Determining the Optimal Set of Solutions for Storage and Conveyance of Tools in a Highly Variable Manufacturing Environment

By

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B.S. Chemical Engineering
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Submitted to the MIT Sloan School of Management and the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degrees of

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and
Master of Science in Mechanical Engineering

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ABSTRACT

In November 2013, Boeing launched a derivative of the 777 airplane, known as the 777X, which will be the largest and most efficient twin-engine jet in the world when it enters service in 2020. In parallel with new airplane development, Boeing is transforming its existing 777 production system through an initiative known as FPS, or Future Production System (FPS), in order to create a more safe, flexible and productive manufacturing environment that accommodates the 777 and 777X. This will require upgrades to be made to the existing 777 manufacturing process.

FPS requirements include the need for a system to better support the mechanic by implementing "final stage tool kitting." My project scope was to plan, design, and implement a tool kitting process for the Service Ready Wing (SRW) area of 777 Manufacturing. The first part of this thesis evaluates the prescribed solution of tool kitting and attempts to evaluate its potential cost and benefit to 777 SRW Manufacturing. The thesis then systematically approaches the problems for which tool kitting is trying to solve, rather than the solution itself. The result is a set of solutions discussed in Chapter 7 that focuses on reducing tool inventory, floor space, and non-value added time of the mechanic.

This thesis is intended to serve as a model for all areas of 777 and 777X Manufacturing as teams continue to work towards understanding how to improve tool management. By providing a systematic approach to evaluating the current-state tool usage in a specific manufacturing area, and focusing proposed solutions on actions that solve a defined problem set agreed to by key stakeholders, this work will help guide other groups towards creating successful, sustainable tool conveyance solutions.

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I would also like to thank my friends for all their support throughout this process: my fellow LGO students who have always made themselves available to share ideas and provide feedback, and my "non-LGO" friends I can always count on to provide the best distractions when I need a break from school.

Lastly and most importantly, I thank my family: my parents, who could not be more supportive of my decision to embark on this incredible 2-year journey, and my younger sister, Lindsey, who has always been my biggest supporter and best friend. I am truly one lucky girl to have you all in my life.

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1. INTRODUCTION

The introduction of any new technology into a longstanding manufacturing system brings about new challenges, both technical and cultural. In most organizations experiencing such changes, scenarios relating to technical concerns will be tested ahead of time (at Boeing, this is a new practice known as Production Integration Testing, or PIT). Cultural concerns however, often go untested and as a result become the toughest to overcome in implementation. This thesis examines a problem, inefficient methods for providing mechanics with the tools they need, for which the original prescribed solution did not fully consider cultural and cost-related concerns that would result in almost assured failure to both implement and sustain meaningful improvements. It then details a re-evaluation of the problem, focusing on implementation efforts that directly address cultural concerns. The solutions discussed in Chapter 7 that are ultimately implemented are done so with complete buy-in of key stakeholders in this process change, including the Manufacturing, Tool Services, and Materials Management organizations. The result is a smaller step-change in the journey towards fully kitted tools than original project goals may have stated, but assures greater success in terms of sustainable systematic improvements than would have been possible had cultural considerations been neglected.

1.1 THESIS OVERVIEW

In order to fully appreciate the learnings and insights gained over the course of my internship, this thesis covers two distinct phases of work: the first half dealing with working on the original project as it was presented to me, and the second half focusing on re-evaluating the project itself and defining my own problem to solve. The time and effort that went into gaining management support to *not* implement the original solution with which I was tasked is something that helped grow my leadership and problem-solving abilities immensely, and is worth highlighting as guidance for future "solution-based" projects. The remainder of this chapter is focused on providing an overview of the project itself. To best understand why decisions were made to change the direction of the project, the reader needs a more detailed understanding of both the company as whole and the day-to-day work that occurs in the 777 SRW area to set the stage: this occurs in Chapter 2. Chapter 3 discusses literature on tool kitting, the concept of "Lean" more broadly, and the systematic problem solving method that was used to provide solutions to tool conveyance issues facing 777 Service Ready Wing. Once the reader understands the background information provided in Chapters 1-3 a discussion of how the first half of the project was managed, which occurred during the first three months of this internship, takes place in Chapter 4. Once the reader is more familiar with the initial efforts in managing this project, the cultural component of working in 777 SRW Manufacturing is discussed in Chapter 5, in order to develop a complete understanding of why this project shifted direction mid-way. Chapter 6 is dedicated to this change and the re-defined problem statement that ultimately shaped the solutions highlighted in Chapter 7. Chapter 8 concludes this work by providing the reader with a full summary of the problem-solving approach that was used in this project, which should be used as a framework for future projects led by 777 and 777X Manufacturing teams.

1.2 Purpose of Project

The purpose of this project was to successfully complete one piece of the overall "Future Production System (FPS)," for the 777 as part of a larger Boeing Commercial Aircraft (BCA) production initiative. This system design update aims to implement automated and / or robotic fixtures that move multi-model (777 and 777X) airplane assemblies throughout the manufacturing line to support single piece flow and improved flow times, while still supporting the massive assembly components and their design and build requirements. Along with automation, a system to better support the mechanics, including "final stage kitting," increased service level support from factory personnel, improved quality plans and significantly reduced flow times will be implemented. My piece of this project scope was to plan, design, and implement a tool kitting process for the Service Ready Wing (SRW) area of 777 Manufacturing. The available build floor space for these areas will be reduced as a part of this production initiative, which is something I needed to consider in my process development.

The mission of tool kitting, as it was defined to me, was providing a shadowbox of necessary tools to the mechanic each time a new IP was performed. An IP is an Installation Plan, or a job that a mechanic performs to build, test or inspect the airplane, and each IP takes approximately two hours to complete. See Figure 1 below for visual examples of a shadowbox tool kit.

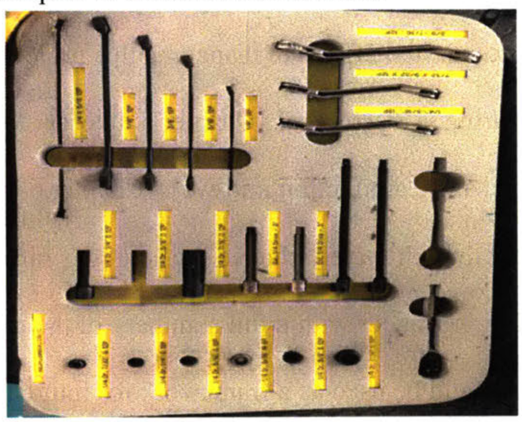

FIGURE 1: 777 TOOLKIT EXAMPLE

Note that, for the purpose of this thesis, "tools" will refer to hand tools only, and not large-scale equipment that is also sometimes referred to by the same term.

1.3 ORIGINAL PROBLEM STATEMENT

The original problem statement that I had based my initial analysis and testing efforts on was taken from a Kitting Vision Future Production System document that was presented to me during my first week onsite. The excerpt that dealt specifically with tool kitting is shown below:

	Initial Kitting Vision	**Long-Term Kitting Vision**
Hand Tools	Delivered in 2 hour (by-IP kits) at bus stop Delivered to bus stop every **8 hours** **2 flow days** of kits stored at TIC	Delivered in 2 hour (by-IP kits) at bus stop Delivered to bus stop every **2 hours** **8 hours** of kits stored at TIC

TABLE 1: ORIGINAL SOLUTION STATEMENT FOR TOOL KITTING PROJECT

My task was to design a hand tool storage and conveyance method that would achieve the "Initial Kitting Vision" of delivering 2 hour by-IP toolkits to a location on the floor near the mechanics' point of use, referred to as the "bus stop." Initially, this vision showed delivery to the bus stop during every shift, or every eight-hour period. Two flow days' worth of kits and carts (on which kits were delivered) were to be stored in the Tool Integration Center, or TIC. The TIC was part of the initial proposed design that was ultimately not used in my final storage and utilization design. The Future State Vision, shown in the second column of TABLE 1, was something that I was asked to plan for, but did not necessarily need to fully implement during the course of my project, due to timing of overall FPS implementation. A detailed discussion of the current state of 777 SRW Manufacturing and how tools were being managed will be provided in Chapter 2.

1.4 PROJECT HYPOTHESIS

My initial hypothesis was that by gathering and analyzing data on tool usage by job, or IP, performed, I would be able to implement a successful "by-IP" kitting process for the 777 Service Ready Wing (SRW) area based off of the Initial Kitting Vision requirements that are shown in Table 1. This would include completing data analysis, workshop sessions with mechanics to gain customer buy-in, and solution testing. After data analysis and workshops had been completed, my hypothesis shifted to a more general statement: by gathering and analyzing data on tool usage by job performed, I would be able to determine the optimal tool kitting/conveyance system for the 777 SRW area of 777 production. This would include definitions of each tool kit, a schedule on how and when they would be delivered to and from the floor, and a detailed understanding of the additional resource requirements that would be needed to achieve this schedule.

1.5 PROJECT GOALS

For the first half of this project, my primary goal was simply to implement a final stage tool kitting process for the SRW area. Key metrics of success were based on the toolkits that I planned to develop:

- Quality – are toolkits being delivered with first-pass quality? How often does the mechanic need to step away from the plane to procure a tool that was not provided to him/her?
- Kit Revisions – are kits being re-defined and iterated in a timely manner (within 24 hours of request)?
- Kit Utilization – are kits being utilized as intended?

- Productivity - Is set-up time for mechanics reduced as a result of kitting?

After better understanding the additional inventory and resources that would be needed to achieve this goal, as described in Chapter 4.2.2, my goals shifted from those stated above to reducing the mechanic's Non-Value Added Time (NVAT) spent setting-up, breaking down, and searching for tools.

One goal that remained constant throughout the duration of this project was to develop a systematic approach for evaluating an existing tool conveyance process in a given area to determine the best possible set of improvement options. Up until this point, other areas in 777 Manufacturing had been developing tool kits without a thorough evaluation of existing state needs. My intention, through company presentations and this thesis, was to provide a blueprint which could be used to standardize the process by which improvements to existing tool conveyance methods were made.

1.6 Project Approach- Original and Revised

My original approach, as detailed in Chapter 4, was to first observe and document how tools were being stored and utilized in the current state process in 777 SRW, and which organizations were involved in and responsible for this. Next, I performed the same analysis in the areas that had already implemented tool kitting: the 787 Program and the FAUB (Fuselage Automated Upright Build) area of the 777 Program, to incorporate best practices from those initiatives into my own work. During my internship I worked with five industrial engineers who interviewed all SRW mechanics to determine which tools were needed to perform each job. I analyzed the data that they collected in order to understand the best type of kitting model for this area. Once I had decided on my ultimate approach, a good portion of my remaining time was spent gaining management buy-in on allowing 777 SRW to implement a tool conveyance design that was different from models previously laid out in other manufacturing areas. I relied on a detailed cost/benefit analysis on the traditional kitting model, shown in Figure 7 (p. 34), to support my conclusion.

2 Operations at The Boeing Company

2.1 Background of Company

Boeing celebrated its 100th year of operation in 2016, and with this came media reflections on the company's achievements over the last century. In an article written in The Atlantic, Boeing's biggest challenges over the next century are said to be minimizing environmental impact of their products while continuing to drive faster, more economical solutions ("A Century in the Sky"). This drive to reduce manufacturing costs can be felt throughout the organization, which is one that prides itself in implementation of Lean Processes, a concept further discussed in Chapter 3.

2.2 Site Background

The Boeing Factory located in Everett outside of Seattle, WA, is the largest building in the world by volume, covering 472 million cubic feet. In January 1967, the facility opened and was originally designed to build the 747 only. Today, it is the location where the Boeing 747, 767, 777, and 787 are all assembled. More than 30,000 people work at this facility, which has its own fire department, security team, and fitness center. The challenges in beginning a new position at a facility of this size were similar to what one may experience when moving to a new city: securing a parking space can be extremely challenging; navigating the entire complex is a difficult task that often results in being late to meetings; the sheer number of people in the building makes one feel a bit overwhelmed at first, but in time it all becomes more familiar. The size of the facility also played a role in the culture within 777 Manufacturing. In "Emerging from Turbulence: Boeing and Stories of the American Workplace Today," authors Leon Grunberg and Sarah Moore note a recent dramatic shift in Boeing's corporate culture due to "a focus on cost-cutting and bottom-line profits, a hard line with unions, outsourcing of work, and a steely approach to layoffs and work transfers." While these changes have undoubtedly also been felt across many other American manufacturing plants, the size of the Everett facility brings more opportunity for rumors to spread quickly. As a result, messaging around any cost-cutting actions needs to be clearly directed all the way down the organizational hierarchy, as discussed in Chapter 3.1.

2.3 Boeing 777

The Boeing 777 is a family of wide-body twin-engine jet airliners, commonly referred to as the "Triple Seven." It was designed to bridge the capacity difference between the 767 and 747, as shown in Figure 1.

Figure 2: Boeing Product Lineup (The Boeing Company, 2014)

The first 777 entered commercial service on June 7, 1995. The advanced technologies implemented in the initial design included glass cockpit flight displays, a fiber optic avionic network, and digital fly-by-wire controls. To accommodate production of this airliner, the Everett factory size was doubled to provide space for two new assembly lines. In January 2016, Boeing announced a rate reduction from 8.3 planes/month to seven planes/month due to a lack of new orders, in part because of the next generation 777 model discussed in Chapter 2.4. This rate reduction generated feelings of low morale among mechanics, contributing to cultural concerns that are raised in Chapter 5. As a regular attendee of mechanic shift meetings, I experienced firsthand the questions raised around job security, for which management was not able to provide definitive answers.

2.4 Boeing 777 Service Ready Wing

The 777 Service Ready Wing manufacturing area, which was the focus area of this project, is where all the work needed to fully prepare the wings before they were attached to the fuselage of the plane is completed. A rough outline of this area is shown below in

Figure 3: the red boxes denote existing toolbox area, which is about 25-40 feet away from most locations in which mechanics are working in this area.

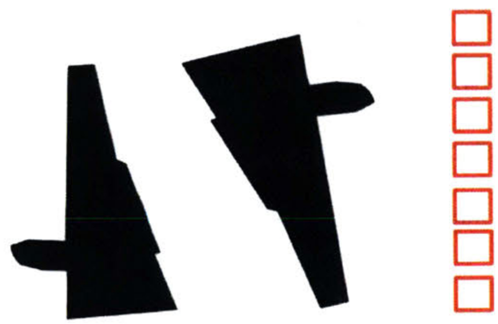

Figure 3: Outline of SRW Working Space

Each job, referred to as an IP (Installation Plan), takes approximately two hours to complete. The jobs completed in Service Ready Wing jobs are performed across three shifts, with approximately 78% of mechanics working on each of the first two shifts, and approximately 22% of mechanics on the third shift. A large subset of these jobs are handled by electricians, as wiring is a critical component to ensuring wing readiness. A wide variety of tools are also needed to support this work: approximately 884 unique types of hand tools are utilized by the mechanics in SRW. A more detailed discussion of how the mechanics obtained, stored, and utilized tools can be found in Chapter 4.2. A number of different organizations support the mechanics in completing their work. During my initial observations, I found that while most tools were kept on the floor in toolboxes, which were managed by the Manufacturing team, certain tools were kept in a tool room, managed by the Tool Services support organization. In general, Manufacturing preferred ownership and management over their own materials as much as possible, by keeping tools in toolboxes on the floor versus in the tool room, which was a cultural nuance that needed to be considered as part of this project, and is discussed further in Chapter 5.

2.5 Market Competitiveness: Why Transformation is needed

In November 2013, Boeing launched a derivative of the 777, known as the 777X, which has already sold a number of airplanes through pre-orders (approximately 300 as of August 2015). The 777X will be the largest and most efficient twin-engine jet in the world, with lower fuel consumption and lower operating costs than the competition when it enters service in 2020. In parallel with new airplane development, Boeing is transforming its existing 777 production system through the FPS initiative, as discussed in Chapter 1.1, to create a more safe, flexible and productive environment that accommodates the 777 and 777X. Both models will be manufactured on the same line in the Boeing Factory, and thus both will need to be supported by the same set of tools and equipment. This will require upgrades to be made to the existing 777 production system.

3 Literature Review

Much of the kitting research available to date focuses on kitting parts rather than tools. In 777 SRW Manufacturing, parts are already kitted through a process that works fairly well: parts are delivered to a specific area on the floor based on the schedule of jobs to be performed for the day, and are consumed as these jobs are performed. While schedule delays often occur in 777 Manufacturing, the fact that each part needs to be consumed at some point in the build process, and only so many parts per airplane exist, ensures that no serious part buildup on the floor occurs. A key difference between kitting parts and tools, and one that adds significant complexity to the overall tool kitting process, is inventory management: tools are not consumed by the plane as the build process evolves (just the opposite: great efforts are taken to ensure that no tools remain on the plane while it is being manufactured). This results in the need for a two-way inventory flow of tools, and not the one-way flow process through which parts are currently managed. Additionally, parts are used exactly once in a specific assembly sequence, while multiple tools can be used for the same jobs, and the same tool can be used for different jobs. All of this adds to the complexity of managing tools.

3.1 Literature on Tool Conveyance and Kitting

A study focused on implementation of tool kits notes that one of the first questions that needs to be asked when evaluating tool kitting is "What are the preferences of service engineers with regards to tools and tool kits?" (Vliegen, Kleingeld, & van Houtum, 2010). The survey results feedback discussed in Chapter 6.2 provides an overview of the opinions of mechanics and other Boeing employees with regards to tool kitting. This study highlights the fact that in order to fully kit tools, a greater number of tools are typically needed than are used in a current non-kitted process state. However, it also warns against considering only increased tool costs without understanding other aspects of tool kitting, because this could lead to the conclusion that tool kits should not be used at all. The need for more tools in order to implement by-IP toolkits was certainly true for 777 Service Ready Wing, as shown in Table 4, but one of my goals was to determine whether this increased cost was justified.

Overall, different kitting strategies seem to have varying degrees of success in different manufacturing environments. The opportunity for improvement is summarized well in a study completed at Caterpillar by Carlsson and Hensvold (2007): "Kitting does not automatically bring the benefits described in this research, it provides an opportunity to bring them, but without an organizational effort kitting might just lead to the opposite. Kitting demands a great deal from an organization, especially when it comes to information. Without accurate information, accurate kits can't be done. Without accurate kits, assembly can't be done without end product quality defects. With end product quality defects you end up with dissatisfied customers and in the long run without any business." With this in mind, a key question that I needed to address as a part of this project was whether 777 Service Ready Wing had the ability to provide the increased organizational efforts that a successful tool kitting process demanded.

Many companies consider kitting to be a "lean" practice, as it attempts to address wasted time associated with waiting for tools and unnecessary movement. In the company as a whole, Boeing places emphasis on utilizing lean manufacturing techniques, and has an entire organization dedicating to implementing these techniques on the shop floor. The theory behind lean processes is discussed in the following section.

3.2 LITERATURE ON LEAN

Feld (2001) breaks down the concept of Lean Manufacturing into five parts, noting that each part is critical to the development of a world-class manufacturing environment. These five parts are described below:

- Manufacturing Flow: the aspect that addresses physical changes and design standards
- Organization: the aspect focusing on roles/functions, training, and communication
- Process Control: the aspect directed at monitoring, controlling, and pursuing ways to improve the process
- Metrics: the aspect addressing visible, results-based performance measures
- Logistics: the aspect that provides definition for operating rules and mechanisms for planning and controlling material flow

He then goes on to note that even with effective operations in each of these areas, true competitive advantage can only be gained through three underlying principles: (1) building an empowered workforce, (2) engaging all employees by steering their collective energies in the same direction, and (3) empowering this workforce with expectations and accountability to get the job done.

During my time at Boeing, I found that the company was diligent about pursuing opportunities within each of the five parts mentioned above. Entire teams were set up around these elements, and all were involved in project improvement opportunities. A huge opportunity for improvement with these teams exists when considering the principles that contribute to an organization's competitive advantage. While select employees demonstrated a feeling of empowerment when working on lean projects, the organization as a whole could have used more engagement and direction, as mentioned in Chapter 5.2.2.

A key concept that is often brought up in the discussion of Lean manufacturing principles is that of "muda." According to Krajewski et al. (2007), the essence of Lean is to maximize the value added by each activity in an organization by paring unnecessary resources and delays from them. These unnecessary resources are referred to as waste, or "muda." Taichhi Ohno, the creator of the Toyota Production System, originally defined seven wastes on which to focus elimination efforts, eventually adding an eighth. These are reviewed by Corakci (2008) and briefly described below:

- Waste of Overproduction: producing items when there are no orders
- Waste of Waiting: waiting time by workers, materials, or customers
- Waste of Unnecessary Movement: bending, stretching, walking, or looking for materials
- Waste of Transporting: inefficient transportation of materials
- Waste of Over processing/Incorrect Processing: unneeded or inefficient processes
- Waste of Unnecessary Inventory: excess raw materials and finished materials
- Waste of Defects: producing defective parts
- Waste of Untapped Human Potential: not engaging or listening to employees

The major goals of tool kitting in general are focused on reducing the wastes of waiting and unnecessary movement. Current state measurements of these wastes are exemplified in Chapter 4.1.2. For my project in particular, I also focused on reducing the waste of untapped human potential. I wanted to involve affected employees in each step of the journey towards developing a sustainable improvement to tool conveyance in 777 SRW Manufacturing, and recognized that many mechanics had valuable insight into improvement opportunities in my project area: they just hadn't been asked for this feedback in the past.

3.3 Literature on Systematic Problem Solving

So, how was the solution of tool kitting determined to be the ideal state scenario for 777 Manufacturing? Was this determined through data analysis or experience and intuition? In general, people tend to be poor intuitive problem solvers. They formulate hypotheses with incomplete data- and even when this information is available, they tend to ignore it if it does not support existing preferences (Dawes, 1982). Tyre, Eppinger, and Csizinszky (1995) examined the role of systematic problem solving versus more intuitive approaches in driving changes on the shop floor. Their results show that systematic problem solving leads to better quality and more robust solutions, without requiring additional time in comparison to using intuitive approaches.

What does a systematic problem solving approach entail? Many different approaches have been established in attempt to answer this question, each with a unique set of questions to answer as one evaluates the problem-at-hand. One of the oldest and simplest approaches to systematically solving a math problem is a set of four principles first published in 1945 by George Polya. These principles are outlined below:

1. Understand the problem: What is the unknown? What data is available?
2. Devise a plan: What is the connection between the data and the unknown? Polya suggests several strategies in devising this plan, including: looking for a pattern, eliminating possibilities, and working backwards
3. Carry out the plan: Be careful to check for mistakes at each step!
4. Check the solution: Check the results and reflect on the experience: What worked/what didn't?

While these techniques may not have originally been intended for use in a manufacturing environment, I found that this problem solving approach provided a way to plan and communicate my project work in a simple, easy to follow methodology.

Building on this, Tyre, Eppinger, and Csizinszky (1995) developed a more robust, eight-step model to problem solving, intended for use specifically in manufacturing-related areas. This model is described below.

1. Problem Description: Recognize a set of symptoms as a problem.
2. Problem Documentation: Gather quantitative and/or qualitative data on the nature of the problem in order to characterize it more fully.
3. Hypothesis Generation: Consider one or more alternative explanations before settling on an agreed "cause" of the problem.
4. Hypothesis Testing: Develop experiments and collect data to test hypotheses.
5. Solution Planning: Once a diagnosis is made, collect, analyze, and select among possible solution ideas.
6. Solution Implementation: Translate the solution plan into hardware, software, and/or procedures as required. This may involve adoption of existing approaches or development of new technology.
7. Solution Verification: Collect data to test whether the solution implemented actually solves the problem.
8. Incorporation: Incorporate the solution into the process so that the problem will not recur.

Steps 2, 4, and 7 involve data gathering and observation, steps 1, 3, and 5 involve analysis. Finally, steps 6 and 8 involve action.

While I did not gain an understanding of the history behind the tool kitting initiative at Boeing, my intuition was that the level of data gathering and analysis recommended by this model is far more than what was used when tool kitting was originally determined to be the most effective solution in tool improvement for the 777 manufacturing process. I relied on an increased focus on analysis to change the mindset of those that were already set on tool kitting as the only feasible solution. Chapter 8 provides a summary of my project work using Tyre, Eppinger, and Csizinszky's 8 step model.

4 METHODOLOGY

This chapter describes the work I did in pursuit of the original problem statement. This comprised benchmarking other kitting operations at the Everett factory, gathering data on existing tool usage and conveyance in 777 SRW, and trying to justify the original vision of kitting. When this effort did not produce a convincing justification, I changed my approach.

4.1 CURRENT STATE ANALYSIS: BENCHMARKING IN FAUB AND 787

Mechanics in the 777 program obtained their tools through a variety of methods, depending on the specific job, or IP. In my first week at Boeing, I spent a majority of my time job shadowing in FAUB, a manufacturing area which had recently simultaneously implemented a new build process and a new tool kitting process. FAUB is a system of robots that fastens 777 fuselage sections together. FAUB is in active use but is also evolving as the company learns more about operating a complex robotic system.

While observing in FAUB, I was examining their process as a model for developing SRW's tool kitting strategy. FAUB was kitting their tools by "bar," where each bar represented one shift of activity for a single mechanic. The overall plans for bars of work to complete each day are held in "bar charts," which are owned by the Industrial Engineering (IE) team. These charts provide a blueprint of work for each airplane that is manufactured across The Boeing Company. I learned quickly that in FAUB, actual jobs being performed changed very frequently and were not often worked according to the bar chart sequence. This caused huge issues in the tool kitting plan, which depended on stability in sequence to kit tools with enough lead time. During my observations, I examined a scramble before each shift to pull together what mechanics would need for the next shift, which was often based on a piece of paper that a manager would hand to a person in the Tool Integration Center (TIC), where tools were being kitted. Overall, the lesson I learned from my time shadowing in FAUB was that in order for any level of tool kitting/delivery system to work, production would need to be stable, and a schedule would need to be followed.

Because FAUB involves a new manufacturing process, whereas SRW is well-established, I was hopeful that a schedule was more closely followed in SRW. In order to better understand the level of instability present in FAUB versus SRW, I evaluated the average time scheduled to complete a job compared to the actual time it took to complete a job (clock-in to clock-out by mechanic) in FAUB compared to SRW. This comparison was taken across the first 500 jobs in performed in each respective area, and averaged over the 25 planes most recently manufactured. For reference, in an ideal state, no variability should exist and every job should be marked at 0% for an on-time completion. Results are shown below: in order to visualize the magnitude of the relative instability in each area, the same axis limits were used for each graph.

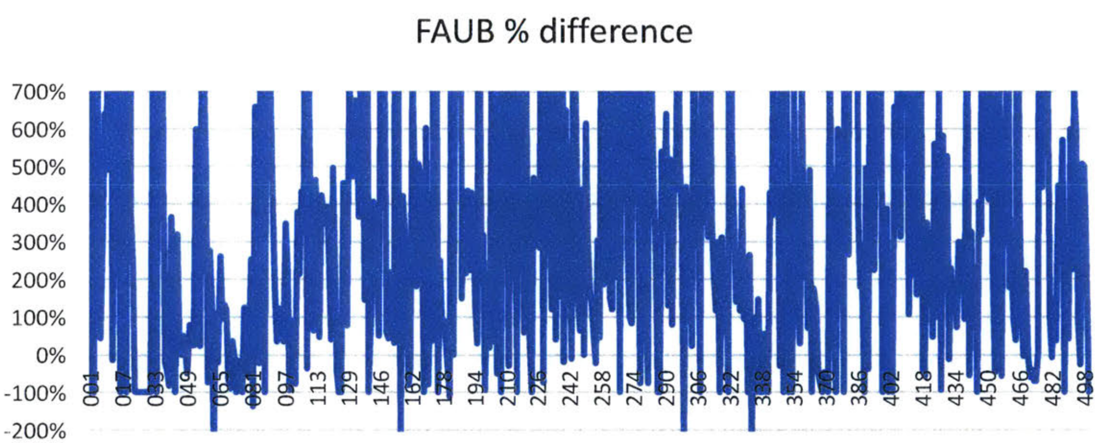

FIGURE 4: % DIFFERENCE IN SCHEDULED V ACTUAL TIME (MIN) TO COMPLETE A JOB IN FAUB

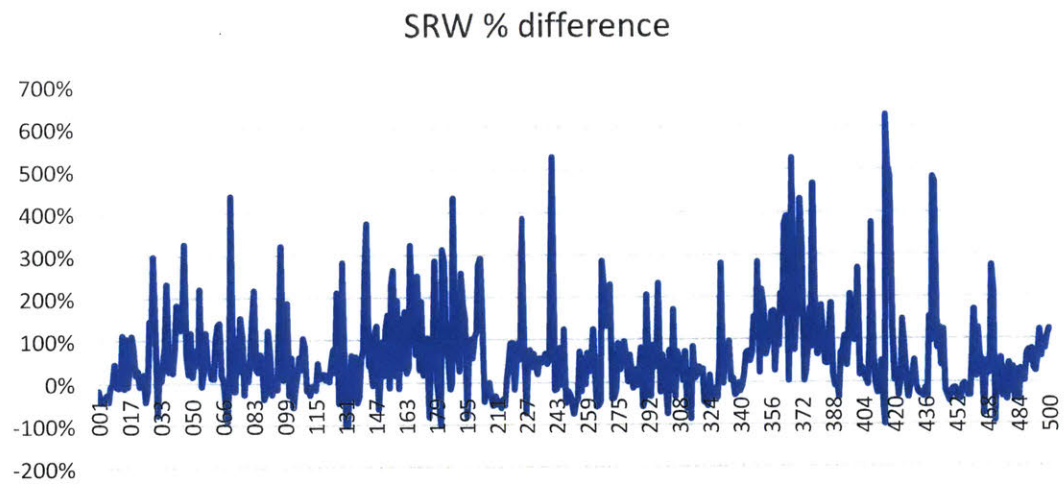

FIGURE 5: % DIFFERENCE IN SCHEDULED V ACTUAL TIME (MIN) TO COMPLETE A JOB IN SRW

A comparison of FIGURE *4* and FIGURE *5* shows that jobs scheduled in FAUB take significantly longer than scheduled to complete versus those in SRW. It should be noted that while SRW is more stable, actual completion time is regularly double (+100%) the scheduled (i.e., anticipated) completion time, demonstrating that the bar chart in SRW was by no means a model to follow, but was just more stable compared to FAUB.

I had originally thought that FAUB would provide me with a model for tool kitting that I would simply need to implement in SRW. After shadowing this area, I left feeling like I had witnessed a system that added cost to the manufacturing process, without seeing any of the benefit that should have been gained from reducing a mechanic's time spent locating tools. Continuing to look for an example of success in tool kitting, I visited the 787 program, which was the only other area in the Everett facility that had also implemented tool kitting. In discussions with members of the Lean team who were associated with this project, the message I received was that their kitting process was going much more smoothly due to better pre-work instructions that they had put in place with mechanics. This included creating paper records with a list of tools by IP and having the mechanic validate that the tools for the jobs they worked were listed correctly.

However, spending an hour with the 787 TIC manager showed me that their kitting process was not running nearly as well as I had been led to believe. By ramping up headcount in support staff, they were able to better handle the increasing amount of work that came with implementing tool kitting, but at a significant cost to the program. The paper records of tools needed by IP that were used to create the initial toolkits were incorrect about 40% of the time. Root cause analyses of the incorrect data led back to a variety of reasons: mechanics were not actually working the jobs when they reviewed the list of tools for each job, and often times more tools were needed than they realized; different mechanics preferred to complete jobs using different tools; ergonomic requirements were different based on size of person; etc. The TIC Manager also expressed a concern over the number of tools that were being purchased in order to support this new kitting system. Unique tools were now needed for each IP, because each job now had its own shadowboxed toolkit. As a result, tools that were previously shared in toolboxes could not be so any longer.

Budget constraints were not something that had been discussed in my original project proposal, but after spending time in the 787 program, I had two main cost concerns: the number of support personnel that would be needed to kit and maintain tools in SRW, and the cost of purchasing new tools to support tool kitting. Before focusing on costs associated with changes, I needed to understand exactly how tools were currently being conveyed within the area where I was assigned.

4.2 Current State Analysis: 777 SRW

Spending time on the manufacturing floor was the best way to understand how mechanics procured the tools that they used to complete each job. In SRW, tools were obtained one of three ways:

1. Toolboxes, which are permanently assigned to the SRW area: 69 toolboxes in total of varying sizes.
2. Tool bags, also referred to as "process kits:" used by mechanics who perform specific job types, such as plumbing and electrical. These are used on a variety of jobs and often require additional tools from the toolbox in order to fully complete an IP.

3. Tool Room tools: Mechanics travel to a tool room to check out any additional tools that might be needed to complete a job.

When watching mechanics set-up their work area for the day, I noted that it took a significant amount of time in order to get all of the materials that they needed to complete their job, which was further demonstrated in the time study data discussed below. While I was only focused on tools, opportunity certainly existed to improve the conveyance strategy for all materials, such as parts, standards (very small parts like fasteners), and cutters (drill bits) and I wanted to better understand how all of this impacted the overall time that a mechanic spent completing his or her job. Industrial Engineers regularly complete time studies on specific jobs to determine how much time is spent doing each particular task of a job. When looking at all of the time study data collected in 2015 in the SRW area (11 time studies in total), the following items were directly associated with tool-related functions:

% of Job Completion Time			
PrepWork	Set Up	Tools	2.0%
PrepWork	Get	Tools	1.4%
PrepWork	Break Down	Tools	1.6%
PrepWork	Return	Tools	1.1%
Delay	Search	Tools	0.2%
	TOTAL		**6.3%**

TABLE 2: TOOL-SPECIFIC TASKS AND THEIR % OF TOTAL JOB COMPLETION TIME

This total amount of time seemed very low to me, especially considering how much focus this project had received as an improvement opportunity. It seemed as though this improvement project was chosen without fully understanding what the root cause of a mechanic's non-value added time actually was. By broadening the scope to include at all "non-value added time" categories, a much bigger opportunity for improvement exists. Only examining items associated with Prep Work and Delays (not associated with lunch time or predetermined breaks) shows that 35% of a mechanic's time is spent performing non-value added tasks that would fall under the waste category of "Unnecessary Movement." A breakdown of this information is shown below.

% of Job Completion Time		
Delay	Inspection	1%
Delay	Other	2%
Delay	Talking	2%
Delay	Waiting	14%
PrepWork	Break down	3%
PrepWork	Clean up	3%
PrepWork	Get	3%
PrepWork	Return	1%
PrepWork	Set Up	6%
	TOTAL	**35%**

TABLE 3: ALL NVAT RELATED TASKS AND THEIR % OF TOTAL JOB COMPLETION TIME

While this was not the focus of my project, bringing this information to the attention of management in the 777 program allowed for a separate project to be approved which examined non-value added time more broadly.

As I spent more time on the manufacturing floor gaining a better understanding of the current state of 777 SRW's tool conveyance, I also had informal discussions with mechanics on their thoughts on the idea of tool kitting. Overall, most seemed to think that the theory of being given all tools they needed exactly when they needed them made sense, but it was clear that they did not think this was realistically achievable and provided me with many very valid concerns surrounding instability of the bar chart, highlighted previously in FIGURE 5, and tool preference by mechanic. Additionally, they were all quick to recount past examples of projects that had similar intentions, but had failed in implementation. The most notable of these was the Andon initiative. Andon is a lean concept, defined by Moore (2007) as a simple visual system consisting of a visible light or sign that shows the state of an operation. Its purpose is to quickly inform the appropriate people when there is a problem so they can attend to it. When lights are used, they are normally coded: Green = Okay, Yellow = Problem, Red = Breakdown. At Boeing, computers were set up around the manufacturing area so that mechanics could enter emergent needs for materials as they arose during the work day, with colored lights as described above to highlight the level of urgency for the request. The mechanics told me that the system worked for certain material requests, but that any time a tool was requested, Tool Services did not respond in a timely manner to the request. As Thomas Watson, former CEO of IBM, once said, "The toughest thing about the power of trust is that it's very difficult to build and very easy to destroy." After a few requests for emergent tools that went unanswered in the Andon system, mechanics simply stopped trusting in and using the system. As a result, these computers sat idle around the manufacturing area; I never once saw them used during my time on the floor, and many were literally covered in dust. Attempting to create a new type of system would first require the difficult step of re-building the trust of the mechanics.

4.3 Tool Data Collection and Analysis

A team of four Industrial Engineers worked across all three shifts in SRW and documented the tools that were used for each job in this area. They entered this information into a database referred to as the Kit Materials Integration system, or KMI. This database is also being used by FAUB to kit tools based on the data entered for each job. After the first-pass data entry had been completed, I was able to analyze each control code, a unique set of work within SRW to complete with an independent crew of mechanics, to understand the quantity and cost associated with the tools used in all jobs across the area. SRW contained three control codes: 128, 129, and 130. A summary of this data is shown in Table 4.

	CC 128	**CC 129**	**CC 130**	**Total**
# of Unique jobs	518	135	237	890
# of jobs requiring tools	421	119	221	761
# of unique hand tools	668	220	382	884
Total # of tools	5,338	1,280	2,781	9,399

Table 4: Tool Data for SRW Areas

The first problem that I was able to solve with this data was whether or not it made sense to create a base kit for each mechanic in SRW. A base kit is a standard kit of identical tools provided to each mechanic. This is something that was utilized in FAUB, and seemed like a potentially simple option for maintenance of toolkits. The concept of a base kit relies heavily on the level of tool commonality across the jobs for which a base kit would be used. If many jobs use similar tools, then providing each mechanic with one set of these tools, and kitting any additional tools that might be needed for specific jobs in supplemental kits, would require less tools to be purchased overall than if tools were kitted by job. However, after evaluating tool commonality across the 890 IPs in SRW, I found that base kits did not appear to be a solution that would be helpful to the mechanic or cost effective to the program. Across all 890 IPs, many tools were used commonly across less than 10 IPs, but very few tools were shared commonly across more than 40 IPs. When trying to understand how many jobs would be well served by the "ideal" basekit, the results showed that at most, four tools could be shared across 16 IPs. FIGURE 6 provides a visual representation of the lack of tool commonality across the IPs in SRW, showing that the highest degree of tool commonality in control code 130 is four tools that are used commonly across 16 IPs. Each circle represents a tool, and the size of the circle represents the number of times that particular tool is used in the completion of an IP. The locations where circles overlap represent where these tools are used to complete the same jobs, which is a very small area for all four circles.

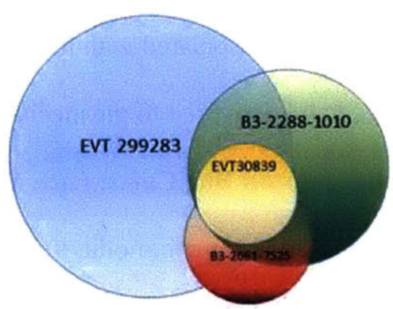

FIGURE 6: OVERLAPPING CIRCLES REPRESENT TOOLS USED ON MULTIPLE JOBS

Implementing base toolkits was just one idea in a series of possible kitting solutions, and in order to determine the best tool kitting option, I relied mainly on discussions with Lean personnel at Boeing in order to determine other tool kitting options for evaluation. Below are the options and descriptions that I evaluated. For each, the type of cart (or conveyance method on which the kit would be placed and used to deliver to the mechanic) is also specified.

1. **IP Kits on IP Carts:** Each job would have a specific toolkit associated with it that contained all tools necessary to perform that job; each job would also have a specific cart associated with it on which all other kitted materials (parts, standards, cutters) would be placed and delivered to the mechanic.
2. **IP Kits on Bar Carts:** Each job would have a specific toolkit associated with it that contained all tools necessary to perform that job; each bar of work (3-4 jobs per shift) would have a specific cart associated with it on which all other kitted materials for that bar of work would be placed and delivered to the mechanic.
3. **Bar Kits on Bar Carts:** Each bar of work would have a toolkit associated with it that contained all tools necessary to perform that complete shift of work; each bar of work would have a specific cart associated with it on which all other kitted materials for that bar of work would be placed and delivered to the mechanic.
4. **Base and Supplemental Kits on Bar Carts:** Each mechanic would have a base kit that contained identical tools, any additional tools that might be needed would be kitted by job; each bar of work would have a specific cart associated with it on which all other kitted materials for that bar of work would be placed and delivered to the mechanic.
5. **Commodity and Supplemental Kits on Bar Carts:** Each mechanic would have a base kit that contained identical tools by job function, or commodity (e.g., plumbing kit, electrical kit), any additional tools that might be needed would be kitted by job; each bar of work would have a specific cart associated with it on which all other kitted materials for that bar of work would be placed and delivered to the mechanic.

After fully defining each of these options, I quantified the amount of kits and carts that would be required to support each option, as well as a list of pros and cons for each option.

	Current State Reference	IP Kits on IP Carts	IP kits on Bar Carts	Bar Kits on Bar Carts	Base & Supplemental Kits on Bar Carts	Commodity & Supplemental Kits on Bar Carts
Option	0	1	2	3	4	5
# Kits	0	761	761	262	>761	<761
# Carts	approx. 50	288	87	87	87	87
Pros		Flexibility to pull/push IP's as needed	Flexibility to pull/push jobs as needed; Less space than IP carts	Less tools and carts		Flexibility to pull/push IP's as needed; Utilizes existing kits
Cons		Requires significant amount of space for carts	Potential for too many kits on a cart.	No ability to push/pull jobs. Potential for too many kits on a cart.	Lack of tool commonality to support this option	Potential for too many kits on a cart.

TABLE 5: SRW KIT AND CART ANALYSIS SUMMARY

Laying out the options in this simplified manner allowed me to quickly eliminate option 1, because of the amount of space on the floor that would be needed to stage 288 carts. While I had not been provided with a clear definition of the amount of space that would be available in our future state to store and convey carts, I knew that an overall goal of the future state was to use space as efficiently as possible, so options that required less square footage would be more optimal. Option 4 was also eliminated based on the analysis performed regarding lack of tool commonality across shifts. Option 3 was originally one that I had thought would be a strong candidate for the foundation of tool kitting in SRW, but after further discussion with Industrial Engineers, I realized that this would also not be feasible. The bar chart was going to be undergoing fairly significant changes as part of the future state production system, and many jobs were going to be shifted between control codes and shifts. This required flexibility in terms of how tools were kitted: I did not want to design a kit for an entire bar of work (approximately 4 jobs), if that bar was going to change after the kit was designed. Given these constraints, options 2 and 5 were left as the best potential solutions. Because mechanics were already using commodity kits for electrical and plumbing jobs (as described in Chapter 3.1.2), and these seemed to be working well for them, the best approach would be to continue using these where appropriate, and kit all supplemental tools for each IP. Thus, I moved forward with continuing to develop a kitting plan based on option 5: commodity and supplemental kits on bar carts

4.4 Working the Prescribed Solution

While I felt confident that I had fully evaluated this data and determined the best tool kitting method for the SRW area, I was still not confident that this method was better at addressing FPS requirements than current state processes in tool conveyance. My main concerns were around square footage requirements for the new system and cost associated with support staff to ensure this kitting system operated properly. Intuitively, it seemed like more space would be required to support all options presented, even though available floor space was being reduced in SRW with FPS implementation.

I performed a cost-benefit analysis in order to gain a better understanding of what level of support staffing SRW could realistically afford in order to achieve a break-even level from a cost perspective. In order to simplify this analysis, I excluded all non-recurring kitting costs, including tools that would need to be purchased for kitting and cost of materials to build kits and carts (assumed to be one-time only costs). I focused on the three key variables that had the biggest impact on the cost and benefit in a kitting system:

1. Ratio of number of mechanics to number of increased level of support staff involved in kitting system
2. Salary delta between mechanic and support staff personnel
3. Potential % time savings for the mechanic that could be achieved

I kept the potential % time savings constant at a maximum of 6% based on the time study results in Table 2. By varying the ratio of mechanics to support staff and salary delta between the two, I was able to show how these two variables impacted the cost and benefit of a kitting system. For the purpose of sharing these results internally, I mainly used a salary delta of $0, as many people felt that only a mechanic could fill the role of support personnel in this new system as they were the ones who knew the jobs and requirements best. Results shown below:

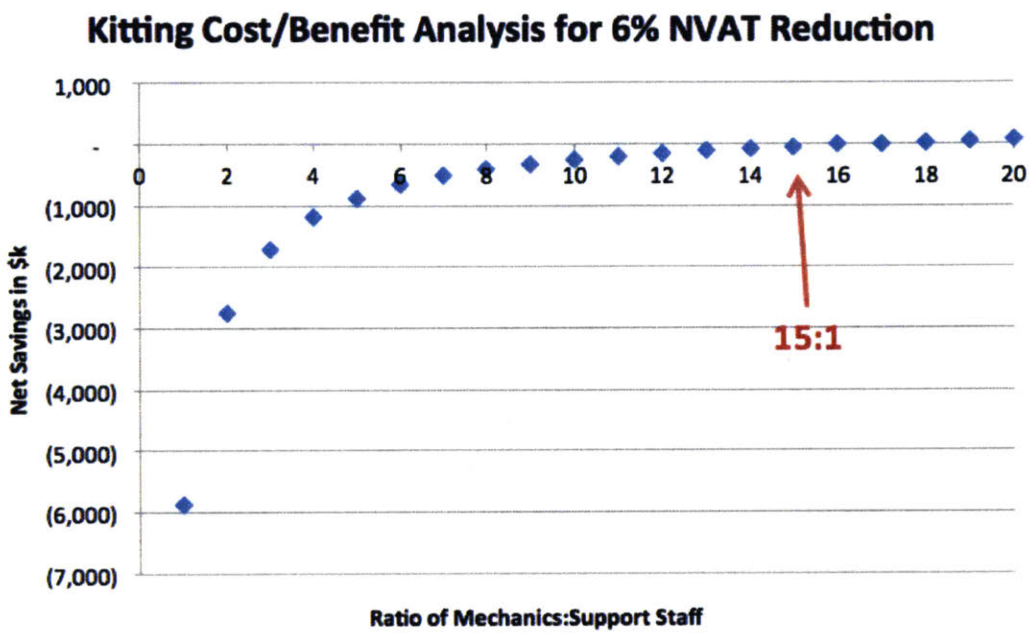

FIGURE 7: KITTING COST/BENEFIT ANALYSIS USING $0 SALARY DELTA AND 6% NVAT

This graph shows that a break-even kitting system can be achieve at a 15:1 mechanic-to-support staff ratio. The logarithmic nature of the graph shows that if this ratio is not achieved, a potential for a huge loss exists, but also that the system design could come very close to break-even at a 12:1 ratio or above.

The next step in this evaluation was to understand whether a 15:1 ratio was achievable in SRW. In order to obtain a reasonable estimate of the number of support personnel that would be needed, I simulated an average day of work for each of 35 mechanics, which is the average number of mechanics in SRW over one shift. The first row of the graph below represents each mechanic, and the first column denotes the time broken down into 10-minute increments. In order for a mechanic to perform each IP without waiting at any point for their materials, four support personnel would be needed. The graph shows that each of these four support personnel would stage the IP kits near their respective mechanics before the IP was scheduled to start and return these IP's kits to the Tool Integration Center after they were finished.

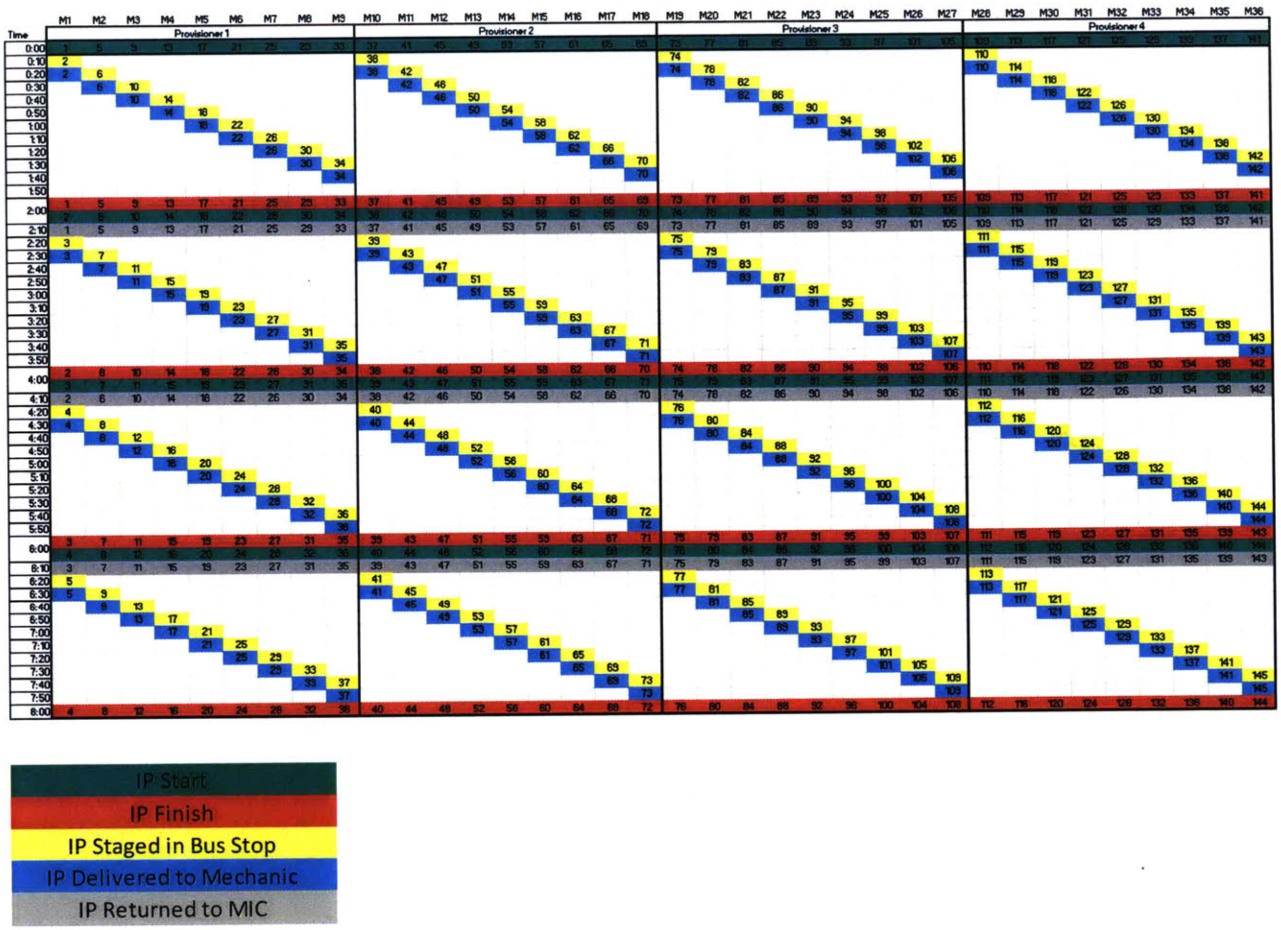

FIGURE 8: MODEL OF SUPPORT PERSONNEL NEEDED TO SUPPORT TOOL KIT DELIVERY AND RETRIEVAL

This model supports the statement that in an ideal manufacturing environment (e.g. no rework needed, on-time job completion) a 9:1 ratio would realistically be needed to achieve the 6% NVAT reduction. Per FIGURE 7, this would put the overall savings of the kitting system at a net loss. My conclusion from Figure 6 and Figure 7 was that the solution to fully kit tools in 777 SRW in order to reduce mechanic NVAT was cost-negative: the program would ultimately lose money with this type of design. Once this conclusion had been determined, I started a difficult process of trying to communicate these results and change the project that I was originally tasked with implementing. I knew that I could still work towards improvements in tool utilization and storage that would be cost effective, but needed management approval in order to do so. This process was much more difficult than simply analyzing the data, and was a significant challenge as a leader and communicator. Until I had worked through changing this narrative, I needed to continue on with the project-at-hand, which included determining what the bar carts should look like that the mechanics would use during the work day, and onto which the tool kits would be delivered.

4.4.1 Long Term Vision Cart Workshop Results

Regardless of the final strategy in tool kitting, I felt that gaining mechanic buy-in would be key to successfully implementing any change and wanted to ensure regular communication with the mechanic teams within SRW to get their insights and feedback on proposed changes. I started this process by holding a one-day workshop with a group of 16 mechanics to design what they thought an ideal cart would look like for the future state. This cart would need to hold their tools, parts, and standards that would be needed to complete each job. While parts and standards were not the focus of my personal kitting initiative, I did want to make sure they were incorporated into the cart design.

In FAUB and 787, they had designed all new carts for the mechanics to work from, so I used those examples (shown in Figure 9 and Figure 10) as a starting point in my discussion.

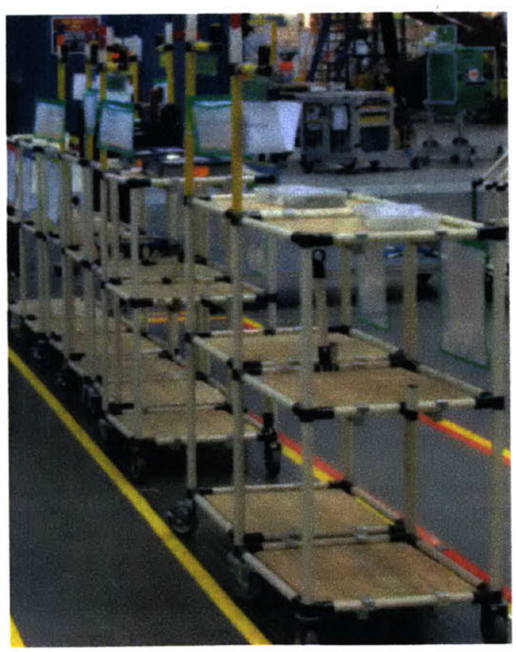

Figure 9: Final Stage Cart for 787

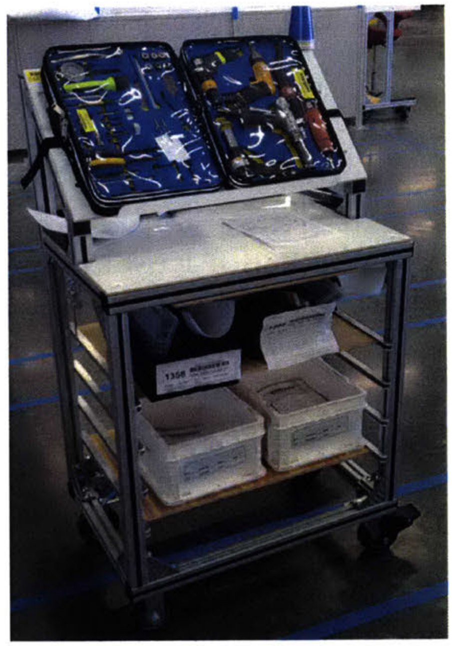

FIGURE 10: FINAL STAGE CART FOR FAUB

While these carts had a neat, uniform appearance, the mechanics in SRW quickly rejected the idea of having a "one size fits all" solution for their work carts. They explained that certain jobs require few tools and are completed in tight spaces better suited for smaller carts, while other jobs utilize tools that require set-up steps and would benefit from a larger working surface area on the top of the cart. I had mechanics split into groups and design carts that would be ideal for different jobs by randomly assigning an IP to each group. They identified a few key parameters that would be helpful for all carts, including: a durable surface, raised sides to ensure that tools do not fall off of the top, and additional hooks along the sides of the cart to allow for more convenient tool access. While each group was designing, one mechanic retrieved a cart that he had already created for himself to show as an example, shown in FIGURE *11* and FIGURE *12*.

FIGURE 11: EXPANDABLE SIDES

FIGURE 12: RAISED EDGING TO ENSURE ITEMS DO NOT ROLL OFF SURFACE

Many mechanics liked the features that had been added to this cart, and requested that we improve their existing carts rather than create entirely new ones. As someone conscious of creating excess waste, I thought this sounded like a very reasonable idea. We left this workshop in agreement that for anyone who felt the existing cart they used was insufficient, we would create a new cart to meet their needs. For most mechanics, we would work on improving existing carts. This started the journey of a "one size does NOT fit all" solution that continued to be a theme throughout the duration of this project.

4.4.2 IP TOOLKIT VALIDATION AND TESTING

In order to validate the accuracy of the tool data that was collected by job, we tested the theoretical "IP toolkit" by physically providing the exact tools that were originally listed by the mechanic while that specific job was performed to see if this was an accurate kit. By going through these hands-on steps, my goal was to reduce the level of re-work that would be needed on kit creation if management ultimately decided to move forward with creating process kits. As mentioned previously, the 787 experienced rework levels of 40% in their initial kit creation, so I wanted to ensure that we did not create this level of waste.

A sample of 5 results demonstrated the huge amount of variability in the first 5 IP's that we tested.

Job	**# of tools in job (start)**	**# of changes to tools pre-test**	**# of changes post-test**	**# of tools in job (finish)**	**% Rework from original data**
1	5	1	2	4	60%
2	13	3	3	9	45%
3	20	16	2	5	90%
4	6	1	0	5	17%
5	4	0	4	6	100%
TOTAL	**48**	**21**	**11**	**29**	**67%**

TABLE 6: RESULTS OF KIT TESTING FOR 5 JOBS

These results were extremely concerning: in a sample of 5 job kits, if we would have created these kits for the mechanics based on the original information provided, we would have had to revise 67% of the work, scrapping every original kit and creating a new one for each. Two main reasons were highlighted as to why the original information provided was inaccurate:

- Mechanic was not performing this job when he was originally asked for this information, so he/she forgot to list item(s)
- New mechanic now working this job who preferred different tools than the mechanic from which the data was collected

The second item was a particular cause of concern. If different mechanics preferred different tools when performing the same work, toolkits would constantly be changing: kits would be mechanic-specific for each IP, unless it could be guaranteed that the same mechanic performed the same jobs on every plane. The concept of "standard work" was something regularly discussed at Boeing, but did not seem to have a set definition. In general, "standard work" referred to an IP being documented precisely so that it was performed in the exact same way by any mechanic every time. As it relates to tool kitting directly, the concept of establishing a standard set of tools being used to perform the same job every time seemed like a necessary precursor for attempting to kit tools by job. Many people within Boeing felt differently about this- a common thought was that kitting tools would generate standard work, but that seemed backwards to me. Any job, or IP, needed to be standardized before the tools used to perform it could be standardized. Up until this point, "establishing standard work" had never been defined as a goal of my project. If the concept of creating job-specific tool kits was going to increase inventory and space requirements, and most likely cost more than the benefit that could be achieved, then what problem was I actually solving?

As I took a step back from my project to redefine the problems-at-hand and understand how I could provide the most beneficial solution during the remainder of my time at Boeing, I recognized the need for a detailed understanding of the culture within I was working. I was not going to realistically make any drastic changes in the culture during my internship, so I needed to focus my efforts on solutions that would be feasible to implement and sustainable in the long term, given the culture in which I was operating.

This chapter described my attempt to understand and justify the original concept of tool kitting in 777 SRW. I found that it would be cost-negative due to the number of support personnel that would be needed as well as the inability to define kits that would serve the intended purpose. At this point I realized that I would have to propose and justify a different solution. But in order to do this I had to understand the cultures of the manufacturing floor and upper management. The next chapter describes these cultures.

5 Overview of Culture

This chapter describes the Three Lenses analysis I performed in order to understand Boeing's culture in support of increasing the likelihood that I could redefine my project and give it a better chance to succeed and help the company.

5.1 Organizational Disconnect

As an intern, I worked seven levels under the President & CEO of Boeing Commercial Aircraft (BCA). While I felt relatively connected with those employees one and two levels above me, any management level higher than that was a name and a face that I recognized, but with whom I never had any direct interaction. Overall, I felt like there was a relatively large disconnect between management levels at the "Executive Level," and those tasked with carrying out initiatives set by these higher levels. This disconnect presented a challenge in attempting to implement a strategic initiative supported at higher levels of the organization, but not clearly defined nor understood at the lower levels that are responsible for tactical execution.

5.2 Three Lens Analysis of the 777 SRW Program Kitting Initiative

Many of the challenges associated with this project were ones that could not be solved with data-driven computations, but required a deeper understanding of the cultural nuances in the program in which I was working. In an attempt to move quickly to solve a problem during the limited timeframe of an internship period, it is easy to become fully consumed in one's own perspective and ignore other forces that may affect a project's success. One technique for managing this that is taught at the MIT Sloan School of Management is to view and analyze the initiative through three types of lenses: strategic design, cultural, and political.

5.2.1 Strategic Design Lens

A key challenge in attempting to implement the prescribed solution discussed in Chapter 1.2 comes from the fact that no single group is dedicated to developing a successful kitting process across all areas of 777 Manufacturing and the Everett site as a whole. Because of this, each team is trying to pull together a group of individuals with plenty of other job responsibilities to create a system from scratch. Ideally, a vertical "Tool Evaluation Steering Team" should be implemented that reports directly to the Everett Site Operations Director. This team would be dedicated to moving area-by-area across the site, fully examining the current state tool and part conveyance, and evaluating how to best eliminate non-value added time from the mechanic's work. Pulling multiple teams together from different parts of the plant only increases the confusion and chaos surrounding this initiative, and makes it more difficult to learn from previous mistakes. Given that extra resources are not readily available to create a new team, the best approach that I found to ensure consistent strategy was to communicate my results as clearly and succinctly as possible, with as wide an audience as possible, focusing on those manufacturing areas that had not yet implemented any sort of kitting system. I also regularly discussed new ideas with members of different manufacturing areas to get feedback on my implementation efforts and influence changes made to their respective tool conveyance processes.

5.2.2 Cultural Lens

Whenever the term "kitting" is mentioned to a mechanic, the reaction is usually one of annoyance and resistance. This is for good reason, as many of them have heard from other mechanics about the disastrous attempts to take tools away and rely on a team of Tool Services support personnel to kit them for delivery in other areas of the factory. As one travels higher up the management hierarchy at Boeing, the reaction to kitting seems to change. At my supervisor's level, employees recognized that an opportunity for improvement in manufacturing efficiency (through reduction of mechanics' NVAT) existed if kitting could be implemented successfully, but employees still did not feel like it was a "sure win" by any means. When I discussed this initiative at the Program's VP level, the response was much more confident that kitting would save the company a large amount of money. While data analysis does not necessarily support this statement, as demonstrated in Chapter 3, it took a meeting with the 777 Program Operations VP to realize how important this kitting initiative was to higher levels of the organization. Afterwards, I was struck by the fact that while he placed high importance on this project, his message – that kitting should be an important focus in operational improvements – had not been received downstream. In order to successfully implement any improvement initiative, teams undertaking these projects need to believe that they will be heard, and need to have a clear understanding from higher levels of management as to what the goals of this initiative are, and the benefits that can be gained.

Likewise, these teams need to be able to communicate their own conclusions effectively within an organization. I believe that if the end users (in this case, mechanics) of my tool conveyance plan were not thoroughly consulted in the development of this plan, then this would lead to three consequences: reduced ownership of the plan, a lack of sustainability, and most seriously: a bad plan from the start.

Gaining buy-in was a major focus of my regular communication with mechanics. In order to provide mechanics with a system that would benefit them most, I realized more and more that I need their input at each step of the process. By using their ideas and feedback, I am hopeful that they will feel like everyone involved is trying to succeed together during the FPS implementation phase, which occurs after the conclusion of my internship. The feeling of being "one team" is not common in changes that involve mechanics and salaried employees, but this is a key aspect of project success and a huge area of opportunity for Boeing.

5.2.3 Political Lens

The ultimate source of power in this project lies with the mechanics. I could design the best tool kitting system possible, but if they do not want to use it and insist on going back to operating under the current state system, my project would fail completely. When developing communication plans surrounding any proposed changes to the existing hand tool management process, I felt like my focus was just as much political as it was process-driven. Political tensions seemed to exist between the Manufacturing team and many different support organizations, most notably the Tool Services organization. Understanding the distribution of responsibilities for tool management between Tool Services and Manufacturing ended up setting the foundation for my set of proposed solutions. Manufacturing felt a sense of ownership over the tools that they were using, and did not feel comfortable handing that ownership to another organization, as had been done in FAUB (discussed in Chapter 3.1.1.) Given the limited time frame of my internship, I chose to create solutions with this existing political tension in mind, rather than attempting to shift political power over tools. This resulted in a solution set that was accepted and supported by the mechanics in 777 SRW as well as Tool Services support staff, something that made initial testing efforts much easier to drive forward.

6 Working Backwards: From Solution to Problem

This chapter describes how I redirected my project so that it was requirements-driven rather than driven by a preconceived solution. I redefined the problem, got buy-in from both mechanics and management, and generated new metrics for judging the suitability of my proposed solution.

6.1 Changing the Directive

At this point in my project, I came to a crossroads: continue working on the best possible implementation plan for a solution that I didn't believe in, or start from scratch and design my own tool storage and utilization strategy. I strongly preferred the second option, but I was nervous that this decision would ultimately bring my manager's leadership of the Future Production System project under scrutiny. The perception from high-level management was that toolboxes needed to be removed from the floor completely, and traditional IP toolkits should replace them. When I finally discussed this with my manager, she could not have been more supportive. She encouraged me to continue in the direction that I felt would achieve the best solution, regardless of the original kitting directive. Soon after this discussion, I had a meeting with the site Materials Management director, and he asked me candidly if I thought the IP kitting solution would be a success. I told him that I thought I would be able to implement the solution with which I was tasked, but that it would not be a success because of both the cost associated with it and mechanic opposition to the initiative. He then told me that if I didn't think we should do it, I had his support to stop and figure out something else. This was great news to me, because I now had the support of high-level management to challenge the solution and change the direction of my project. He provided me with an example of someone at Boeing who was concerned with reducing the "Waste of Untapped Human Potential," as discussed in Chapter 4.2. Given my limited time onsite, it was clear that he did not want to see that time wasted implementing a solution that would not add value to 777 Manufacturing.

Finally, I could go back and take a look at the problem itself, and start coming up with some unique solutions to test.

From a personnel management perspective, I was somewhat daunted: I already had a team of four people working with me full-time to design and fill the kits that we "had to" create. I was nervous that if I went into work the next day and told them to stop everything, and that we were wiping the slate clean and starting fresh, they would be frustrated at the lack of consistent direction. However, building on the principles described by Feld (2001), I relied on my focus to engage these employees and empower them to developing their own conclusions regarding this change of direction, and found that they were all supportive of it.

Once I had established that I would be able to change the initial goal of this project from implementing a traditional kitting system, I needed to understand exactly what problem I was solving. I had my own ideas on this, but wanted to get the perspective of key stakeholders that would also be affected by this project.

6.2 Survey Result Feedback

To gain this perspective, I sent this survey out to a team of people that included employees from a variety of organizations, all with direct involvement in my project. These organizations included Tool Services, the Materials Management Organization (MMO), Manufacturing, Boeing Research & Technology (BR&T), and Production Systems Integration (PSI). The survey was a simple one with only a couple of questions, the main one being: What problems (if any) do you see with how tools are being stored, conveyed, and utilized today?

At first, I was surprised by the variety of responses that I received. However, every organization works directly or indirectly with tools in a different way, so their concerns were coming from various perspectives. I was able to bucket responses into the categories shown below:

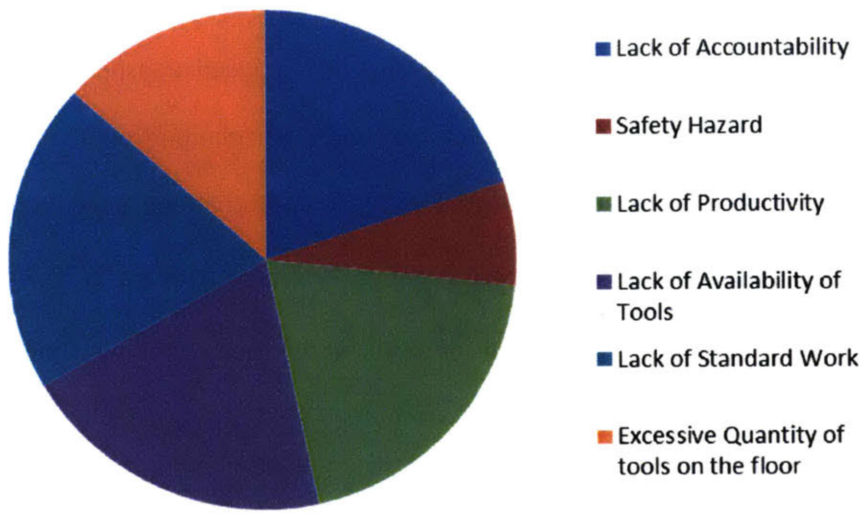

FIGURE 13: SURVEY RESPONSES ON PROBLEMS ASSOCIATED WITH TOOLS

Overall, my takeaway from this survey was that a wide variety of concerns existed regarding our current tool conveyance methods, and plenty of opportunity existed for improvements to be made. Two of these categories in particular related directly back to the time study results related to non-value added time that are highlighted in TABLE 2. Because I already had data to support these, I decided to make this piece a key focus of my problem statement.

6.3 ESTABLISHING THE PROBLEM

In order to gain buy-in on the new direction of tool kitting, I began all tool kitting discussions by talking through the following problem statement and highlighting that any solutions that I would test for implementation would be focused on solving this problem:

"777 SRW is preparing for FPS implementation, which will reduce available floor space that is currently being used to store tools. In addition, SRW mechanics currently spend approximately 35% of their time performing non-value added tasks. Cost-effective solutions are needed that achieve 2 goals:

1. *Minimize tool inventory and floor space footprint*
2. *Maximize mechanic productivity by reducing non-value added time"*

I chose to use the broader 35% NVAT value obtained from Table 3 instead of the 6% tool-specific NVAT value obtained from Table 2, because I wanted to encourage discussion that included all aspects of work processes that contributed to NVAT, and not develop tool-specific solutions in isolation from the larger NVAT reduction goal. When questions came up surrounding kitting tools by-IP (options 1 and 2 in TABLE 5), I often acknowledged that this was a potential solution, but given the current state of the 777 SRW system, I did not think that it was the best solution to achieve the goals set out by my problem statement.

6.4 Re-defining the Solutions

The only rule I used in determining solutions to test with regards to tool conveyance was that any potential solution needed to directly address one of the two goals previously stated in my problem statement: minimizing inventory and floor space foot print, and maximizing mechanic productivity.

6.4.1 Inventory Reduction

Early on in this project, I was told that kitting tools successfully would provide a reduction in inventory. This statement is correct when applied to an area moving from mechanic-specific toolboxes to a tool kitting model. As Vliegen, Kleingeld, & van Houtum demonstrate in their tool kitting study (2010), this inventory reduction is not a guarantee. For example, in 777 SRW, toolboxes are already shared today. In one area of 777 SRW Manufacturing, 19 toolboxes currently support 221 jobs across two shifts- far less toolboxes than mechanics performing this work. In a sense, these boxes are really just large kits, which are defined to serve multiple jobs instead of a single job. However, many opportunities still existed to optimize the inventory in these boxes and bags, including:

1. Removing unused tools from boxes and bags
2. Adding commonly requested items from the Tool Room to toolboxes and bags, thus reducing mechanic NVAT

6.4.2 Floor Space Reduction

In addition to the opportunity to reduce tools, thus reducing toolkit/toolbox footprint as noted above, another major opportunity for floor space reduction included decreasing the amount of toolboxes on the floor at any given time. The implementation of this solution requires a detailed understanding of the IP's supported by each toolbox. In some cases, a single toolbox supports only a single day or single shift of work. Why should a toolbox that is used only for work performed on day three of the plane build process be kept on the floor for seven days? Storing these toolboxes at a location away from the mechanic working area where space is more limited, and having a tool champion, or other responsible party, cycle these toolboxes on/off the floor at the beginning/end of the shift is a simple, cost effective way to achieve the goal of floor space reduction. The cost of the tool champion still needs to be taken into account and tested to ensure this is a cost-effective solution, as discussed in Chapter 7.1.3. Continuing to look for more opportunities where toolboxes can be consolidated and shared across shifts is another way to achieve this reduction. With FPS implementation, the SRW area will physically have less space in which to operate, making it necessary to reduce floor space. The benefit of this floorspace reduction is that by only having what is needed on the floor at a given time, standardized processes can be driven forward by continuing to focus on jobs being performed according to the bar chart schedule. This process comes with a tradeoff: the longer length of time that materials are placed at planeside, the more floor space is taken up but the less cycling of carts is needed. Testing to achieve an optimal balance between these two is discussed in Chapter 7.1.3.

6.4.3 Decrease NVAT

While time study data in 777 SRW does not suggest that a significant amount of NVAT in a mechanic's day is directly attributed to setting-up, breaking-down, or searching for tools (6% total, as shown in Table 2), attempting to reduce this time provides an opportunity for Manufacturing to work cross-functionally with Tool Services. Today, 777 SRW mechanics that walk to their designated tool room during the beginning of a shift often face a queue to retrieve whichever tool(s) (most commonly safety glasses or batteries) they need for the day. Placing these items closer to the mechanics' POU (point of use) and dispensing them using Automated Tool Dispensers (ATDs) will help reduce travel and wait time, and eliminate the need for a person to provide this tool. In addition, automated solutions are equipped to provide metrics which show how the quantity and frequency that these disposable tools are being taken from ATDs at the individual level. This data will allow 777 SRW Manufacturing to correct bad habits and reduce spending on over-used disposable items. Utilizing ATDs will also allow Tool Services to service the mechanic better by focusing their efforts on improving responsiveness to emergent requests. Currently, the existing Andon system is barely being used in 777 SRW, mainly due to distrust, as discussed in Chapter 5.1.2. If the tool service team was able to ensure a quick response time for emergent tool requests, then the mechanic could stay productive and continue working until their requested tool had been delivered to them from the tool room.

In this chapter I redefined the problem and got buy-in from upper management to pursue it. After conducting a survey I concluded that any solution had to address two major issues: keep the number of carts and tools under control and reduce the mechanics' NVAT. The next chapter describes how I implemented pilot solutions.

7 Pilot Testing of the Selected Solutions

This chapter describes the solutions I tested. The aim in each case was to reduce floor space and mechanic NVAT. The solutions piloted were rationalization of commodity tool bag contents, rationalization of toolboxes, and addition of a toolbox monitor or tool provisioner.

7.1 Methodology/Approach to Testing

Overall, the strategy underlying the areas within SRW to focus initial testing efforts on was based off of three key factors:

1. Stability of schedule: was the job schedule for this area relatively stable, or were there plans to add new jobs? In a number of areas within SRW, jobs were shifting as a result of Future Production System changes through a coordinated effort between Manufacturing and IE. While I was provided with a detailed understanding of the jobs that would transition, I was hesitant to try to change too much with the toolboxes and bags that were used in these areas. I could sense anxiety from the mechanics and first line managers on the teams most affected by these changes, and decided that it would be best for them to work through these schedule changes before trying to adopt any tool changes. I also wanted to have test results that were unaffected by external factors as much as possible.
2. Level of existing communication with first line Manufacturing managers: throughout my project, I interacted with first line Manufacturing managers regularly to discuss project updates and get their feedback on different ideas. I quickly learned which were most responsive and had a genuine interest, and wanted to keep those managers involved and prioritized in my testing efforts.
3. Opportunity for improvement: especially with regards to toolboxes, some areas had many more on the floor than did others. Given that I was already over halfway through my time at Boeing when I began developing this set of solutions, I wanted to focus testing efforts on those areas where I could get the biggest "bang for the buck," where the most toolboxes could potentially be eliminated.

7.1.1 Inventory Reduction

The effort to optimize tool inventory provided a unique challenge of getting mechanics to agree on what tools should be added and removed from bags and boxes, even though all agreed that this needed to happen. I initially approached this problem with the mindset that the best action plan would be to provide the mechanic with a list of what I saw as "opportunities for removal" based on data collected on tools used for each job, and then have them review this list during a time that was convenient for them and come back to me with what they agreed with or disagreed with and why. However, I quickly realized that handing out papers and expecting them to be returned was not a realistic expectation. Instead, I needed to set aside dedicated time where we could evaluate this inventory on the floor as it was being used. Together with the IE team, we worked across all shifts to coordinate this inventory optimization effort and ensure mechanic buy-off before final decisions were made.

The first commodity bag to be updated was the plumbing bag used in CC 128. This bag consisted of two pallets and 30 tools: see Figure 13.

FIGURE 14: AREA 2 PLUMBING BAG PALLETS. EACH 15" X 20" X 6"

Mechanics confirmed that they did not require two of these tools, which were removed. They also noted that the two pallets were bulky and not easy to transport around different parts of the plane. Through better design, we reduced the remaining tools down to a single 13" x 17" x 5" pallet, which reduced the space taken up by these bags by over half, as shown in Figure 14:

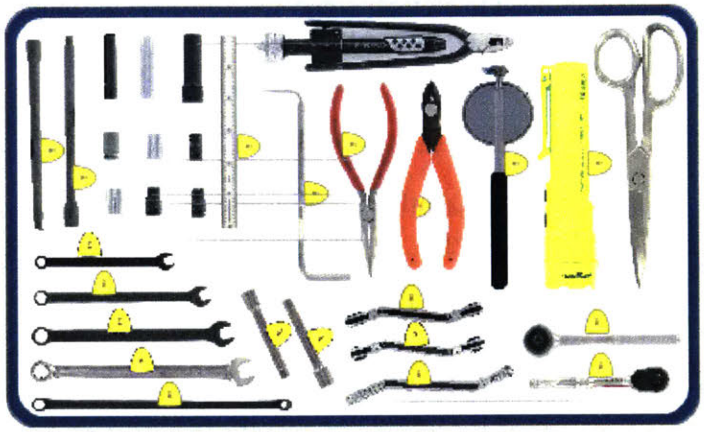

FIGURE 15: REVISED AREA 2 SINGLE PALLET PLUMBING BAG

This was a relatively easy bag update to make, and one that mechanics were pleased with because it was easier to use, and management supported it because of the overall space reduction. Small improvements like this allowed our team to gain traction and move forward with more improvement opportunities. Overall results from the tool bag inventory optimization effort are shown below:

		Tools added	Tools removed	# Bags	Tool Qty Change	Savings/ Cost Per Bag	Total Savings
CC 128	Plumbing- 1st	0	28	15	-28	$ (402)	$ (6,030)
CC 128	Electrical- 1st	29	0	9	29	$ 347	$ 3,125
CC 129	Electrical- 2nd	4	-4	8	0	$ 222	$ 1,779
CC 129	Plumbing- 1st & 2nd	0	1	24	-1	$ (24)	$ (582)
CC 130	Plumbing - 1st	0	10	3	-10	$ 422	$ 1,266
CC 130	Plumbing- 2nd	26	50	3	-24	$ (813)	$ (2,439)
CC 130	Electrical- 1st	4	0	4	4	$ 125	$ 499
CC 130	Electrical- 2nd	13	5	9	8	$ 148	$ 1,328
	TOTAL				-22	$ 25	$ (1,054)

TABLE 7: SUMMARY OF COMMODITY BAG UPDATES

7.1.2 FLOOR SPACE REDUCTION

The effort to reduce our floor space footprint went hand-in-hand with tool inventory reduction. The table below shows overall decrease in square footage as a result of the commodity bag effort specifically. While this does not represent a large reduction, it does show that even with optimizing these bags to include exactly what the mechanics need to do their work, we were able to simultaneously remain in-line with the goal of overall floor space reduction.

		Width (in)	Depth (in)	Height (in)	Change to Pallet Qty	# of Bags	Square Footage Gain/Loss*
CC 127	Plumbing- 1st & 2nd	22	13	6	-1	15	(6.0)
CC 127	Electrical- 1st	22	13	6	2	9	7.2
CC 127	Electrical- 2nd	22	13	4	0	8	-
CC 128	Plumbing- 1st & 2nd	22	13	2	-1	24	(9.5)
CC 129	Plumbing - 1st	22	13	6	-1	3	(1.2)
CC 129	Plumbing- 2nd	22	13	6	-3	3	(3.6)
CC 129	Electrical- 1st	12	9	2	0	4	-
CC 129	Electrical- 2nd	15	12	2	0	9	-
	TOTAL						(13.1)

TABLE 8: TOOL BAG SIZE REDUCTION *ASSUMING BAGS ARE STACKED IN GROUPS OF FIVE

The major focus of floor space reduction, however, was on toolboxes. I piloted the effort for toolbox reduction in one specific control code: CC 127, with plans to replicate the reduction process used across the remaining areas in SRW. To understand how the 47 toolboxes in CC 127 were utilized, I monitored which boxes were used on which shifts. Results shown below:

Shift(s)	# Toolboxes
1	9
2	6
3	11
1 & 2	6
1 & 3	4
2 & 3	1
1 & 2 & 3	10

TABLE 9: CC 127 TOOLBOXES BY SHIFT

Actions that were taken to optimize these toolboxes focused on four main efforts:

1. Remove unused tools from toolbox

2. Add commonly requested items from tool room to toolbox
3. Remove duplicated toolboxes
4. Consolidate multiple toolboxes into one

The work steps taken to complete the actions listed above were done mainly with the CC 127 shift leads, who had worked many of the jobs on each shift and who best knew how, where, and when each toolbox was used. After discussion with mechanics on all three shifts of CC 127, it was determined that 30% of the existing toolboxes in this control code could be eliminated. A summary of these results is shown below. Note that this summary only details the 28 boxes to which changes would be made. The remaining 19 boxes would remain as-is, after confirming that these were already optimized for the current state.

Toolbox Name	Current State Qty	Future State Proposal	Future State Qty
777127WBJOB1	1	Toolbox can be eliminated (tools available in other boxes)	0
777127WBJFS1 777127WBJFS2	2 3	Toolboxes can be consolidated	1
777127WBJRS1 777127WBJRS2 12733WBJ7 12732WBJ7	4 5 6 7	Boxes can be consolidated into 2 toolboxes across 2 shifts	2-3
777127WBJOBE 777127WBJOBO 777127WBJO2O 777127WBJO2E 777127WBJO30 777127WBJ03E	8 9 10 11 12 13	Boxes can be consolidated into 3 Lead Toolboxes across 3 shifts	4-6
777127EVG 777127EVA 777127ODC 777127ODI 777127ODA 777127ODH 777127ODF 777127EVB 777127EVD 777127EVF 777127EVI 777127EVC 777127ODG 777127ODB 777127EVH	14 15 16 17 18 19 20 21 22 23 24 25 26 27 28	Boxes can be consolidated into 8 Toolboxes starting 12/2016	7-14

TABLE 10: SUMMARY OF CC 127 TOOLBOX CONSOLIDATION

In total, 28 toolboxes could be reduced and consolidated to 14 (50%). The average cost of tools per box was approximately $8,000, resulting in a total savings of $114,000 in tool costs to the CC 127 program. These tools were returned to the tool room, where tool service analysts routed them to other areas of the 777 program, or potentially other programs, if needed, to avoid paying to procure additional tools.

The space reduction in CC 127 was also significant with the elimination of these 14 boxes. Each box took up a footprint of approximately 8.75 sq ft, resulting in a total floor space reduction of 122.5 sq ft. In an area where a reduction of available floor space was a critical part of FPS implementation plans, being able to operate effectively with less available space was key in preparation efforts. The steps taken above in CC 127 to begin consolidating floor space provided a blueprint for other areas across SRW to reduce their own toolbox footprint.

7.1.3 NVAT Reduction

While the steps taken to reduce tool inventory and floor space were valuable to the overall FPS efforts, a reduction in Taichhi Ohno's third waste – the waste of unnecessary movement – would drive forward progress towards a more Lean manufacturing organization. Due to the timing of my internship, I was no longer onsite for the actual Future Production System implementation in 777 SRW. I did, however, develop a toolbox cycling plan that I predicted would result in a time savings to the mechanics that would far exceed the cost to implement. This cycling plan relied on a single support personnel per shift, referred to as the "provisioner."

My plan for this provisioner was similar to the theory laid out in FIGURE *8*, however it only required one provisioner per shift of 36 mechanics, as opposed to four that would be required in a system where individual kits were delivered. Toolboxes that were only used for a single shift would be stored in a Toolbox Center, which was a storage area located approximately 300 feet away from the main floor workspace, next to where the existing toolroom is today. Consider a provisioner that was placed on first shift: this provisioner would arrive 30 minutes before shift start, and cycle any first shift toolboxes from the Toolbox Center onto the floor, at designated areas that would require the least walking distance for mechanics that were using these boxes. He or she would then cycle the third shift boxes off of the floor, once third shift mechanics had clocked out and gone home. The provisioner role would serve as one for continuous improvement to reduce waste: he or she would get a tool from the tool room any time it might be needed by the mechanic, and would evaluate whether this tool should be added to a box based on the number of times it was requested. The provisioner would be performing time studies on mechanics traveling around the airplane any time they needed to step away from their immediate area of work, and provide solutions to reduce this non-value added time.

With this system in place, my hypothesis was that the reduction in non-value added time (NVAT) that each mechanic in SRW would experience as a result of provisioner implementation would more than exceed the 40 hours/week of time that this provisioner would work. My initial proposal for implementation of this role was a two-month "provisioner pilot," where time study data would be performed at the beginning and end of this period to determine the reduction in NVAT that resulted. During my last few weeks at Boeing, my supervisor had decided to hire-on a full time employee to this project after I departed. This employee's first proposal to management for a provisioner pilot was rejected by the senior Manufacturing manager, who said the program did not have the budget to fund an additional employee in the area.

About one month after this proposal was rejected, one of the first-level Manufacturing managers suggested that one of her mechanics could be the pilot for this initiative. She felt like the hypothesis that I proposed had merit, and that her crew would be able to function sufficiently with one less mechanic as a result. While this proposal would add complexity to the study because the crew would no longer be operating under typical conditions, it was encouraging to know that at least one manager was invested in projects that were focused on waste reduction in the manufacturing process. The study had a planned start date for one month from the time that this thesis is being written, so results will not be shared here.

In addition to the steps taken above, my successor and I discussed other opportunities to test potential solutions to reduce mechanic NVAT. One of these was implementing Automated Tool Dispenser (ATD) devices at strategic areas on the manufacturing floor, where commonly needed disposable items such as safety glasses and batteries may be more easily accessible. These types of solutions would require capital investment and research to support potential benefits, as well as a plan to re-stock dispensers and actively utilize data they provided to continue working towards creating a more productive work environment with less waste. At the time of my departure, two ATD's had been approved for purchase and implementation testing on the floor, and would be managed as part of a Tool Services team initiative.

7.2 Discussion of Results

By focusing on the three main opportunities for improvement listed in Chapter 6.1: inventory reduction, floor space reduction, and mechanic non-value added time reduction, I was able to direct the efforts of the Kitting Team and work on measurable improvements that were in-line with the overall goals of the 777 Future Production System. Had I chosen different opportunities for improvement, such as establishing standard work and standardizing the tools used for every job by adding them to IP documentation (two items that were often recommended to me as benefits of a successful kitting system), then my set of proposed solutions would have been different. However, I think I chose the best opportunities to tackle, especially given FPS needs and requirements.

As my time at Boeing progressed and I continued discussions on tool kitting with various stakeholders, one of my main learnings was that everyone had a different opinion on what problems could be solved by kitting tools. By taking a step back from the solution (i.e., prescribed tool kitting), and evaluating the problems for which I was trying to solve (using my problem statement in Chapter 6.3), I was able to develop unique solutions that benefited 777 SRW but did not add the additional cost of tools and headcount that would have been required for a full tool kitting solution, as defined by the 777 Program. Deliberately, I referred to my solution set as the 777 SRW Tool Conveyance Plan, trying to step away from using the term "kitting" as a one-size-fits-all solution for hand tools in Boeing Manufacturing.

7.3 Application to Other Areas of 777 Production Line

My goal in developing this strategy for evaluating a manufacturing area and determining the best set of solutions for tool storage and conveyance was not only to improve the 777 SRW area of manufacturing, but to provide a blueprint for other areas of 777 Manufacturing as they work through Future Production System implementation changes, and for 777X development. These solutions were discussed with and presented to a number of employees that were critical to FPS implementation efforts for 777, and worked hand-in-hand with the kitting point-of-contact for the 777X program. I also led communication upline to upper level management in 777 Manufacturing and gained support for my solutions by using the data presented in this thesis to drive my discussions. Through these continuous communication efforts, I am confident that a systematic problem-solving approach will be used in future areas of Manufacturing as they continue to undergo these changes.

8 Recommendations and Conclusions

Below is a summary of my problem-solving approach to tool conveyance using the 8-step method developed by Tyre, Eppinger, and Csizinszky:

1. Problem Description: 777 SRW is preparing for FPS implementation, which will reduce available floor space adjacent to the wing that is currently being used to store tools. Mechanics currently spend approximately 6% of their time gathering, setting up, and breaking down tools to perform each job. Cost-effective solutions are needed that achieve two goals:
    1. Minimize inventory and floor spacc footprint, and
    2. Maximize mechanic productivity by reducing non-value added time.
2. Problem Documentation: I gathered and analyzed quantitative data, focusing on tools used by job and time study data. I issued a survey and set up meetings with key stakeholders to understand qualitative data around cultural perceptions with regards to tool kitting.
3. Hypothesis Generation: My hypothesis was that effective tool conveyance methods could be implemented in one of two ways: through a more traditional "tool kitting" approach, as had been done in 777 FAUB and the 787 program, or through alternative optimization efforts that focused on improving existing tool usage practices rather than creating new ones. In order to determine which pathway to focus solution efforts, I needed to fully evaluate both of these options.

4. Hypothesis Testing: I performed tool commonality studies and cost-benefit analyses in order to determine how effectively the goals I had set could be reached through the two pathways discussed above. Results shown in FIGURE 16.

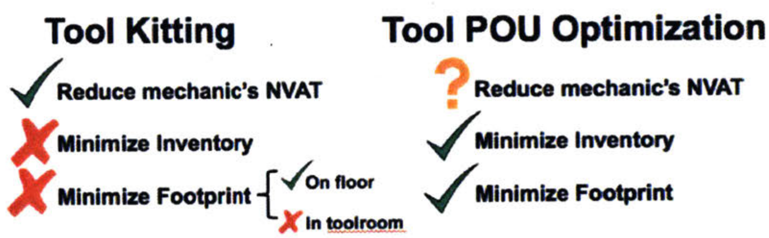

FIGURE 16: HYPOTHESIS TESTING RESULTS

The item that I was still uncertain of after hypothesis testing was whether tool point of use (POU) optimization efforts would result in a reduction in mechanic NVAT. This was something that would need to be tested further.

5. Solution Planning: Once the diagnosis was made, I began working with the tool kitting team on possible solutions to test. We focused our efforts on control code 127, working towards implementing the following initiatives: tool bag and box optimization of existing tools and overall reduction in space and quantity of these items, and implementation of provisioner role to facilitate mechanic NVAT reduction.
6. Solution Implementation: I was present through full implementation of tool bag optimization, and part of toolbox optimization. These efforts went very smoothly overall, mainly due to over-communication with mechanics and their managers in advance of any changes to be made. The most difficult part of coordinating toolbox optimization efforts was from a personnel perspective: tools were changed and removed from boxes during third shift, when the least amount of activity occurred and thus our team would least likely to interrupt activities. This required a Tool Services staff member to be present to facilitate returning tools that were no longer required to the tool room, and reallocating them appropriately to other areas as-needed. Because this took place

during the summer months, many Tool Services staff members were on vacation and our efforts to complete toolbox optimization were delayed from original anticipated completion dates.

7. Solution Verification: For toolbox and bag optimization efforts, solution verification was simply to measure the reduction in cost and space that resulted from these efforts, and meet with mechanics to ensure that the revised boxes and bags were continuing to meet their needs. A more detailed verification effort is needed for the implementation of the provisioner role, as discussed in Chapter 7.1.3. While results are not yet available to verify and validate this solution, a plan is in place to do so, which will be led by my successor.
8. Incorporation: By providing a successor to my role at Boeing, my supervisor was placing an investment in continuing to develop lean manufacturing solutions and incorporate these into processes going forward. While I did not work on formal process documentation changes during my six months at Boeing, this was something that my successor and I talked about extensively to ensure that best practices were documented and shared after solutions had been verified.

The work completed during the course of this project was the first step for 777 SRW Manufacturing in the journey towards developing more sustainable tool conveyance solutions, and will hopefully serve as a guide for other manufacturing areas at Boeing as well. By focusing on a strategic problem-solving approach to this project, I was able to develop a set of solutions that were not originally prescribed, but were ultimately the optimal improvement opportunities for the specific area in which I was working.

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10 Appendix

BCA: Boeing Commercial Aircraft

BR&T: Boeing Research & Technology

FAUB: Fuselage Automated Upright Build

FPS: Future Production System

IE: Industrial Engineer

IP: Installation Plan

KMI: Kit Material Integration

PIT: Production Integration Testing

POU: Point of Use

PSI: Production Systems Integration

MMO: Materials Management Organization

NVAT: Non-Value Added Time

SRW: Service Ready Wing