts quality approved, etc.) earlier. Therefore, if the information does flow through to the ERP system before the PO is placed, purchasing will be physically much closer to actually placing the PO than if they had waited for the automatic signal.

This report, at a minimum, is a forecast of what parts should be expected to flow through to the ERP system from CAM in the future. If management decides, for whatever reason, that this report should not be acted upon, it will at least provide purchasing with a list of parts that it should expect to soon see coming into the ERP system in the form of demand.

## **6.3 Risks**

The ERP system is not currently set up to fully accept this report. When a PO is placed for part X on this advanced ordering report, the ERP system reports an error saying that purchasing currently has excess part X and tells the purchasing individual that he or she

should cancel this order because supply exceeds demand. There is a risk that purchasing individuals would cancel this PO for part X because the ERP system is telling them to do so. Although it is not catastrophic if the individual cancels that order, it puts the SHC program back into the same position it is currently. This error message is eliminated when the actual demand flows into the ERP system from the CAM system. Proper training on the cause of this error message will ensure that the PO will not be unnecessarily canceled.

There is risk that the parts could be ordered too early. The best need by date generated by the report is based on the milestone date provided in the ECN. The milestone date is not a manufacturing need date but rather an event by which the change needs to be incorporated. The most reliable estimate for a need date for these parts would be approximately a month before the day milestone is scheduled. Therefore, BSS could potentially be stuck with unnecessary inventory for a month. Conversely, a month is a small percentage of the SHC's current delays. This is not considered an important risk because the program is so far behind that early parts are much better than risking receipt later than the need date. Mitigation at this point in the program is, therefore, considered unnecessary.

There is also risk of manual error. The current report is not very user friendly since it is excel based. There is a lot of manual transcription involved, from part number to contract numbers. A system that is manual, especially with complex number and letter combinations, is susceptible to human error. An example situation where this could hurt the SHC program is if a purchasing individual were to purchase an incorrect part number because either the report or the individual had the number incorrect. The result could be that the SHC program receives inventory of a part number that it may never use. This situation is not unheard of in the current system because some of the installation instruction writing involves transcription of part numbers and data, but care should be taken by the purchasing individual to ensure manual inputs are correct.

Another potential risk is that the design partner associated with the part number on the report may not be the correct company to purchase from. During the ECN development process, BSS and the designing partner decide on an M/N in the future to install the change in-sequence at the partner. All M/Ns before this typically will have the change installed out of sequence at SHC FID. At this point in ECN development, BSS and the partner come to an agreement on who will provide the parts for the out of sequence installations at FID.

Typically, the partner will fabricate (or outsource the fabrication) the parts and supply them to BSS. However, sometimes BSS and the partner will come to an agreement that states BSS will source the parts from an outside vendor for all out of sequence installations. With the POs being placed to the partner, there is risk that the partner may receive the PO and not act on it because they don't think that they are responsible for those parts as agreed upon in the ECN negotiation phase.

This report will correct a situation which has occurred in the past where BSS was supposed to source from the partners for the out of sequence M/Ns but didn't end up doing so. Instead, BSS found an outside vendor and sourced the out of sequence parts from them while the partner was left with an inventory of parts that BSS was supposed to purchase.

#### **6.4 Results**

After implementation of this report through the end of the internship, approximately 40% of the parts on this report had POs written against them. Essentially, 40% of the parts provided on this report had been purchased earlier than if the current SHC IT infrastructure, as designed, had been allowed to work as designed.

However, the impact on shortages is much harder to quantify because it is unknown how much of the 40% would have resulted in a shortage. Figure 20 below shows a large view of the last quarter of the X axis of Figure 6. This area reflected in Figure 20 corresponds to the time period just after the implementation of this report (see inset).

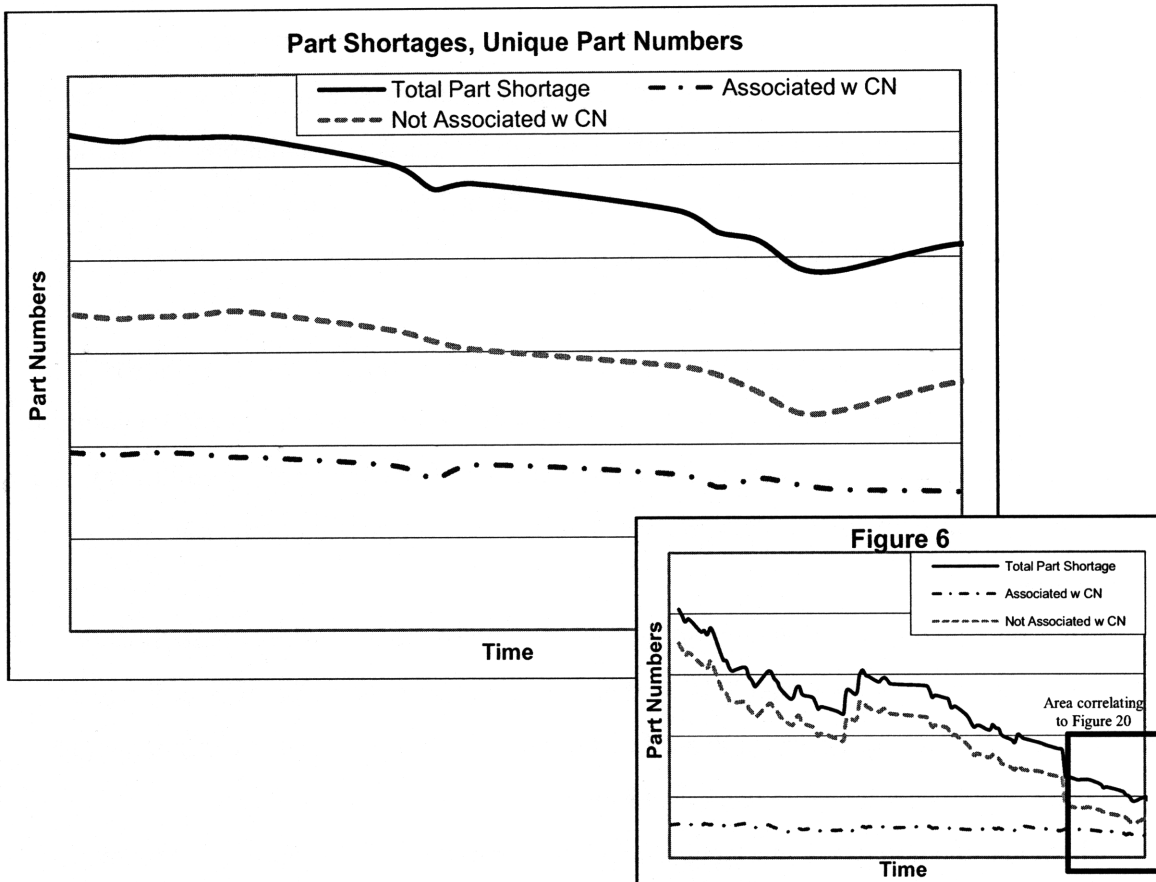


Figure 20: Exploded view of Figure 6, right quarter of X-axis

It is interesting to note that, after a significant time being relatively flat (see Figure 6), shortages associated with change started to decrease. The cause for this decrease is inconclusive. However, it is probable that the advanced ordering report temporary had an impact on shortages creating this change in the trend.

## 6.5 Summary

The temporary solution is intended to be a simple patch to improve the SHC's engineering change process purchasing. The aim of this temporary solution is to provide part ordering information to purchasing earlier in the change process by extracting the data from various internal BSS databases. This report delivers information to purchasing before it flows through the normal IT channels. This gives purchasing the ability to react earlier (potentially significantly earlier) to parts needs by placing purchase orders for items earlier than they ordinarily would have.

This report is a very manual workaround of the normal process, and there are risks when using this new report. The risks include:

- Unintentional cancellation of purchase orders placed off this report
- Ordering parts too early
- Transcription errors
- Purchasing from the wrong partner

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## **7 Long Term Solution Options**

This section presents several options which, if implemented, can potentially improve the engineering change parts visibility problem in the long term. The options presented here are intended to be user friendly alternatives of and improvements to the short term solution. Certain options will provide information that is not currently provided in the short term solution, making some more useful than the short term solution. These options will be used to create a long term recommendation for the SHC program in chapter 8.

### **7.1 Earlier Demand Creation**

Using the very manual temporary advanced ordering report to place POs in the ERP system will result in error messages telling purchasing individuals to cancel orders for these items. An option to eliminate this issue would be to connect demand to a CAD release in lieu of a CAM release. This would eliminate a lot of the manual work currently needed to place a PO off the advanced ordering report. As a result, it will reduce the number of transcription errors. The connection between CAM and ERP currently automates a lot of the ERP data creation and pre-purchase process. The same type of application could be incorporated to connect the CAD release and ERP demand creation.

The current CAD and ERP systems have the appropriate architecture to accept this type of connection. Both systems fundamentally run off the same part tracking coding. Both systems use a part code known as a “part instance” which is a series of numbers that is unique to every single part on the bus, no matter the part number. For example, if there are 100 part Xs on M/N 4, there will be 100 different part instance numbers to cover the 100 part Xs. If 75 of M/N 4’s part Xs are used on M/N 5 in the same place on the bus but M/N 5 has an additional 40 more of part X installed in a different way on the bus, 75 of the part instance numbers of M/N 5 would match 75 of the M/N 4 part instance numbers. The additional 40 will have unique part instance numbers that do not match any other instance number for part X on any other M/N that does not use this part number in the same exact way. A computer application could easily be created to link these part instance numbers between the CAD and ERP systems just as the current CAM/ERP system connection does. The CAM/ERP system link can still be used to validate the data coming from CAD to ERP and to assign the installation instruction number, but would provide little added value.

## **7.2 Detailed ECN Schedules**

A detailed ECN schedule similar to the EDCS of the legacy programs for each ECN would prove useful to create metrics and a sense of accountability throughout the program. This could also be used to track exactly what parts are intended to be released in the future. This would provide a significant document to ensure that work is completed and, if not on time, show which area is the offending area. The ECN owner could then work with the offending area to create a recovery plan in an attempt to minimize the impact of the delay on the program.

## **7.3 Forecasting Reports**

The SHC program could create a document that provides the part numbers scheduled to be released over a given horizon. If a report was provided to SHC purchasing which showed all parts scheduled to be released from CAD over the next 60 days and those which are behind schedule, it would provide purchasing the proper visibility into future purchases. In addition, it would allow purchasing to determine lead times before engineering approval for all of these parts and make purchases as necessary to support manufacturing. The part would require a special engineering approval in order to actually place the PO before CAD approval. Early ordering approval can be granted by engineering if the design is at a high fidelity but this is at risk of future part definition changes. If early ordering permission is not granted in time, purchasing would at least have advanced notice that part engineering will be late and could work with the supplier to attempt to reduce lead time.

This forecast would most easily be implemented in conjunction with a strict scheduling procedure proposed in section 7.2. It would be simple to extract all part numbers and scheduled completion dates from a detailed and well organized schedule. Provided that the schedule is created in a relatively flexible computer program, it could be possible to automatically (i.e., electronically through the use of an in-house created computing program) extract all the required information (part number, quantity, completion date, etc.) from the scheduling program. If completion dates need to change and are changed for a given part, the extraction program could be used to catch any completion date slippage and inform purchasing of the revised completion date, showing the new estimated completion date with the original date followed in parenthesis.

Newly developed SHC ECNs are being created in a program which documents all the new part numbers to be added and the part numbers to be removed by the ECNs, in a more user friendly format. This is an improvement over the old ECN documents which either doesn't include part number information or buries the information within the document. This new program could potentially be used to generate a forecast of parts to be completed by ECNs. However, this document lacks anticipated completion dates for CAD work. Therefore, using this document to create a forecasting document would be of limited value. It would only provide part numbers contained in an ECN, not the expected date of completion for the CAD work.

#### **7.4 Require Purchasing Participation in Change Board Meetings**

Purchasing involvement in change board meetings could be beneficial in that parts added are typically discussed during the ECR and ECN change board phases. However, these discussions are typically very technical, too technical for the average purchasing individual (most do not come from an engineering background). In addition, these meetings are so frequent (due to the number of ECNs) and purchasing is so small (relative to an ME or DE function's size) that covering this meeting would require too large a percentage of purchasing's manpower resources. Additionally, an ECN may cover areas that several purchasing individuals have cognizance over. This would require multiple purchasing individuals or transfer of second hand information to the appropriate individual from a representative that may not be very keen on those parts.

The amount of benefit to purchasing derived by attending these meetings may not prove to be worth the value of the manpower used to attend because there are other, less manpower intensive options available that could provide more information, in quantity and robustness, to purchasing.

In addition, this CB meeting is not aimed directly at purchasing. Using the requirements for change communication criteria presented in section 3.4.1, this meeting is not a good choice to communicate requirements of the change to purchasing because it is not tailored to purchasing's needs in any way.

#### **7.5 Stay the Course**

Another option for the SHC program would be to keep the same systems in place that have created this problem with the hope that the different SHC groups will figure out how to

properly manage their statement of work in order to attain the goals set forth by upper management. This would be the easiest to implement because it would require no change by employees. However, the risk that the situation does not improve is very high. If management wants to take a proactive approach to fixing the part shortage situation then they need to implement improvement initiatives aimed at increasing the chance of successful improvement of engineering change parts ordering.

## **7.6 Summary**

There are several options that could potentially improve this situation in the long term. The options are as follows:

1. Create demand earlier: by connecting demand in the ERP system with CAD release in lieu of CAM release will avoid the cancellation messages and manual transcription required by the temporary report. Requires IT infrastructure changes, potentially significant changes.
2. Include detailed schedules in all new ECN documents: detailed schedules on par with the EDCS of the legacy programs will help ensure accountability and ease of tracking.
3. Forecasting reports: a report that is provided to purchasing which contains all the parts to be released from CAD over a given horizon. This report can be used by purchasing to plan for any work that will be soon coming their way. This option would be most easily implemented in conjunction with the detailed ECN schedule.
4. Require purchasing participation in the current change board meetings: parts requirements are discussed in the change board meetings. However, these meetings are typically very technical and any information pertaining to purchasing is buried in the conversation.
5. Remain with the current infrastructure: hope that the stakeholders involved determine how to properly manage to the performance goals dictated by upper management.

## **8 Long Term Recommendations**

Chapter 7 presents some options which can be implemented by the SHC program in order to improve the parts shortage situation the program is currently facing. These recommendations can be used to both improve the SHC program and to help avoid similar situations from occurring on future new coach program launches (i.e., the next all new coach bus BSS and its partners design and manufacture).

It is recommended that the SHC program implement a stringent scheduling routine that is aimed at scheduling all steps required for each ECN, implement a digital forecasting tool that can be used by purchasing to determine upcoming needs, and to create earlier demand in the ERP system. Each of these three programs should be implemented in the order presented in the preceding sentence in order to properly balance all the needs of the program with the needs of the future situation. In addition, each subsequent step can use information from the preceding step to improve functionality. The aim of this long term recommendation is to reduce the complexity and the congestion effects of the process upstream of purchasing. This happens to be in-line with recommendations provided by Terwiesch and Loch.

The SHC should not stay the course because it will not improve the problem. It should also not require purchasing to attend these CB meetings because it is not the right forum or method to communicate new, removed and revised parts to them. The solution in this section would be an effective solution for communicating the essence of the part requirements for purchase.

### **8.1 Step 1: Implement Detailed Scheduling for all New ECNs**

Ensuring that all new ECNs have a detailed and accountable schedule will ensure that every step in the ECN is properly tracked. It may not be feasible to create a schedule for all past ECNs because there are a significant number of them, there are several which have disjointed information, and many are already complete. The manpower required to collect, analyze, and format the information from all the ECNs would be prohibitive. However, all new ECNs should have a stringent, easy to read schedule as part of their contents, similar to the legacy engineering/design commitment schedule (EDCS).

To ensure every ECN document has this, the SHC program must import the same change management style of the legacy programs. The legacy programs have excelled under the EDCS and the management style, and this needs to be applied to the SHC program. The

most efficient way to accomplish this is to obtain the change managers from the legacy programs to oversee the SHC change process transformation. These individuals are integral to the success of this initiative because they have the knowledge about how to properly manage an engineering change process within BSS Coach Busses.

The main benefit of this improvement is that it can have a large impact on the entire program, bigger than an impact on just the purchasing area. This document can be used to create metrics for each area (ME, DE, purchasing, partners) and group (individual groups within ME, DE, purchasing) to see where problems exist. Where problems do exist, SHC management can properly address those problems and correct them before they become too big. For example, in a hypothetical situation, if partner A is routinely late when completing CAD work, BCB and partner A can hold a kaizen event and work together to properly diagnose the problem and correct it. If the problem at partner A is diagnosed as a manpower issue, BCB can work with partner A to get the resources it needs (through hiring, redesigning processes to use less manpower, etc.) to fix the problem.

In addition to accountability, this schedule can be used by the downstream steps to determine when they should be starting work on a given ECN. This will ensure communication between the adjacent steps because the subsequent steps are hinging on the completion of the preceding steps to complete their jobs on time. If a subsequent step does not communicate with a preceding step and the preceding step is late, the subsequent step will ultimately be late which will be reflected on all subsequent steps' metrics. A late start due to previous steps late finish will require the subsequent steps to move their starting point accordingly and inform the processes downstream that there will be a delay upstream in order to meet metric requirements. This will ultimately benefit purchasing because they will see the "hiccups" in the schedule upstream and will be able to adjust accordingly. Of course, any schedule shift must have a valid reason and CB approval to take effect.

Another benefit occurs when creating the schedule. The schedule will ultimately be driven by the bus delivery date because there are large financial and intangible (e.g., customer satisfaction which may impact a future purchase) penalties for delayed delivery. However, the true date driving the ECN will be the manufacturing need date for the job which supports the delivery date. To create a proper schedule, the SHC program must use this manufacturing need date and backfill (from right to left on a physical schedule) all previous steps required to

implement this change. When this is completed, it may show that the start by date for the first step has already passed, and individual steps must be compressed (e.g., through use of overtime) to support the manufacturing need date. If this issue is realized earlier in the process, it can be mitigated and there will be less risk of a part shortage.

## **8.2 Step 2: Create Forecasting Site**

A forecasting webpage on the BCB intranet or a tracking program would create a user friendly forum for purchasing and ME to detail the work that will be flowing downstream over the next 60 days. Accordingly, the webpage/program needs to be capable of being filtered by individual manager and individual contributor (e.g., individual purchasing individual who will ultimately make the purchase) responsibility so metrics can be created to track an individual's and group's future responsibilities. This gives purchasing a great view of what is coming down the pipeline so that individuals can do pre-purchase work as necessary to ensure that the PO is released as soon as it is needed.

This webpage/program will be backfilled from the data included on the detailed schedules created for each new ECN. The webpage/program would take each individual part number, part instance number, purchasing individual responsibility, estimated CAD completion date, purchase by date, part lead time, ECN number, and manufacturing need date by M/N from the detailed schedule and compile it into a user friendly online database. In addition, if any dates are adjusted upstream from purchasing, it would be reflected in the forecast and purchasing can react accordingly, potentially working with the suppliers to reduce lead time of parts.

Once the part is approved in CAD, the part number will disappear from this site, but will appear in an associated site where all of the parts approved in CAD over the past 60 days. A separate link to a subpage will exist which will include historical approval data. This will ensure that purchasing does not lose track of the part once the part is eliminated from the forecasting report.

## **8.3 Step 3: Create Demand Earlier**

Concurrently with addition to the recently approved site, the parts will be added to ERP system in the form of demand. The purchasing individual would see these parts on the ERP screen with all of his or her part responsibilities. Each part would have a pre-demand column, an intermediate demand column, and a true demand column with numbers representing the

quantity in each category. The pre-demand column would serve as a signal to the purchasing individual that a part has flowed through the CAD system but not yet the CAM system. The purchasing individual would then investigate any pre-demand to determine the actual purchase by date. This investigation should be easy as the purchasing individual should be aware of the need for the part through the forecasting site. If the purchase by date is determined to be approaching (e.g., less than two weeks from the current day), the purchasing individual would promote the applicable part instance number(s) to intermediate demand, which signals that a PO has been placed to cover a pre-demand. Any parts which had been approved by CAM would flow through the system and move the matching part instance number from either the pre-demand or intermediate demand (depending on if a PO was previously placed for that instance) to the true demand column. Figure 21 describes the common situation which the purchasing individual might face and the proper corrective actions.

Each part number would have a quantity of supply against it (which it currently does in the ERP system) which consists of the sum of the quantities of the item in stock and the quantity currently on PO waiting for receipt. The supply column in ERP should match the sum of the intermediate demand and demand columns. Anytime the supply column is less than the sum of the intermediate demand and demand columns, the purchasing individual would know that they need to increase the quantity on the purchase order in order to cover the demand.

Situation	Proper Reaction by Purchasing
Pre-demand	Investigate purchase by date
Pre-demand - purchase by date far in future (i.e., >2 weeks out)	Note purchase by date, leave as pre-demand
Pre-demand - purchase by date past or in near future (i.e., <2 weeks out)	Place appropriate PO, advance pre-demand to intermediate demand
Approval by CAM	Pre- or intermediate demand will be automatically advanced to true demand. Place POs for any discrepancy between sum of intermediate demand and demand
Sum of intermediate demand and demand columns do not sum to supply	Place POs to account for discrepancy

Figure 21: Purchasing reaction to common situations involving pre-demand, intermediate demand, and demand

### 8.4 Summary

Figure 22 serves as a graphical representation of the flow through the CAD, CAM, ERP, and new applications for the proposed long term solution. The figure details the inter-program connections between each new step and existing steps through dotted lines. The notes following the figure explain the significance of each new interconnection.

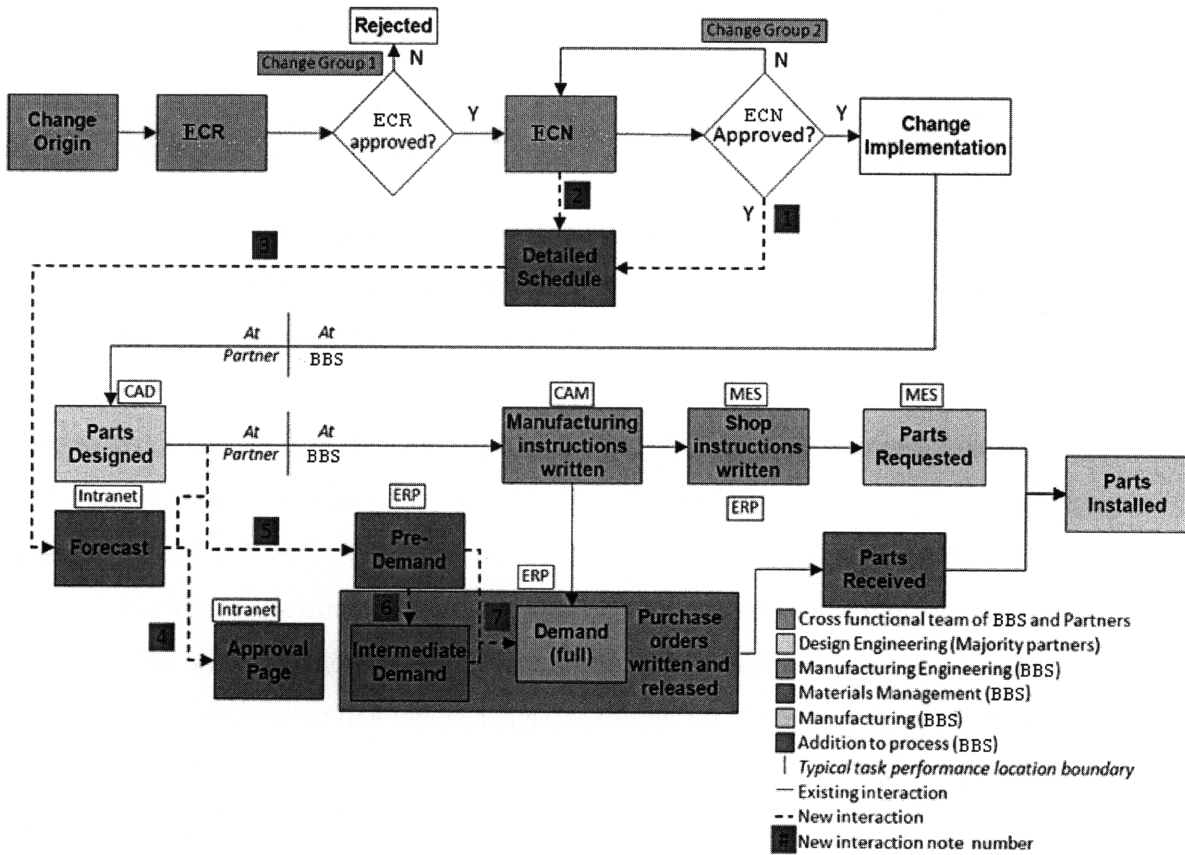


Figure 22: Graphical representation of recommended new change management system

#### Notes (correspond to numbers in red boxes in Figure 22):

1. Once the ECN is approved by the change board, the schedule created in the ECN step is official and can be acted upon by the downstream processes (specifically CAD work). All changes to the schedule must also be approved by the change board.
2. The essence of the schedule will be created during the ECN creation period but needs CB approval to proceed with schedule implementation.
3. The schedule is used to populate the forecast. Every part on every detailed schedule to be approved during the following 60 day period will be reflected on this report. This

report will also reflect any delays and any parts that are delinquent on their CAD approval. The forecast will include the following details:

- a. Part number.
  - b. Quantity.
  - c. Part instance number(s).
  - d. Responsible purchasing individual.
  - e. Estimated CAD completion date.
  - f. Purchase by date.
  - g. Manufacturing need date.
  - h. ECN number.
4. Once a part is approved in CAD, the schedule will be updated to show a completed task. The forecast page/program data will be adjusted to remove that part from the rolling 60 day forecast, while the approval page will gain that part number (all applicable part instances that have been approved in CAD). The approval page will include the same part information as note 3, but “estimated CAD completion date” will change to “actual CAD completion date” and include any other part information that may have been created during the part design phase in CAD. This will also be a rolling 60 day report so that users have a 60 day history of CAD approvals. Archived information from outside the 60 days will be available through a separate link.
  5. In parallel with the update of the approval page, a signal will be sent to the ERP system to create pre-demand. In the ERP interface, the part number will have three quantity columns against under the demand heading. The first will be pre-demand which is the quantity of any part number instance approved in CAD which does not have a manufacturing instruction written for it or a PO issued against it. Items in this category will be investigated using the approval page to determine purchase by dates.
  6. Upon completion of investigation by the purchasing individual, he or she may uncover that part instances may need to be purchased because their purchase by date is occurring very soon (within 2 weeks) or has already passed. These part instances have a PO written against them to purchase those items. Once these POs are written and submitted, the purchasing individual reduces the pre-demand quantity by the quantity reflected in the PO. This is done by selecting the part instance numbers in ERP the POs

account for, and then transfer the numbers behind the scenes to the intermediate demand column (this capability will have to be added with the same ERP revision that will create the three demand groupings). The intermediate demand field will automatically increase by the same number the pre-demand field was reduced by. The intermediate demand field represents any CAD approved part instance that has a PO written against it but does not have a manufacturing instruction written against it. This will make the PO writing occur in parallel or before installation instruction writing.

7. Upon installation instruction approval, a signal (which currently exists in the IT infrastructure) will be sent to the ERP system to create “true” demand – essentially the demand that purchasing individuals see and act on in the baseline system. The signal from CAM will automatically adjust downward the quantity in either the pre-demand or intermediate demand basket, depending on which group the applicable part instance number(s) are in. A resulting automatic increase of the quantity in the “true” demand basket will also occur in the same quantity the other two baskets were decreased. If the sum of the intermediate demand and the true demand column do not add up to the supply column, the purchasing individual will know that recently some of the pre-demand had been reassigned as true demand and now needs a PO to account for the discrepancy. An automatic signal will be sent to the purchasing individual to eliminate the discrepancy if this situation does occur. This would be similar to the current automatic signal sent to purchasing individuals if existing supply is smaller than demand.

## **8.5 Summary**

This chapter presented a proposed future state of the ordering system that would help prevent shortages associated with engineering change. This long term solution is not simple and would require a lot of manpower and training to implement. It may require significant capital to create and implement the computing systems that will link the different elements of the change process. The following summarizes the steps needed to implement this long term solution.

1. Implement detailed ECN scheduling: This is completed first because it has the benefit of creating both accountability and an easy to use schedule for every stakeholder in the process. Scheduling requirements akin to the EDCS of the legacy programs should be

implemented as soon as possible because it will only cover new ECNs as it would be very time intensive to retrofit all ECNs which have already been developed. The implementation of a detailed schedule requirement will set the stage for the following steps.

2. Create a forecasting site: A website or application which purchasing individuals can easily access via the BCB intranet that provides a forecast of the parts which are scheduled to be released from CAD over the next 60 days. Each part on this site will have an associated purchasing individual's name attached to it so responsible individuals can filter by purchase responsibility. An associated page will account for all the parts approved in the past 60 days so purchasing does not lose track of parts which have been approved. Purchasing will be able to access a history archive of CAD approvals via this page.
3. Create demand earlier in ERP: Linking CAD approval directly to ERP demand will eliminate the cancel PO messages received by purchasing in the short term solution. Once approved in CAD, a signal will be sent to ERP to create demand. There are three buckets of demand that need to be created. They are as follows:
  - a. Pre-demand: Demand that has been created by CAD approval but does not have either an approved installation instruction in CAM or a PO against these part instances
  - b. Intermediate demand: Demand created by CAD that does not have an approved installation instruction in CAM, but does have a PO placed for these part instances
  - c. Demand: Demand approved in CAD and has an applicable installation instruction approved in CAM. May or may not have a PO against them. In order to determine if a PO is needed, the purchasing individual must sum the intermediate demand and demand and compare to the supply value (which includes items in stock and items on PO). If the sum is less than the supply value, POs need to be placed to cover the discrepancy.

Optimal visibility for the SHC's Materials Management Department will hopefully be the result of this implementation of a knowledge infrastructure to support knowledge sharing.

## 9 Summary and Conclusion

The SHC program's problems with shortages (and resulting two year delay) could have been avoided with the proper foresight and planning. These shortages during the SHC's ramp up were caused by insufficient alignment of the change management sub processes. Other aspects impacting the performance of the current system are lack of accountability, lack of processes to support proper purchasing visibility, and lack of proper triggers. The result of these elements is the significant number of shortages which has plagued the SHC program throughout its history.

When designing a change management system, it is essential that it be treated as important as the supply chain which it will support. It is just as important to have a flexible change management system as it is to have a flexible supply chain for any innovative product. If the change management system is not sufficiently flexible the change management system will suffer just as a supply chain would suffer if the supply chain itself was not sufficiently flexible. This is especially true during the ramp up phase of any innovative product because the nature of these innovative products is that of uncertainty. Uncertainty is always greatest during the ramp up phase of a product, especially when a company and its partners have very little experience with the product's materials. It is therefore necessary to design both the change management and supply chain processes to have the flexibility to overcome the uncertainty of the most risky part, the ramp up, where the company is still learning about the product and materials. Once the ramp up phase has passed, there will be more flexibility in the change process than BSS needs. BSS will then be able to focus on making the change process more efficient when this time comes.

Management can use the same supply chain strategy principles to design the engineering change management system. The change management system must be treated as a supply chain because it is essentially an information supply chain. Instead of transferring material and parts downstream, the change management system transfers different types of information of different fidelity to the sub processes downstream. By implementing supply chain strategy techniques, management can ensure the change management processes are aligned with the needs of the supply chain and any stakeholders impacted by the change process.

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## **Appendix 2: Acronym Glossary**

BCB	BSS Coach Busses
BP	Broad Power
BSS	Bus Solution Systems
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CB	Change Board
CIB	Change Incorporation Board
DE	Design Engineer
DOT	Department of Transportation
EDCS	Engineering/Design Commitment Schedule
ECN	Engineering Change Notice
ECR	Engineering Change Request
GECP	General Engineering Change Process
ERP	Enterprise Resource Planning
FID	Final Integration to Delivery
ISE	In-Service Entertainment
IP	Installation Instruction
IT	Information Technology
LATC	Lithuanian Autobus and Transportation Conglomerate
M/N	Manufacturing Number
ME	Manufacturing Engineer
MES	Manufacturing Execution System
MMD	Materials Management Department
PI	Papelbon Integration
PO	Purchase Order
REDR	Revised Engineering Design Report
SAC	Super Alpha Coach
SBC	Super Beta Coach
SCC	Super Charlie Coach
SCP	Seoul Collision Protection

SDC	Super Delta Coach
SFC	Super Foxtrot Coach
SGC	Super Golf Coach
SHC	Super Hotel Coach
STRACK	Shortage Tracking Tool
TBC	Tokyo Bus Construction
TCCP	The CAD/CAM People
VBS	Venice Bus Solutions
YSBS	Yellow School Bus Systems