Identifying, Categorizing and Quantifying Primary Sources of Manufacturing Variances for Process Improvement and Reduction of Overall Cost Variance

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Dedication

The author wishes to dedicate this work to her mother, Dr. Helen Parke for her inspiration and leadership during her life and her father, Dr. Michael Weaver, for his continued support and encouragement of a higher education.

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The author wishes to acknowledge management (Engineering Manager, Director of Operations, and President) at *XYZ Industries* for agreeing to collaborate with her for her Praxis research. The author also wishes to acknowledge her primary Praxis advisor, Dr. Timothy Blackburn, for his guidance and feedback during her project.

Abstract of Praxis

Identifying, Categorizing and Quantifying Primary Sources of Manufacturing Variances for Process Improvement and Reduction of Overall Cost Variance

This Praxis research developed a Management Control Plan to enable a manufacturing company to determine, control, and eliminate potential root causes of variances in the production of more than 12,000 products. After cost variances in materials usage, waste, and labor were identified, categorized and quantified, lean six-sigma process improvement tools were applied to reduce and control variances. The presence of high unfavorable variances indicated problems that should be addressed for quality and financial purposes. Root cause analyses were used to identify the sources of variance and control charts were utilized to establish and analyze process performance. Time series data was collected and analyzed on select product workstation assembly operations that were applicable to all company products. Implementation of the Management Control Plan increased profitability, maintained and improved product quality and drove continuous improvement.

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List of Symbols

Cpk	Process capability index
Ppk	Process performance index
USL	Process capability index
LSL	Process performance index
$\bar{X}$	Average of all data
s	Standard deviation
X_n	n^{th} data point
n	Population size
$\sum$	Summation

List of Acronyms

ABC	Activity Based Costing
DMAIC	Define, Measure, Analyze, Improve, Control
KPI	Key Performance Indicator
LSS	Lean Six Sigma
PCA	Process Capability Analysis
PCC	Process Control Chart
R2R	Run-to-Run
RAH	Run Actual Hour
RCA	Root Cause Analysis
REA	Run Earned Hour
SAP	Systems Applications and Products
SME	Small and Medium Size Enterprises
SPC	Statistical Process Control
SPM	Statistical Process Monitoring
SQC	Statistical Quality Control
SS	Six Sigma
TQM	Total Quality Management
WC	Work Center

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Glossary of Terms

Activity analysis - tool to account for how an employee spends time during a workday

Activity based costing - a form of cost accounting focused on costs of performing specific functions rather than on costs of organizational units

Cause and effect diagram - graphical tool that displays cause-and-effect relationships to identify, classify, & prioritize causes of operational problems

Chance cause variance - natural or expected variance in a manufacturing process

Continuous improvement - a manufacturing practice of making incremental, sustainable changes that lead to improved efficiency, performance, and profitability

Continuous process improvement - an intentional manufacturing practice to focus on eliminating process variability that leads to improving efficiency and performance

Control chart - graphical tracking of a process input or output over time

Direct labor cost - depends on the hours of labor worked by factory operators engaged directly in making a product

DMAIC - data-driven quality methodology for improving processes

Efficiency - the level of performance or output of a process per unit of input

Facility layout diagram - graphical representation of the facility layout showing relationships between work centers, processes, and equipment

Gemba walk - continuous improvement technique that observes the place where work is being done

Key performance indicator - measurable value demonstrating a company's effectiveness in achieving business objectives

Lean manufacturing - a manufacturing principle to maintain or increase productivity by

minimizing waste and saving costs through improving processes and creating efficiencies

Lean Six Sigma - data driven philosophy of improvement reducing variation and waste and valuing prevention over detection

Lean - a philosophy of continuous improvement that identifies and eliminates unnecessary activities that do not add value to the final product

Overhead - any cost not directly associated with a product; representing all costs other than direct labor costs and direct materials costs

Pareto chart and 80/20 rule - graphical tool to categorize and summarize process causes for further investigation where 20% of the activities account for 80% of the results

Process capability index - an analysis determining whether a process can produce products according to specifications

Process control chart - used to trace sources of process variability and often used to support root-cause analysis

Process Improvement - systematic approach to identify and eliminate process variation and gaps in performance

Process performance index - analysis that shows how well a process is running compared with specifications

Process variation - variation in every process

Productivity - the ratio of outputs to inputs

Quality - a state of being free from defects and from unwanted or uncommon variance

Root cause analysis - tools and techniques to uncover causes of problems

Six Sigma - a quality control methodology with tools and techniques to improve business processes by reducing process variability and reducing the probability of errors occurring

Special cause variance - unnatural or unexpected variance in a manufacturing process

Statistical process control - a process improvement methodology to monitor and control variance during the manufacturing process

Statistical quality control - an industry standard methodology to measure and control quality during the manufacturing process

Systems Applications and Products Implementation - *XYZ Industry*'s operating system

Time study - procedure to determine standard time to complete a task

Total Quality Management - a management system for a customer focused industry involving all employees in continual improvement

Variance - deviation from the process mean or from what was expected

Variation - describes the consistency of a process output

Waste - a step or action in a process that is not required and considered non value adding

Workflow analysis - a table that shows steps in a process and essential information like processing times

Chapter 1 – Introduction

1.1 Background

This praxis focuses on a small U.S. manufacturing company with annual gross sales of 61 million dollars. The company will be referred to as *XYZ industry* for purposes of confidentiality requested by the company. The manufacturing facility has 375,000 square feet with 200 employees. Two shifts are run every twenty-four hours. The company has one corporate office and one manufacturing facility. There are four distribution centers reserved for their Quick Ship program that enable customers to receive custom product orders in less than one week. *XYZ Industry* customers include educational and government organizations.

The layout of the manufacturing plant includes 15 primary work centers for high volume fabrication, high volume subassembly fabrication, paint, and packaging. In November 2018 the plant reorganized the assembly line at Work Center 24 - *Frame Assembly and Door-to-Frame Assembly* to reduce waiting time and increase throughput. Manufacturing variances currently represent in excess of 8% of revenues at *XYZ Industry*. A reduction of manufacturing variances represents an opportunity for *XYZ Industry* to increase profit without making significant capital investments. Identifying, categorizing and quantifying these sources of manufacturing variances in order to prioritize targets for variance reduction will assist *XYZ Industry* in improving company profitability and decrease overall variance by 10%.

The current process begins when an order is placed and ends when the order is shipped. The process that is being analyzed and improved is limited to high volume products that the customer assembles themselves, known as knock-down (KD) lockers. For

KD lockers, seven parts make up about 80% of the finished product. Locker composition is both heavy and light gauge steel. Most of the products go to distribution centers for future delivery to customers. Order entry, processing, scheduling, planning, fabrication, painting, packing, and shipping comprise the order fulfillment process. Within the entire process, fabrication requires the most substantial amount of time.

When a customer requests a quote from the sales team, the sales team enters the requested product(s) into a system called ProQuote that populates the financial information for the product(s) into a contract. Engineering does not maintain the ProQuote system, so when customized orders require new product numbers, the sales team is not able to find the appropriate product number and instead fills the quote with free text and approximations of pricing. A quote for approval is then sent to the customer. Once the signed quote returns, the order is given to order entry to be checked. If the order contains all the appropriate information, it is recorded in the company's operating system, Systems Applications and Products Implementation (SAP). If the order cannot be entered SAP for any of the reasons listed on the Detail Order Checklist, then the order is sent to engineering to be detailed. Some customer orders require specialized parts which may not have existing part numbers assigned. In this case, order entry notifies engineering that additional information is required (detailing). Engineering researches to find previously existing part numbers for what the order contains. If a part number does not exist, then engineering creates a part number. The description of the created part number is as detailed as possible, so when the part is ordered again, it can be found quickly in the system. Once the order has part numbers for all the pieces ordered, the engineer returns it to Order Entry to enter the order into SAP.

The Master Scheduler is responsible for the scheduling process. Order Entry at the corporate office sends an order to the master scheduler and requests a ship date. The posted schedule for the order determines the ship date. The schedule is based on the order items as well as paint pound per day (pounds of product painted per day) and color. Similar orders are scheduled together. Orders are moved forward or backward depending on the availability of materials and overloading. The master scheduler can also cancel and reschedule orders as necessary. The items that are part of the Win program, consisting of lockers that are simplest to manufacture, are short-dated with a lead time of three weeks. After an order is scheduled, the planning department decides how orders are grouped. A workload sheet, created daily, states the capacity of each machine and is used to prevent overloading. Once orders have been grouped according to machine capacity, they are released to the fabrication floor to be manufactured.

Manufacturing of the doors and frames occurs concurrently. The first step in door production is to create the blank for the door. Once a blank is produced, it is roll-formed using the machine as shown in Figure 1-1 to bend the sides of the door. The next step begins when the door is punch-pressed using the machine as shown in Figure 1-2 to bend the top and bottom of the door and create louvers. The door is then placed on a pallet until it is ready to be assembled with the frame.

Figure 1-1. Roll formation of the door

Figure 1-2. Creation of louvers and bends

The frame production is very similar to the production of the doors. The top, bottom, and sides are roll-formed, punch-pressed, and placed on pallets as shown in Figure 1-3.

Figure 1-3. Pallet of frame side channels

The sides are then welded with tabs or hinges depending on whether it is a left or right-side frame. Once the pallet of doors and the pallets of the different frame pieces (top, bottom, intermediates, left side, right side) are complete, they are transported to Work

Center 24 - *Frame Assembly and Door-to-Frame Assembly*. There is one two-man assembly line for frame assembly and three one-man work stations for door-to-frame assembly. Figure 1-4 illustrates the frame assembly and the door-to-frame assembly during manufacturing. The operators pace the process, making the entire sub-process only as fast as the employees working on a given shift. The first step in Frame Assembly is pre-

Figure 1-4. Frame Assembly and Door-to-Frame Assembly

assembly of the frame. An operator assembles the top, bottom, middle, and side pieces of the frame. The subassembly is pushed down the line to the second operator on the line, who uses a stationary spot-welding machine to weld the frame. Figure 1-5 illustrates the welding station on the frame assembly line where the frames are assembled. The frame is placed on a pallet and the process is repeated until the work order is complete. Concurrently, at Door-to-Frame Assembly, an operator working on a different work order aligns the holes on the frame hinges with the holes on the door and attaches the door to the frame with mechanical fasteners (rivets).

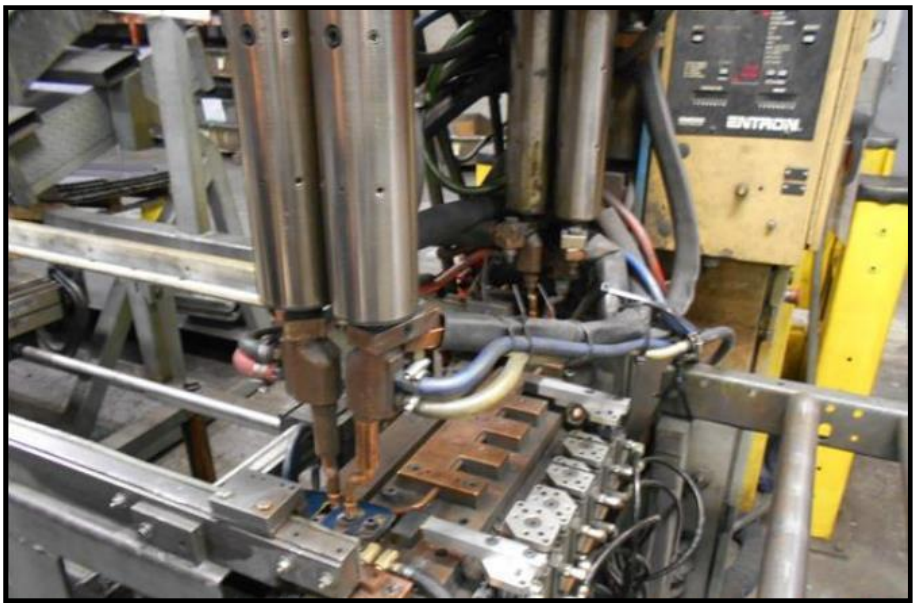

Figure 1-5. Welding station at Work Center 24

A quality check is performed every 30 minutes to 1 hour to prevent defective parts from continuing through the process; however, defective parts occasionally make their way through the process and must be scrapped or reworked. After completing the fabrication process, parts are taken to part stores where checks are performed to confirm all the parts for an order are complete. After verifying all parts are present, they are transported to the paint department. The parts are hung on the paint line and go through a five-stage chemical wash. The parts travel through the paint booth for the appropriate color paint to be applied, then proceed to the cure oven to bake on the color.

After leaving the paint department, the order is packed and prepared for shipment. A pick list is drawn, and labels are printed for the boxes. The parts of an order are packed and placed on a pallet. The boxes are shrink wrapped and proceed to shipping, where the order is confirmed, placed on a truck, and shipped to the customer.

Figure 1-6 illustrates the process map for order placement to order shipment. The Work centers upstream to Work Center 24 are listed in Table 1-1. The work centers

downstream to Work Center 24 include Work Center 45 – *Paint and Pack* and Work Center 65 – *Packaging*.

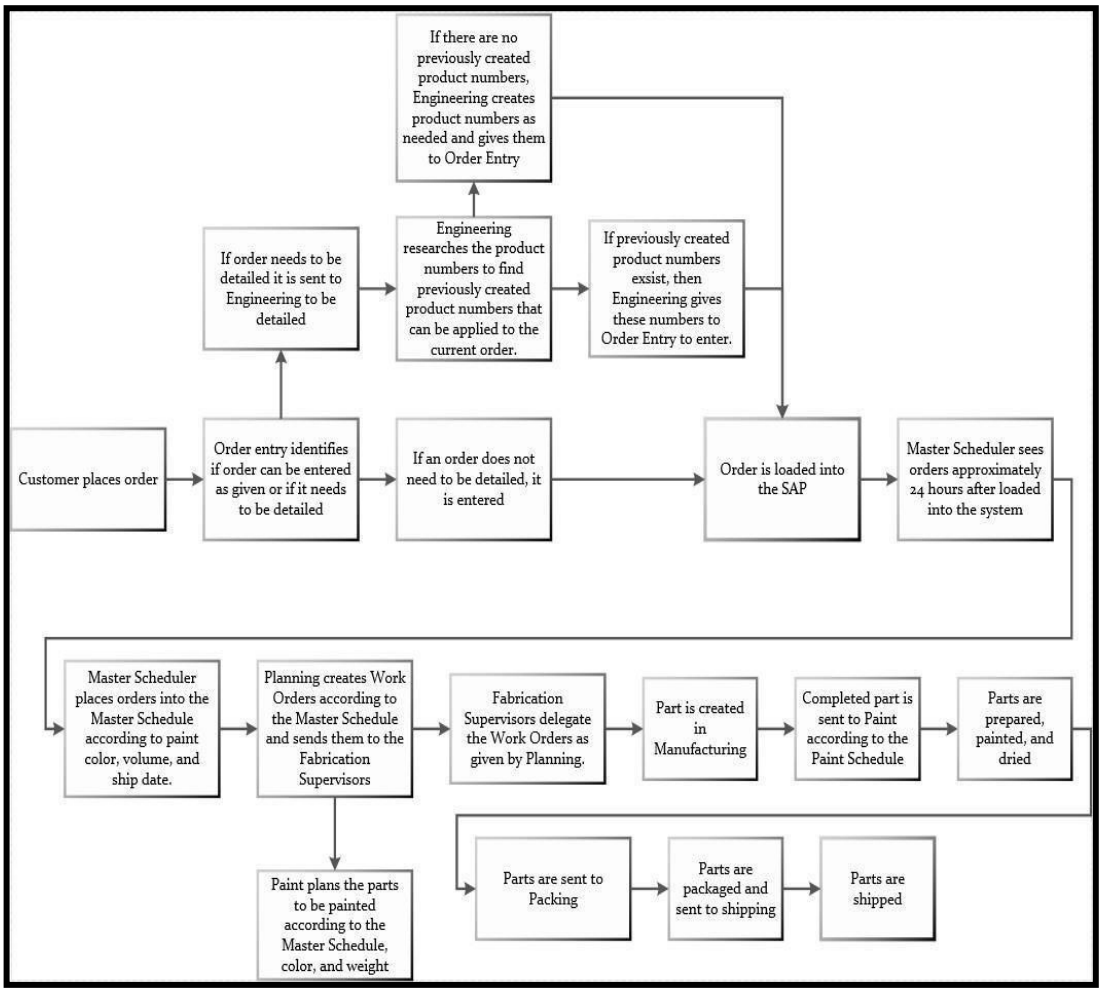

Figure 1-6. The full ordering process map

Table 1-1. Work Centers

Work Center	**Description**
12-21	Tabs and Shelves
13-21	Diamond Press
1H	Frame Channel Line 1
1KPUNCH	Blank Locker Doors
1M	Roll Form Door Top/Bottom

1T	Deburr
2R	Roll Form Door Sides
P8	Frame Channel Line 2
25	Hook Welders
20	Finger Lift Assembly
22	Hinge Welders
4R	Installation of Latch Channels

1.2 Research Motivation

Variances represent in excess of 8% of revenues at *XYZ Industry*. A reduction of manufacturing variances represents an opportunity for *XYZ Industry* to increase profit without making relatively large capital investments. Identifying, categorizing and quantifying sources of manufacturing variances to prioritize targets for variance reduction will assist *XYZ Industry* in improving company profitability and decrease overall variance by 10%.

Some of the waste expressed as a concern by *XYZ Industry* includes inventory waste and non-utilized talent. Inventory waste is an issue within fabrication. While it is efficient for each part required to create a locker to be manufactured concurrently, once a part is finished, it sits on a pallet next to the machine until each part of an order is completed. Only after an entire order is completed is it transported to the next step in the process. This disrupts the process flow resulting in unprocessed material and time lost. Waiting waste is another problem within the paint department. Painting cannot begin until all the required parts of an order are completed and brought to part stores. Often, all the parts within an order have not been transported to part stores and the paint department is unable to begin

painting. Another area of waste within fabrication is non-utilized talent where workers are not effectively engaged in the process. To minimize costs, *XYZ Industry* hires more personnel to perform simple tasks which could be eliminated by the introduction of simple machines. Various workers perform tasks such as sliding parts from one area to another, holding side channels in place for tabs to be welded on, and placing parts in the correct location for roll forming.

1.3 Problem Statement

Manufacturing variances represent in excess of 8% of XYZ Industry revenues resulting in loss of profitability.

1.4 Thesis Statement

Design and implementation of a management control plan for process improvement using lean manufacturing tools to reduce labor variance by 10% will increase profitability of XYZ Industry.

1.5 Research Objective

To apply the tools and techniques of Six Sigma methodology for process improvement of manufacturing practices at *XYZ industry.*

1.6 Research Questions and Hypotheses

Research Questions:

RQ1: What are the significant sources of manufacturing variances at *XYZ Industry*?

RQ2: Is the variance controllable for a given source?

RQ3: What are the root causes of these variances?

RQ4: Does implementation of a management control plan decrease variance?

Research Hypotheses:

H_1: Labor is a significant contributor to unfavorable cost variances.

H_2: By implementing a management control plan, then efficiency (earned hours/actual hours) will improve and overall cost variance will decrease by 10%.

1.7 Scope of Research

The research analyzes company efficiency and cost data as recorded in the SAP system for December 2018 through June 2019, prior to any new company improvements. On site observations and time studies of Shift 1 were collected during March 2019 through June 2019. Efficiency and cost data were analyzed after improvements were in place for the time period June 10, 2019 through July 20, 2019. Data from onsite observations after improvements were in place were analyzed for the months of June and July 2019.

1.8 Research Limitations

Although efficiency and cost data for the two shifts are collected from the SAP system, only Shift 1 is directly observed by Gemba Walks. The timeframe for Shift 1 is 5:30 am to 1:30 pm. When calculating labor variance, not all operators are equally skilled. Operator skill levels are not factored into the results per shift. Human behavioral issues as pertaining to labor hours are excluded from the study.

1.9 Organization of Praxis

This chapter is an introductory chapter. Chapter two presents a review of the literature on process improvement and quality engineering. The third chapter is a detailed description of the methodology applied in this research, which includes a comparison of the beginning state of the manufacturing process with the manufacturing process after improvements are implemented. The fourth chapter is reserved for the results of

implementing the research methodology. The fifth chapter includes the discussion and the conclusions. Appendices are found at the end of the paper for additional information.

Chapter 2—Literature Review

2.1 Introduction

Successful companies respond effectively to the demands of a global marketplace where customers search for optimal combinations of quality and pricing before purchasing products. One challenge for firms is the robust competition for product sales because these worldwide consumers are informed by instant access to a plethora of product marketing and product choices. In this environment, industry investment in product and process improvement is critical in maintaining profitability. To remain competitive, these businesses and industries must offer quality products while at the same time keep costs at a minimum (Yasin, Czuchry, Dorsch & Small, 1999; Snee, 2008). Additionally, companies must remain flexible in adjusting to market demand fluctuations in product volume and product types (Liu, Li, Lian & Yin, 2012).

Business improvement can be traced back to Taylor's literature on scientific management (Taylor, 1911). Taylor proposed that scientific investigation using time and motion studies would improve organizational efficiency and productivity. He examined task design and work standardization. Although controversy exists about the value of Taylorism, the concept has influenced total quality management literature (Boje & Winsor, 1993). Another early influence was Farrell's work on mathematical calculations of production efficiency (Farrell, 1957).

After the end of WWII and the surrender of Japan, occupying forces focused on rebuilding infrastructure. Companies were encouraged to apply techniques like quality control to assist in decisions about financial performance. Total Quality Management (TQM) was considered one of the foundational management theories for improving

performance and achieving quality and excellence. Value propositions of TQM included adding value for customers, creating a sustainable future, and promoting creativity and innovation. In 1950 W. Edwards Deming taught a quality control class to Japanese engineers. When sharing U.S. manufacturing principles, he referenced statistical quality control (SQC) as a tool for quality improvement. It would be thirty years later before the quality transformation became widespread globally (Kolesar, 1993; Folaron, 2003; Dahlgaard-Park, Reyes & Chen, 2018).

Motorola adopted quality after being impacted by quality improvements in products produced internationally. Motorola began sharing quality practices with other companies. In the mid-1980s, Motorola introduced the Six Sigma methodology focused on the improvement of quality. TQM principles were the basis of Six Sigma. In 1995 Jack Welch at General Electric made Six Sigma methodology a corporate requirement. (Dahlgaard-Park, Reyes & Chen, 2018). Modeling quality at the task level provided insights for management decisions about planning and scheduling. Evaluating the tradeoffs between time, cost, and quality guided managers in achieving project objectives (Liberatore & Pollack, 2013). A framework for making trade-off decisions about quality, uncertainty, risk, and opportunity guided project planning and monitoring (Browning, 2014).

2.2 Lean Manufacturing

In the 1990s lean manufacturing, based on the Toyota Production System, focused on eliminating waste from organizational processes, thus allowing companies to deliver savings in production by improving process efficiency (Holweg, 2007). Investigations examined operational improvements that resulted from lean implementations such as the impact of lean manufacturing on productive efficiency and profitability (Meade, Kumar &

White, 2010; Bharathi, Vinodh, Devarapu & Siddhamshetty, 2017). Automotive plants manufacturing a wide range of models exhibited high levels of quality and productivity when they applied strategies of lean production. The analysis of data showed that the geographical location of an assembly plant was not correlated with productivity and quality levels (Krafcik, 1988).

Lean was proving equally beneficial for any sector (Panwar, Nepal, Jain & Rathore, 2015). There was evidence that process improvement increased productivity in manufacturing and construction projects when lean principles were adopted (Bayou & de Korvin, 2008; Yu, Al-Hussein, Al-Jibouri & Telyas, 2013; Sharma & Rao, 2014; Das, Venkartadri & Pandy, 2014; Yang, Kuo, Su & Hou, 2015). There were indications, however, that improvements in quality level did not necessarily lead to improvements in productivity (Hotard, 1988).

The performance of projects improved when customers received better quality products with fewer variations. Statistical thinking guided the application of quality engineering tools (Vining, Kulahci & Pedersen, 2016). Because variability impeded performance, managing variability was an essential dimension of lean thinking. Lean production systems had the capability to produce diverse manufactured products at lower costs (Thomas, Horman, de Souza & Zavrski, 2002) through reliable workflows that reduced process variability (Han, Chae, Im & Ryu, 2008). There was, therefore, demand for increased consideration of the concepts of lean design (Freire & Alarcon, 2002). When manufacturing companies decided to adopt lean principles, they realized that even if they could not apply the precise method, they could follow many of the same principles of lean (Billesbach, 1994).

2.3 Challenges of Lean

Lean implementation faced challenges, such as in the case of accounting systems poorly aligned with lean thinking (Ahlstrom & Karlsson, 1996). There was a negative impact on income statements as a result of the lean implementation that was not offset in the short term by operational savings. One suggestion was using additional metrics that tracked improvements in direct and indirect labor monthly as an alternative lens with which to view the value of lean implementation (Meade, Kumar & White, 2010). The complexity of lean management implementation in manufacturing systems was complex, but less so if the implementation became part of a continuous improvement strategy. Each company was unique and adapted the tools to its specific manufacturing characteristics (Domingo, Alvarez, Pena & Calvo, 2007). Continuous process improvement (CPI) teams engaged in improving manufacturing operations, applied techniques such as reducing non-value-add steps. In transitioning to a lean production environment, the team applied quality tools like Pareto charts, cause and effect diagrams, and control charts. With the variety of tools available, their success depended on selecting and using the appropriate tool for the identified problem-solving scenario (Componation & Farrington, 2000).

Another challenge for businesses was that every work process was variable to some degree. People did not perform activities identically every time, so wide variation in productivity was possible. Processes themselves varied, which impacted process performance. These impacts changed an activity's duration, cost, frequency of occurrence, and relationship with other activities. Most processes were variable and had inherent uncertainty in their outcome. Process models that accurately related costs to individual activities were valuable because companies could predict the cost to produce a product and

thus identify areas for process improvement. It was critical to relate cost and time at the activity level of a process. Activity-based costing (ABC) was an analytical tool used for examining manufacturing processes to determine the relationship between cycle time and cost. Computer simulations allowed examination of these complex processes. The processes were experimentally modified to reflect strategic initiatives under consideration, allowing companies, before investing, to observe how selected processes responded to change (Back, Maxwell & Isidore, 2000).

Another caution for managers of lean implementation efforts was not to expect significant short-term improvement in performance since lean was an ongoing process of continuous improvement (Goh, 2011; Zhu & Lin, 2017). Construction project managers benefited from identifying the impact of management strategies when they sought to improve labor productivity. For example, managers quantified the effectiveness of communication and incentives to determine if these strategies improved labor productivity. Tools were available to benchmark the level of implementation success of management strategies allowing construction managers to measure their progress against other projects (Ghodrati, Wing, Wilkinson & Shahbazpour, 2018).

Some studies suggested that the future success of lean depended on the innovation of management (Emison, 2004). A different perspective for improvement was to integrate the concepts of sociotechnical systems and lean manufacturing (Mehta & Shah, 2005). Other studies identified that lean implementation, when complemented with other resources, was more effective in achieving a high level of performance (Prajogo & Sohal, 2006). One study emphasized that the quality of the engineering deliverables was critical in project success (O'Conner & Woo, 2017). There was a study that combined lean,

simulation, and optimization (Uriarte, Ng, Zuniga & Moris, 2017) and a study that suggested hybridizing lean manufacturing and advanced manufacturing (Ghobakhloo & Azar, 2018).

It was crucial to comprehend lean in its entirety to apply the right tools and strategies to provide customer value. Although lean companies experienced benefits, there were limitations and instances of low rates of successful lean initiatives. All types of manufacturing systems adopted lean principles, but there was a crucial need to develop lean manufacturing standards and rigorous metrics for its evaluation. These standards applied to the company before they implemented lean, while they were implementing lean, and when the lean initiative was completed to measure impact (Bhamu & Sangwan, 2014).

2.4 Six Sigma

Developed by Bill Smith at Motorola in 1987, Six Sigma is a disciplined and data-driven business improvement methodology for increasing customer satisfaction and improving financial results. In 1995 Six Sigma was enhanced by General Electric as a business strategy to improve business profitability. Initially, the manufacturing sector adopted Six Sigma. Service industries, financial institutions, healthcare facilities, and public sectors accepted Six Sigma (Hammer, 2002; Thomas, Barton & Chuke-Okafor, 2008). At the core of Six Sigma thinking is variance reduction. It is imperative to gather evidence about what causes it and how to reduce it. The use of statistical methods is a critical component of this approach (Montgomery & Woodall, 2008; Firka, 2010).

DMAIC (design, measure, analyze, improve, control) is one of the Six Sigma tools used for problem-solving. Successful application of DMAIC is reported numerous times in the literature (Li, Al-Refaie & Yang, 2008; Mandal, 2012; Saravanan, Mahadevan,

Suratkar & Gijo, 2012; Sharma & Rao, 2014; Gijo & Scaria, 2014; Li, Jiang, & Zhang, 2019), yet DMAIC is limited in its usefulness for ill-structured problems that are subjective in nature (de Mast & Lokkerbol, 2012). Table 2-1 lists the most commonly used tools and techniques in Six Sigma methodology. Each tool or technique is associated with one or more phases of the DMAIC approach.

Table 2-1. Six Sigma Tools and Techniques (Ismyrlis & Moschidis, 2013)

SIX SIGMA TOOLS & TECHNIQUES	**PHASE OF DMAIC**
Affinity diagram	A
Analysis of variance	AI
Arrow diagram	D
Benchmarking	MI
Brainstorming	I
Cause-effect diagram (fishbone)	A
Checksheet	D
Control chart	M
Correlation analysis	AI
Critical to quality matrix	DMIC
Descriptive statistics	M
Design of experiments	AI
Failure mode effect analysis (FMEA)	AI
Flow chart	DAI
GANTT chart	D
Histogram	A

Hypothesis tests	AI
KANO model	D
Matrix data analysis	D
Matrix diagram	D
Mistake proofing (poka yoke)	I
Non-parametric tests	AI
Pareto diagram	DMAI
Pies, bar charts	A
Prioritization matrix	D
Process capability analysis	DAC
Process map	DAI
Process decision program chart	I
Quality function development (QFD)	DDAI
Regression analysis	AI
Relations diagram	I
Run chart	A
Scatter diagram	A
SIPOC diagram	DI
Six Sigma indicators	DI
Statistical process control (SPC)	MAC
SWOT analysis	D
Tree diagram	D
Voice of the customer	D

There are numerous citations in the research literature describing the successful implementation of Six Sigma strategies along with other studies revealing the lack of success in applying Six Sigma methodology. Studies of successful implementations included applications for restructuring management processes (Lee & Choi, 2006), in a ceramics plant (Chung, Hsu & Yen, 2008), for packing lines (Shu & Liu, 2011), in Italian companies (Brun, 2011), for quality improvement in construction (Lee & Su, 2013), in a small-scale foundry industry (Gijo, Bhat & Jnanesh, 2014), in a small Brazilian company for their zinc coating process (Amitrano, Estorilio, Bessa & Hatakeyama, 2016), in the wood furniture industry (Guerrero, Leavengood, Gutierrez-Pulido, Fuentes-Talavera & Silva-Guzman, 2017), and in tire manufacturing (Gupta, Jain, Meena & Dangayach, 2018). Successful implementations of Six Sigma also provided evidence of cost-effectiveness in both manufacturing operations and nonmanufacturing operations (Rodin & Beruvides, 2012).

Despite the significant successes Six Sigma had received, much criticism was voiced because of the incompleteness in its methodology and misconceptions in the literature as to what constituted Six Sigma theory. This paper presented a chart of 39 Six Sigma tools and techniques. Included was a description of critical success factors for achieving improved clarity about Six Sigma. Comparing results from the implementation of these success factors in real world settings filled in the gap between theory and practice (Ismyrlis & Moschidis, 2013). Companies were asked to determine success factors associated with initiating a quality improvement process as contrasted with success factors associated with maintaining a quality improvement process. The framework identified the phase during which the success factor was used and the phase during which emphasis was

placed on the success factor. Recognizing the differences in emphasis assisted firms to improve their quality planning (Bullington, Easley, Greenwood & Bullington, 2002).

To improve the implementation impact of Six Sigma, research studies proposed combining the Six Sigma methodology with other approaches. One suggestion was to integrate Six Sigma with quality management systems (Pfeifer, Ressiger & Canales, 2004). Another idea was to merge the Theory of Constraints (TOC) and Six Sigma into a framework to improve manufacturing system performance. TOC delineated the direction of improvement while Six Sigma provided the statistical tools and engineering techniques (Ehie & Sheu, 2005). More recent recommendations proposed either the integration of Six Sigma with lean (Pepper & Spedding, 2010) or the incorporation of Lean Six Sigma and project management into Six Sigma methodology (Galli, 2018a).

Rather than propose another rendition of Six Sigma implementation, Matthews suggests a model based on key improvement practices. Improving operational processes improved performance whether through continuous improvement or quality improvement or process improvement. The model focused on a comparison of these three forms of improvement and the effects on short and long-term performance (Matthews & Marzec, 2017).

2.5 Lean Six Sigma (LSS)

In 2003, Lean Six Sigma (LSS) became part of the evolution of Six Sigma. Lean management and Six Sigma, two popular business strategies, were combined to enable continuous improvement with improved bottom-line results. Lean focused on removing waste from the process for efficiency while Six Sigma concentrated on controlling the process statistically and removing variation from the process for effectiveness (Thomas,

Barton & Chuke-Okafor, 2009; Snee, 2010; Salah, Rahim & Carretero, 2010; Stankalla, Koval & Chromjakova, 2018).

Several recent studies have integrated LSS with other methodologies. One illustration was a service industry study focused on fleet maintenance. This investigation implemented a quality improvement model that integrated LSS and PM (preventative maintenance) optimization to improve service processes (Rabii, Naoufal & Omar, 2018). Another recent study investigated the synergy of LSS projects using data science tools in three different case studies. The authors suggested that this integration will increase the impact of LSS due to the increasing importance and availability of data (Zwetsloot, Kuiper, Akkerhuis & de Koning, 2018).

Although underlying principles of LSS were applicable across a variety of industry sectors, construction has faced challenges with LSS application. Principles of quality and efficiency, used in manufacturing, did not necessarily translate to the construction industry because of its unique and integrated delivery system (Sullivan, 2011). Also, the challenge of successful implementation of LLS for small companies was the lack of procedures and records that provided evidence of process performance. Critical success factors, such as commitment and management involvement, were lacking thus creating barriers for achieving quality management systems (Timans, Antony, Ahaus, & van Solingen, 2012; Guerrero, Leavengood, Gutierrez-Pulido, & Fuentes-Talavera, 2017; Galli, 2018b).

2.6 Small and Medium Enterprises (SMEs)

Small and medium enterprises (SME)s had become increasingly aware of the value of implementing LSS and Six Sigma for improvement initiatives. They faced challenges with the availability of financial and management resources due to their size (Thomas &

Webb, 2003; Thomas & Barton, 2006). The SMEs wanted to know how these initiatives would enhance quality and productivity in their manufacturing environments. Investigations identified critical success factors for SMEs that resulted in the success of LSS and Six Sigma implementations rather than producing inadequate results. Requisite success factors identified were a commitment by top management to the implementation process and approval by leadership to incorporate the Six Sigma approach into the business strategy (Stankalla, Koval & Chromjakova, 2018).

Unrestricted access to tools and techniques were critical success factors for successful implementation of LSS and Six Sigma in SME companies to allow SMEs to develop quality enhancements. These tools and techniques were essential for the company's continued quality development. They included problem-solving strategies and continuous improvement strategies. These techniques were more effective when supported by statistical data. The companies achieved greater success when the implementation occurred within a systems approach tailored for a particular SME (Alaskari, Ahmad & Pinedo-Cuenca, 2016).

Questions remained whether SMEs could effectively implement and use formal processes and quality enhancement approaches. With the high degree of diversity among SMEs, a valid pursuit affecting the ability of SMEs to implement formalized quality techniques was to develop a rigorous implementation model that was simultaneously applicable for the unique contexts of a given SME. The uniqueness of a given SME's manufacturing operations was a limiting factor to quality enhancement implementation. It was critical to integrate those dimensions unique to a given SME into the model; otherwise,

accomplishing the goals of LSS and Six Sigma could be jeopardized (Husband & Mandal, 1999).

SMEs made decisions and improved their processes based on accurate and updated information related to the performance of their manufacturing process. They realized that addressing variation was essential for performance improvement. SMEs learned to use tools and techniques to identify the causes of variation and how to correct the variation (Deleryd, Garvare & Klefsjo, 1999).

2.7 Productivity in Multi-stage systems and Multi-project systems

Multi-stage systems with multiple work centers are common in manufacturing. There are numerous interactions among multiple stages in the manufacturing process that impact the quality of the final product. Studies showed that variations impacted quality characteristics at a given work center. Variations occurred within the given work center, but variations also occurred upstream to that work center. When investigating the relationships among quality characteristics, there were management challenges as well as opportunities. In one study, the application of computer modeling was applied to investigate quality control issues and solutions for improvement at the various stages (Shi & Zhou, 2009).

Multi-project systems are also common in manufacturing. Manufacturing companies used project management methodologies to improve workload processes. It was helpful to differentiate the factors of success for traditional single project management from those factors of success for multiple project management. The comparison identified differences in resource allocation and scheduling flexibility. Success factors of little relevance in single project management scenarios were significant in the success of multi-

project management scenarios. Findings indicated that project management of multi-project environments had unique characteristics. There were different factors of success for multi-project settings when compared with single project management environments. Goal clarity and management support were required for project success in multi-project management as well as adequate resource allocation. Prioritization in managing the variety of projects was a significant factor of success. One recommendation to increase productivity was to dedicate resources by project type. The challenge was to allocate the required resources to priority projects while maintaining adequate resource allocation for smaller, less critical projects (Fricke & Shenbar, 2000).

2.8 Statistical Process Control (SPC)

Quality control in manufacturing either controls the product or controls the process. Statistical process control (SPC), or sometimes referred to as statistical process monitoring (SPM), is a statistical measure that informs management about variability. In industrial applications, SPC is used to calculate variability by determining the effect of process parameters on the level of quality. SPC originated at Bell Laboratories with Shewhart in 1924. Since then, research studies continued to investigate the advantages and the challenges of the method (Motamedi & Kimbler, 1989; Montgomery, 1992; Kolesar, 1993; Montgomery & Woodall, 1997).

Statistical Process Control (SPC) used statistical tools, such as control charts, to analyze a process. The intent was to control, manage, and improve the quality of the output or the capability of the process. Natural variability in production processes was due to numerous unavoidable causes described as a chance cause pattern. If the sources of variability were operator errors or improper machine adjustments, the causes were

described as *assignable causes.* The value of SPC charting was to detect the instances of assignable causes, guiding management in taking corrective actions. The process capability index informed management about how well the process met specifications (Hoopes & Triantis, 2001; Gijo, 2005; Chen & Huang, 2006; Ng, 2018); however, SPC methods had to adapt to changes in the manufacturing environment, such as an increase in the availability of data and greater computing capability (Woodall & Montgomery, 1999).

One study focused on efficiency performance while measuring process factors simultaneously. When statistical process control charts, measuring one variable at a time, were applied in conjunction with efficiency performance measures it was valuable in identifying potential root causes. Management used this information to initiate process improvements (Hoopes & Triantis, 2001). In manufacturing processes when applying capability indices like C_{pk}, a specification limit was set. The challenge was to determine how preliminary specification limits were determined. A C_{pk} below 1 represented unacceptable performance. A C_{pk} above 1.6667 represented acceptable performance (Weusten & Tummers, 2017).

The applicability of SPC was shown to be beneficial in monitoring average part size variation for sawn lumber in an automated lumbermill. Real-time SPC was applied to manufacturing processes exhibiting *between* and *within* part size variability in wood products.

A control charting procedure produced successful results (Maness, Kozak & Staudhammer, 2003). In another industrial application, SPC monitoring was integrated with run-to-run (R2R) control in production environments. The procedure detected changes in tool or product effects irrespective of the tool and product distributions (Lee,

Wong, Sun, Chen & Jang, 2015). Understanding the practical application of SPC in manufacturing environments improved the ability of manufacturers to apply SPC and SPM in their respective process improvement initiatives (de Mast & Does, 2010; Woodall, 2017).

2.9 Variation

Successful manufacturing companies made decisions about process improvement based on accurate data related to the performance of manufacturing processes. These businesses were more successful in quality improvement initiatives when they applied statistical methods in the process. These companies investigated variation and its causes to understand how to correct unwanted variation (Deleryd, Rickard & Bengt, 1999; Horel & Snee, 2010).

Variation in production systems created interruptions in the production system, which was a root cause of waste. Variation was distributed throughout the production flow, thus reducing productivity. The study confirmed that variation affected task starting time and task duration. By concentrating on root causes of variation, managers designed strategies that were effective in reducing variation and improving productivity (Wambeke, Hsiang & Liu, 2011).

In four different construction simulations, the analysis indicated that variation did not create waste. Interestingly, waste developed between handoffs. The findings reported that increasing work task duration decreased the effect of variation. The impact of variation depended on the design of the sequence of the workflow (Lindhard, 2014). In another study the ability to identify sources of variation in manufacturing processes detected and reduced variation in manufacturing processes, giving companies a competitive advantage. These

companies were able to provide better quality products to their customers (Loose, Zhou & Ceglarek, 2008). SPC techniques were used to estimate the variance of the variables in the manufacturing of ceramic tiles, which resulted in quality improvements (Heredia & Gras, 2010).

In a study of automobile manufacturing processes, control charts were used to monitor the sheet metal stamping processes. Out-of-control signals indicated the process mean had changed. Management ignored these signals for corrective action since the process could not be adjusted. When manufacturers segregated the variations into three categories of part-to-part variation, of batch-to-batch variation, and within-batch variation, they had a more well-defined conception of the sources of overall product variation. Quantifying the sources and magnitude of variation guided manufacturers in developing a variation reduction plan. The manufacturers were able to isolate the location of variations in the automotive body panels and improve productivity (Majeske & Hammett, 2003).

2.10 Variance

In industrial and manufacturing settings, process variance was caused by variation in purchase price, materials usage, scrap, labor, and overhead. Process improvements resulting from the reduction of variance provided consistency in production and reduced manufacturing losses (Orczyk, 1989; Tahera, Chan & Ibrahim, 2008; Tahera, Ibrahim & Lochert, 2010; Shishebori, Akhgari, Noorossana & Khaleghi, 2015).

The relationship between workflow variance and labor productivity was examined in an oil refinery expansion project. The investigation sought ways to assist managers in focusing on those factors that contribute to productivity. Labor productivity was measured by a productivity ratio calculated by dividing earned hour by actual hour. The findings

were that variance in workflow, as measured by percentage complete, was positively correlated, at the 0.05 level of significance, with labor productivity. There was an improvement in productivity when workflow was predicted, so managers proceeded with aligning the available workload with capacity (Liu, Ballard & Ibbs, 2011).

Identifying and eliminating major sources of manufacturing variance in the assembly process at an automobile manufacturer revealed ways to improve product quality. The study identified how to add and adjust sensors in the assembly line. Dimensional measurement data were used to identify major root causes of part-to-part dimensional variation. The company was able to diagnose an optimal sensor layout to reduce variance and increase productivity (Apley & Ding, 2005).

A case study on biodiesel production technology investigated sustainability improvement. The challenge was to identify bottleneck issues and improve sustainability. A systematic approach to sustainability root cause analysis was implemented. The findings verified that the flowsheet of the chemical energy production process was sufficiently general to be applicable in different production systems (Jayswal, Li, Zanwar, Lou & Huang, 2011).

2.11 Management Control Plans

Management control systems assist managers in improving performance within the organization. Management control systems provide information useful to managers, such as detailed knowledge of how the business works (Otley, 1999). In the construction industry, Key Performance Indicators (KPI) measured process performance, but they were used as a review after project completion. Critics argued that KPIs did not provide the opportunity to control the work while in progress. The study designed a measurement

system that was representative of an active control process. A series of questions related to process completeness and process quality was tested on two projects. Project managers were instructed about what to control within the process and how to control it. The project managers acted to achieve desired results. It was determined that most of the existing KPIs were not useful for control purposes. The process performance was defined as the percentage of the standard performance concerning completeness and quality. Rather than attempting to achieve accurate performance measurements, the objective was to design guidelines. The measurement system focused on identifying critical issues and their attainment. It was used to monitor process performance and to gain control (Haponava & Al-Jibouri, 2012).

Control of manufacturing quality and productivity is increasingly important for both single manufacturing operations and multistage manufacturing operations. The ability to control manufacturing processes has advanced due to increased computational capacity and sophisticated sensing technologies. Minimizing variability and achieving process consistency is achievable with new approaches such as adaptive control strategies and R2R control. Being able to anticipate deviations and make corrections in advance of deviations holds promise over the traditional approach of reacting to deviations. The combination of solutions as mentioned previously by integrating SPC with R2R is one example of recent advances in applied methods of control for manufacturing processes (Djurdjanovic, Mears, Niaki, Haq & Li, 2018).

Manufacturing environments with multidisciplinary teams, multiple objectives and uncertainties in cost, performance, demand, and operational needs have added complexity to engineering management decision analysis. These decision-makers requested a

systematic approach for improving decision analysis because they were under pressure to reduce lead times and reduce costs while improving the value of products. Efficient, effective, and repeatable decision-making processes enabled them to monitor and control performance (Yassine & Chelst, 2018).

2.12 Summary and Conclusion

The literature review examined research that focused on process improvement methodologies. The history and evolution of the methodologies illustrated a relationship to world events that drove their origins and applicability. As research studies informed the business communities of practical applications of the methodologies and new insights emerged among theorists and practitioners, adaptions to more current environments were possible. It became clear that quick fixes in solving problems using these methodologies did not result in levels of desired outcomes. It was through long term commitments to quality that companies realized significant improvement. More importantly, the research community did not hold back criticisms or concerns but viewed them as part of the evolutionary process.

Openness to sharing advanced thinking about process improvement was evident as international communities sought to build on published studies to expand and extend those ideas that proved beneficial and closely examine those that failed so as not to repeat them. When it made sense to integrate or to combine methodologies, practitioners found willing businesses and companies eager to participate. Recommendations suggesting future research opportunities were of value in considering next steps.

The literature review made evident the connections among quality, lean thinking, and statistical thinking. Tools and techniques for examining data as provided by Six Sigma

methodology apply across companies, across industry sectors, and across countries. As more evidence of applicability and practicability emerges, improved guidelines for implementation can be designed.

The impact of Lean, Six Sigma, and LSS on quality improvement, productivity, and efficiency has been significant. It remains a priority for business and industry to be well informed of contextual limitations of implementation and to use research-based guidelines in their endeavor of process improvement whether to improve quality or reduce costs or both. Advances in technology and computer simulations will become more widely disseminated to support process improvement efforts. The question is if it is possible to reach a level of process improvement implementation, so no business fails.

Chapter 3—Methodology

3.1 Introduction

The methodology section describes the Praxis research and how it was conducted step by step. The study partnered with a manufacturer of metal goods purchased by government and educational institutions. The facilities plant operated fifteen primary work centers to produce and ship these metal goods, which customers pre-ordered. The company also manufactured the parts used in producing the metal goods. The purpose of the research was to isolate root causes of manufacturing process problems at three work centers to identify corrective actions for process improvement. A two-sample t-test compared efficiency data before and after corrective actions were implemented.

The company plant manager agreed to the application of Six Sigma DMAIC methodology since the cause of and solution to process problems were unknown. The identified goal was to improve efficiency at the five work centers by reducing variance in the manufacturing process, thereby increasing efficiency and reducing manufacturing costs.

3.2 Six Sigma DMAIC Methodology

The DMAIC (Define, Measure, Analyze, Improve, Control) framework has five phases that guide process improvement projects (Rodin & Beruvides, 2012; Ismyrlis & Moschidis, 2013; Rabii, Naoufal & Omar, 2018; Li, Jiang & Zhang, 2019). This praxis applied Six Sigma tools and techniques during each phase of DMAIC to improve effectiveness and efficiency of the manufacturing processes at *XYZ Industry*. The objective was to reduce special case variance, thereby improving efficiency. An improvement in efficiency should result in increased productivity and cost reduction in manufacturing

operations. Figure 3-1 illustrates the five phases of the DMAIC methodology and actions taken at each phase.

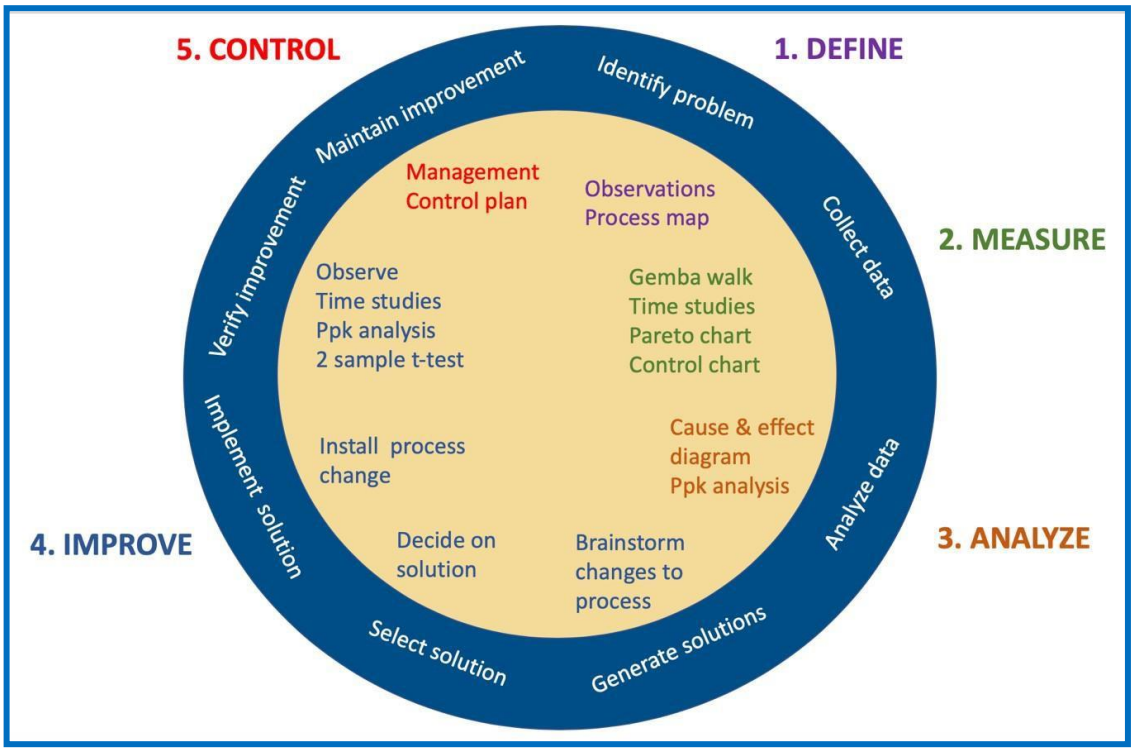

Figure 3-1. Six Sigma DMAIC Phases

1. During the first phase, *Define*, the researcher defined the process problem and project objectives for achieving expected results. The facility floor was mapped.
2. During the second phase, *Measure*, the process problem was quantified. Time study data were collected from two work centers. Pareto charts were analyzed for these work centers. The processes at each work center were described in detail to elucidate areas for possible performance improvement. Process capability analyses and control charts were formulated using Minitab to assist management in defining the improvement strategy. Ppk analysis and process stability were determined for the current manufacturing processes for Work Centers 24 and 1KPUNCH.

3. During the third phase, *Analyze,* evidence was gathered to identify the root causes of inefficiencies (variance) in the process to determine process changes that would produce the most effective results. A cause and effect diagram mapped the possible causes of variance at different work centers. Another useful tool, the 5 Whys Method, provided a more thorough explanation of the root causes and why they were occurring. By following the steps of root cause analysis, the identified potential root causes were either accepted or rejected.
4. During the fourth phase, *Improve*, process changes were piloted to improve the manufacturing process. A vital tool used to identify the potential risks of implementing the process changes was a Failure Mode and Effects Analysis (FMEA). The impact of the changes were then measured with time studies and data collection from the SAP system and analyzed Ppk analyses, two sample T-tests, and non-parametric testing.
5. The fifth and final phase, *Control*, used metrics to monitor the level of improvement and control the improvements implemented. A management control plan was provided to management as a guide for monitoring and controlling the change process.

3.3 Research Data

The raw data included observational data, SAP system data, and time study data. The SAP system recorded efficiency data weekly by work order and by the work center manufacturing that order. Run earned hours, run actual hours, and efficiency data were extracted from the SAP system. During the Define phase, a Gemba Walk recorded direct observations of the manufacturing facility to map the location of manufacturing lines, work

centers, and operator stations. During the Measure phase, videotapes of work center activities were created to chronicle the manufacturing processes to be investigated. Time study data for work centers were collected from February 2019 through May 2019 to determine production rates. During the Analyze phase, SAP system data were examined for six months, December 2018 through May 2019. During the Improve phase, SAP system data were examined for June 2019 and July 2019 to examine efficiency rates after improvements were in place. Time study data were collected from June 2019 through July 2019 after improvements were in place to determine production rates.

The CFO provided cost variances for the 2019 Fiscal Year (May 2018 to April 2019) for the following categories: Labor and Overhead, Purchase Price, Material Usage, and Scrap. Direct Labor recorded was the labor of the production operators assigned to a specific work order. Direct labor variance happened when the expense affiliated with labor differed from the expected expense. Labor efficiency variance was calculated by taking the difference between actual and expected hours worked and multiplying it by the standard hourly rate.

Manufacturing overhead included indirect factory costs incurred when the products were manufactured. At *XYZ Industry*, each work order was assigned an overhead cost calculated from a percentage of indirect costs such as electricity, equipment maintenance, insurance, and administrative costs. The Overhead variance was directly linked to labor variance.

Direct Materials Usage variance represented the difference between the actual and expected quantity of material needed to manufacture the product. Direct materials usage variance was calculated by subtracting standard usage from actual usage, multiplied by

standard cost per unit. Purchase Price variance was the difference between the actual price paid to buy an item and its standard price, multiplied by the number of units purchased. A positive variance indicated actual costs increased. A negative variance indicated actual costs declined.

Material yield variance was determined as the difference between the actual amount of material used and the standard amount anticipated to be used, multiplied by the standard material cost. An unfavorable variance meant the unit usage was greater than expected. One reason was that unusual amounts of scrap were generated at specific work centers.

3.4 Research Approach

The DMAIC steps were followed to achieve an objective of identifying, categorizing, and quantifying manufacturing variance at *XYZ Industry*. If process improvements were implemented that reduced variance by correcting the root causes of the variance, *XYZ Industry* would have an opportunity to increase profits without making relatively large capital investments. The five phases of the DMAIC approach are outlined in the following sections and described by discussing activities that occurred in each phase.

3.4.1 Define Phase: Data Selection and Preparation

The initial step was to meet with the *XYZ Industry* managers to discuss the current manufacturing process and issues impacting company productivity. The objectives of the study for achieving expected results were defined. The next step was to describe the manufacturing process flow by mapping the location of work centers, assembly lines and operator stations in sequential and parallel order. The company granted full access to their SAP system where raw data was housed by weekly input. Data were scrubbed by the researcher and entered into excel worksheets based on variance categories of Labor and

Overhead, Purchase Price, Materials Usage, and Scrap.

3.4.2 Measure Phase: Data Collection

During this phase, the process problem was quantified. To measure process performance, data were extracted from the company's data system and data were collected by conducting time studies of the work center processes. A pie chart of cost variances was created from the SAP data organized in Excel. The pie chart illustrated the percentage of variance contributed by each category of Labor and Overhead, Purchase Price, Materials Usage, and Scrap.

To measure operator activity, an activity analysis was used to examine how employees spent their time during an eight-hour shift. Some operators were trained for multiple work centers.

Pareto charts for each work center were created from time study data collected at each work center by the researcher. Figure 3-2 represents an example of Pareto analysis. These charts were shared with the company manager to use in brainstorming a list of those instances of manufacturing variance having the greatest potential to impact process improvement.

Work Center One Issue	# of Occurances	Cumulative %
Issue one	43	43.4%
Issue five	37	80.8%
Issue seven	4	84.8%
Issue two	4	88.9%
Issue eight	3	91.9%
Issue three	3	94.9%
Issue four	2	97.0%
Issue nine	2	99.0%
Issue six	1	100.0%

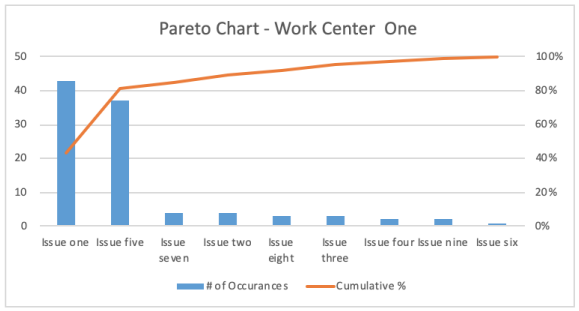

Figure 3-2. Example of Pareto Chart

The 80/20 rule was applied to graphically illustrate whether 20 % of the observed process issues represented 80 % of the total process issues. This tool helped categorize and summarize process issues at each of the work centers categories for further investigation (Shu & Liu, 2011). Statistical process control methodology and process capability analyses were applied to help define areas for improvement.

3.4.2.1 Statistical Process Control

Statistical Process Control is a methodology that can be used to cut costs by controlling or eliminating special cause variation. Every process shows some amount of variation. Chance or common cause variation is common and expected in the process. Unstable or special cause variation is not common and is unexpected in the process. Unexpected variation results from unusual occurrences. For example, unusual occurrences might be operators leaving the work center to talk with a friend or operators improperly stacking products, so they break. Quality control eliminates sources of variance not common to the process. Once the special cause variation is identified, it is monitored with control charts to determine when the process goes beyond the natural range.

Statistical Process Control maintains processes stability, consistency, and predictability to ensure product quality. One of the most common tools used is the control

chart. Control charts show how a process or output varies over time. The charts distinguish between common cause and special cause variation. Identifying different causes of variation informs managers about when and how to take corrective action on a process without overcontrolling it. Managers are then able to address unwanted variation using data to guide their decisions to achieve process improvement (Hoopes & Triantis, 2001; Ng, 2018).

Control charts plot process data in time-ordered sequence displaying observations graphically. A center line represents the process mean. An upper control limit and a lower control limit are included. Control limits are drawn at distances approximately three sigma above and below the central line. Points that randomly fall inside the control limits exhibit common cause variation. Points that display a non-random pattern or fall outside the control limits represent the presence of special cause variation indicating the process is out of control.

A control chart indicates when the process is stable and consistent over time or if it is out of control. It identifies the presence of special cause variation. If special cause variation is present, the process is not stable and corrective action is required. Figures 3-3 and 3-4 show examples of tracked measurements with the center line included. Each example displays a different scenario with respect to consistency over time. Control charts assess the effectiveness of a process change. Shifts in the process mean and changes in the process variation can be compared easily.

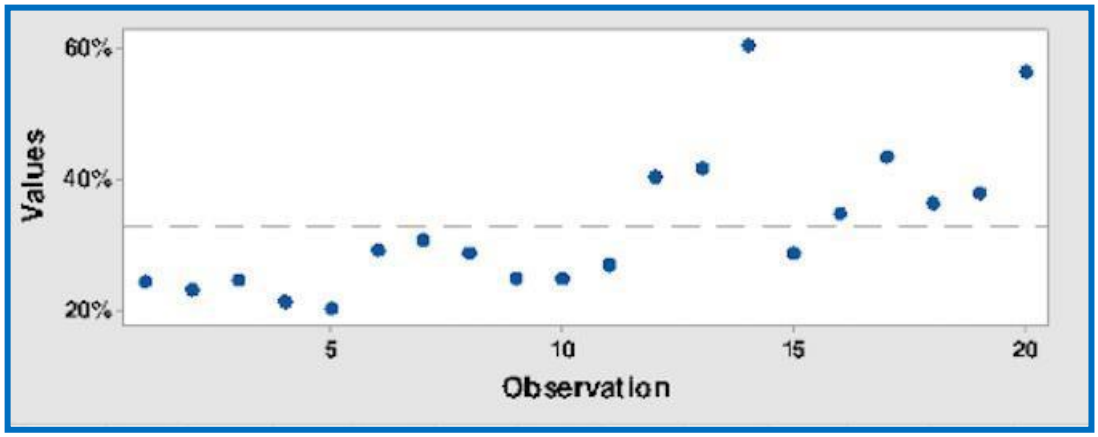

Figure 3-3. Control Chart: Example One

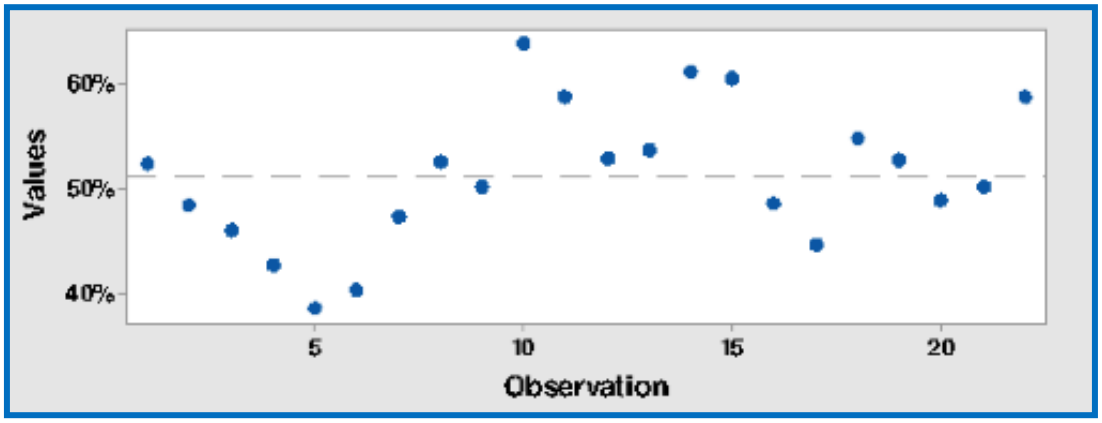

Figure 3-4. Control Chart: Example Two

3.4.2.2 Process Capability

Process performance shows how well a system performs at the upper and lower specification limits. It focuses on the spread. The Process Capability Index (Cpk) is a statistical tool that measures the potential capability of a process at time intervals to determine if the process produces outputs within specification limits. Cpk can be used to estimate the proximity to a target and the consistency around the average performance. It identifies improvement opportunities in the process that can be achieved by reducing or eliminating sources of variability.

Manufacturers use capability indices to evaluate whether the process can produce

parts within specifications or standards. The higher the Cpk value, the better the process is. A Cpk equal to or higher than 1.33 indicates the process is capable and meets specification limits. Lower Cpk values indicate the variation is too wide compared to the specification. It is essential to verify the process is stable before performing a capability analysis. A capability analysis is valid only when performed on a stable process. The Cpk also estimates future process performance, assuming the performance is consistent over time.

The Process Performance Index (Ppk) uses standard deviation to determine process variation. A Ppk greater than 1 means the process can meet specifications. Figure 3-5 shows a Ppk analysis with a value of -1.11, which means the process does not meet specifications.

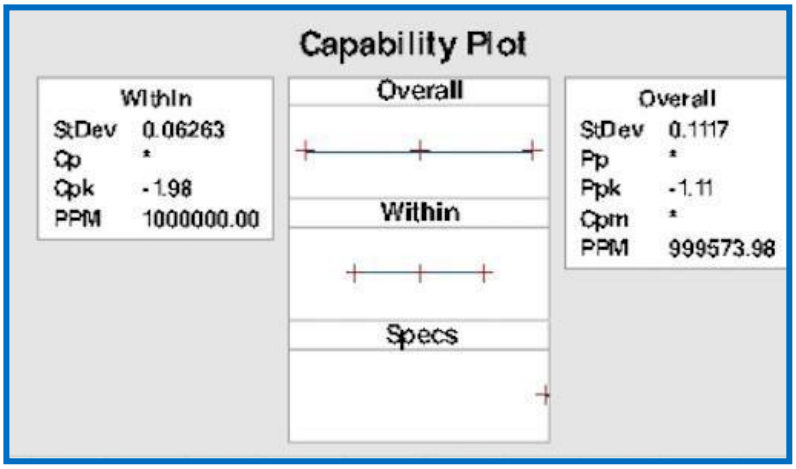

Figure 3-5. Example of Ppk Analysis

Figure 3-6 shows a capability histogram example that indicates the process is not stable because there is a substantial difference between the two curves. The process spread, shown by the solid curve, is larger than the specification spread, shown by the dashed curve, suggesting poor capability. The capability histogram shows data in relation to the distribution fit and the specification limits (USL and LSL).

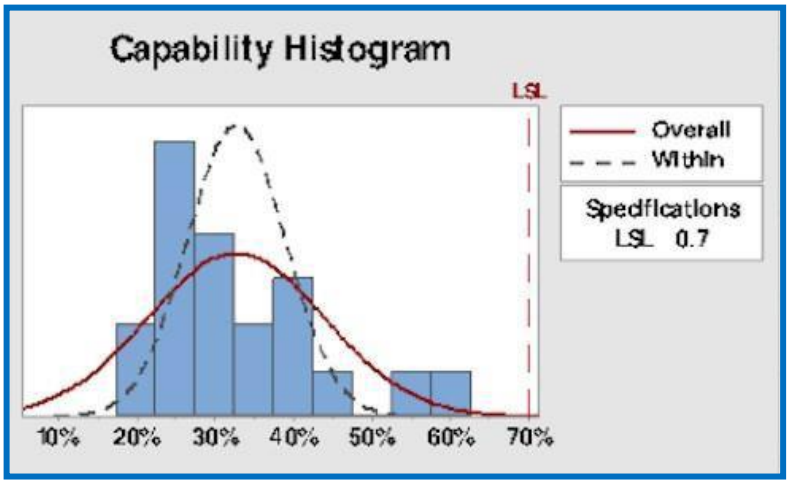

Figure 3-6. Example of Capability Histogram

The process performance index (Ppk) informs how well the system is meeting specifications or how well the system is running compared with specifications. It also examines how well the process is centered within specification limits. Ppk values higher than 1 indicate the output is within specifications. The higher the Ppk value, the less variation there is between process output and specifications. Ppk values between 0 and 1, mean that not all process output meets specifications.

The Ppk formula is shown in Equation 3-1.

Equation 3-1. Ppk Formula

$$\text{Ppk} = \text{Minimum of } \frac{\text{USL} - \text{X}}{3s} \text{ or } \frac{\text{X} - \text{LSL}}{3s}$$

$$\text{X} = \text{Average of all readings}$$
$$\text{USL} = \text{Upper Specified Limit}$$
$$\text{LSL} = \text{Lower Specified Limit}$$

$$s = \sqrt{\sum \frac{(X_1 - \bar{X})^2 + (X_2 - \bar{X})^2 + \cdots (X_n - \bar{X})^2}{n - 1}}$$

n = sample size
X_n = n_{th} data point
$\bar{X}$ = average

Ppk uses the actual sigma value. It is used to measure whether the process is meeting requirements (Weusten & Tummers, 2017; Jensen, Szarka & White, 2019)

This praxis used a Ppk analysis to determine if variation in the manufacturing process at *XYZ Industry*'s work centers was a result of chance variance or due to special cause variance. The process performance analysis informed management as to the nature of the improvements that needed to be considered.

3.4.3 Analyze Phase: Data Analysis

Data were analyzed to determine and confirm root causes of process problems. This analysis guided the researcher and company managers in identifying opportunities for process improvement based on root cause analysis (RCA). The Six Sigma tool used in this phase was the cause and effect diagram and the 5 Whys method.

A cause-and-effect diagram was used with brainstorming and Pareto analysis to display causes or sources of variation that led to defects or unwanted variation in a process. Brainstorming sessions suggested possible reasons why a process was out of control. Figure 3-7 is a graphical representation illustrating the cause and effect relationships between potential causes. Root causes were identified by data-based validation of these possible causes. The researcher grouped causes into major categories then continued asking why until root causes were identified. The causes identified as root causes were confirmed by data collection and analysis, such as performing a Gemba walk to observe the process in real-time or designing an experiment to confirm if the cause was a root cause.

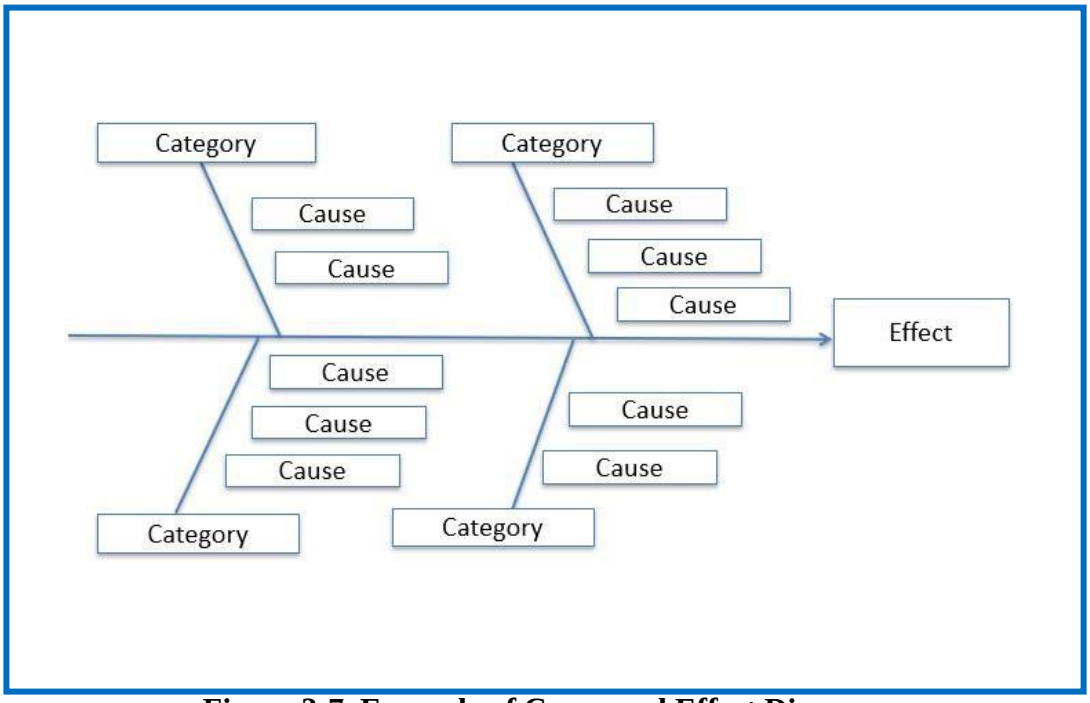

Figure 3-7. Example of Cause and Effect Diagram

A validation plan was organized in chart form to represent the types of data available and possible analysis techniques to be performed for validation of all potential causes in the cause and effect diagram. Based on the validation plan, each potential cause was confirmed or not confirmed. Evidence-based conclusions were made regarding whether the cause was a root cause or not (Gijo & Scaria, 2014; Guerrero, Leavengood, Gutierrez-Pulido, Fuentes-Talavera &Silva-Guzman, 2017).

3.4.4 Improve Phase: Implement New Process

Time study data, SAP efficiency data, and observational data were collected and analyzed after improvements were implemented. A two-sample t test compared time study data before and after improvements to determine the level of significance of improvements in efficiency. A two-sample t test compared efficiency data in the SAP before and after improvements to determine if there were significant reductions in unwanted variance. Tests for data normality were conducted, as shown in Figure 3-8.

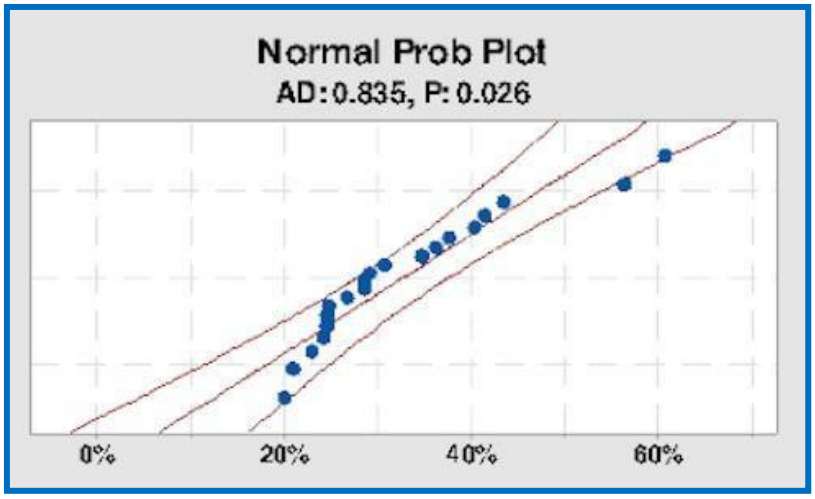

Figure 3-8. Example of Normal Probability Plot

Control charts and a Ppk analysis were completed for each work center after the improvement was implemented.

3.4.5 Control Phase: Management Control Plan

The goal of a quality improvement initiative is to collect data-driven evidence that corrective actions or process improvements resulted in the reduction of variance, which increased productivity. During the Implement phase, changes and improvements were put in place at *XYZ Industry*. These process improvements were monitored to determine if a statistically significant improvement in processes could be documented. It was essential to maintain and sustain the changes to achieve the objectives of improvement; otherwise, the company may not benefit from the changes because it returned to practices that were in place before the improvements that resulted in a condition of unwanted variances negatively impacting profits.

During the Control phase, a Management Control Plan was designed to guide the company in sustaining the improvements over long periods to maintain a high level of product quality. The plan included a checklist to assist management in identifying whether corrective action or process improvement was or was not being sustained. The company

incorporated its previously established process checklist for verifying customer-driven quality requirements into the Management Control Plan.

The Management Control Plan described procedures such as how to conduct quality checks, how to monitor process parameters, and how to standardize time measurements required at each phase of the manufacturing process to ensure process outputs conformed to customer requirements. The Management Control Plan provided the plant manager with the information needed to control the process and produce quality products. The plan included instructions about actions to take if non-conformance was detected by observation or statistical process control tools.

One advantage of a documented Management Control Plan was to ensure quality was maintained in a process. By keeping records of process improvements that were archived when new process improvements were introduced, the company maintained a historical record. It established a standard for quality inspection and process monitoring. It was important for management to view the Management Control Plan as a dynamic document that was periodically updated as measurement methods and controls were improved at future dates.

The Management Control Plan was formatted in Excel. It included input cells for the type of process improvement, a process improvement identification number, the projected date for initiating the process improvement, the actual start date of the process change, a description of the process improvement, contact information of the individual or team responsible for the process improvement, dates of any revisions to the process improvement plan, description of the revision, a listing of any tools or equipment or machines required to make the revision, key characteristics of any process revised, the

revised plan for collecting data and controlling the process, and the cost associated with the revision. The dynamic form included a set of instructions for managers that simplified the process of updating form so minimal training was required.

3.5 Summary

Raw data was collected by observation and time studies. *XYZ Industry* data from an internal company system was extracted to Excel to be included as part of the raw data for analysis. The DMAIC methodology was followed in identifying, categorizing and quantifying primary sources of manufacturing variance for process improvement. The first step was to define the goals and objectives of the investigation and to identify data sources. The second step was to measure the current process performance using time studies verified by videotaped time measurements. The third step was to analyze the collected data using statistical process control tools and process capability tools. A cause and effect diagram was used to detect root causes of the process variation. The fourth step was to identify and implement process improvements, using statistical tests to determine if the improvements reduced variance and improved company profitability. The final step was to create a management control plan to ensure control and maintenance of the process. In summary, by defining the problem and implementing solutions for root causes of variation, a company builds an optimal method of quality improvement implementation and ensures the sustainability of the solutions.

Chapter 4—Results

4.1 Introduction

Cost variances represent in excess of 8% of revenues at *XYZ Industry*. The purpose of this research was to implement the tools and techniques of Six Sigma methodology for process improvement of manufacturing practices, as described in Chapter 3, to reduce cost variances by 10% to increase profitability. The results of applying the DMAIC framework to the collected data for each phase and implantation of a Management Control Plan are presented in the sections that follow.

4.2 Define Implementation

Implementation of the Define phase began in February 2019 by meeting with the company President, Plant Manager, and Engineering Manager on three plant visits. The first visit was to identify the problem, discuss the scope of the project, establish a timeline for implementation of a Management Control Plan and project completion. Management expressed concern specifically for one of the Work Centers included in the fabrication process. Results based on bi-monthly cost variance reports communicated verbally from management showed that Work Center 24 – Frame Assembly and Door-to-Frame Assembly contributed to the largest cost variance in the fabrication process, specifically the Frame Assembly Process. While Chapter 1 provides a process map (Figure 1-6) for order placement to order shipment of products at *XYZ Industry*, the second visit was dedicated to touring the plant, observing the layout of the plant, and meeting the operators. During the third visit, access was granted to the company's SAP system in order to move to the second phase of the DMAIC methodology.

4.3 Measure Implementation

During the measure phase, data was initially collected from the SAP system on the Frame Assembly process at Work Center 24 from December 2018 to February 2019 on a weekly basis. Data included run earned hours, run actual hours, and efficiency. Run earned hours defines the time the process should take while run actual hours defines the time the process actually took. Efficiency is defined as the level of performance or output of a process per unit of input and is calculated as a percentage, as shown in Equation 4.1.

Equation 4.1 Efficiency

$$\text{Efficiency} = \frac{\text{REA}}{\text{RAH}} \text{ x } 100$$

where, REA = Run Earned Hours

RAH = Run Actual Hours

The graphical results of the Process Capability Analysis (PCA) for Work Center 24-Frame Assembly efficiency data are shown in Figure 4-1.

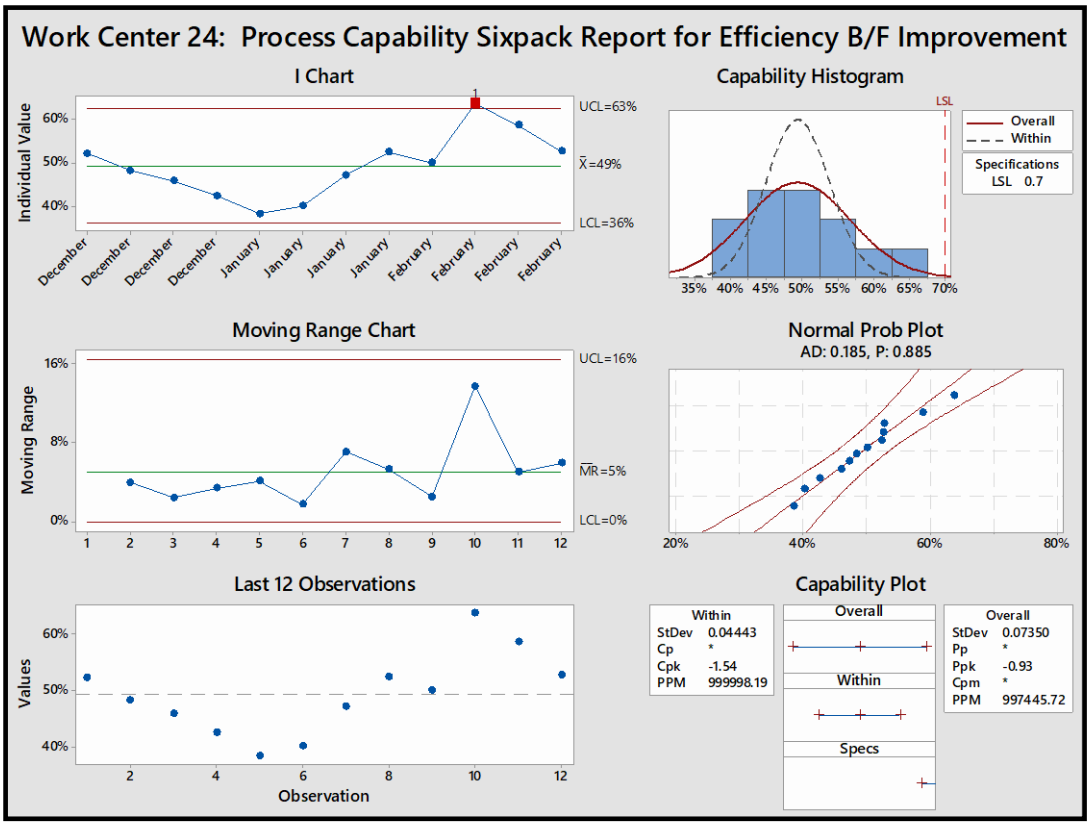

Figure 4-1. PCA for Frame Assembly (Dec – Feb)

Process Capability Analyses can be performed to determine whether a current process is capable of sustaining customer (in this case, management) requirements. The lower specification limit was set at 70% efficiency. Results showed the efficiency data were normal, which is required for the Ppk analysis. However, the Ppk value for this data set was -0.93, indicating that the process was not meeting the company's specifications.

Before time studies were conducted, several Gemba Walks took place to gain a more thorough understanding of the manufacturing process at Work Center 24 by observing the process, identifying potential sources of waste, determine possible areas of improvement, and obtain verbal feedback from the operators. A Gemba Walk is an important doctrine of lean manufacturing that can be implemented to investigate opportunities for improving processes by taking personal observations of a process.

Engaging with the operators also established a positive rapport so that they did not feel they were being judged or would be penalized by their supervisors based on the results of the time studies.

Time studies began in March 2019 and continued through April 2019 to in order to determine how long each part of the process took place at Work Center 24. The steps for the Frame Assembly process were as follows:

1. Operator 1 manually assembled the top, bottom, intermediate(s), and side pieces of the frame.
2. Operator 1 pushed the assembled frame down the assembly line.
3. Operator 2 grabbed the assembled frame and used a stationary spot-welding machine to weld the top, intermediate(s), and bottom pieces of the frame to the side pieces of the frame.
4. Operator 2 placed the welded frame on a pallet.

Steps 1 through 4 were repeated until the work order was completed. As mentioned in Chapter 1, Frame Assembly required two operators on the assembly line.

Figure 4-2 illustrates a Pareto Analysis of the Frame Assembly at Work Center 24. Results revealed that the most frequent problems during the process were the first operator on the assembly line was not actively engaged in the process and the frames were not square after the frame pieces were welded together.

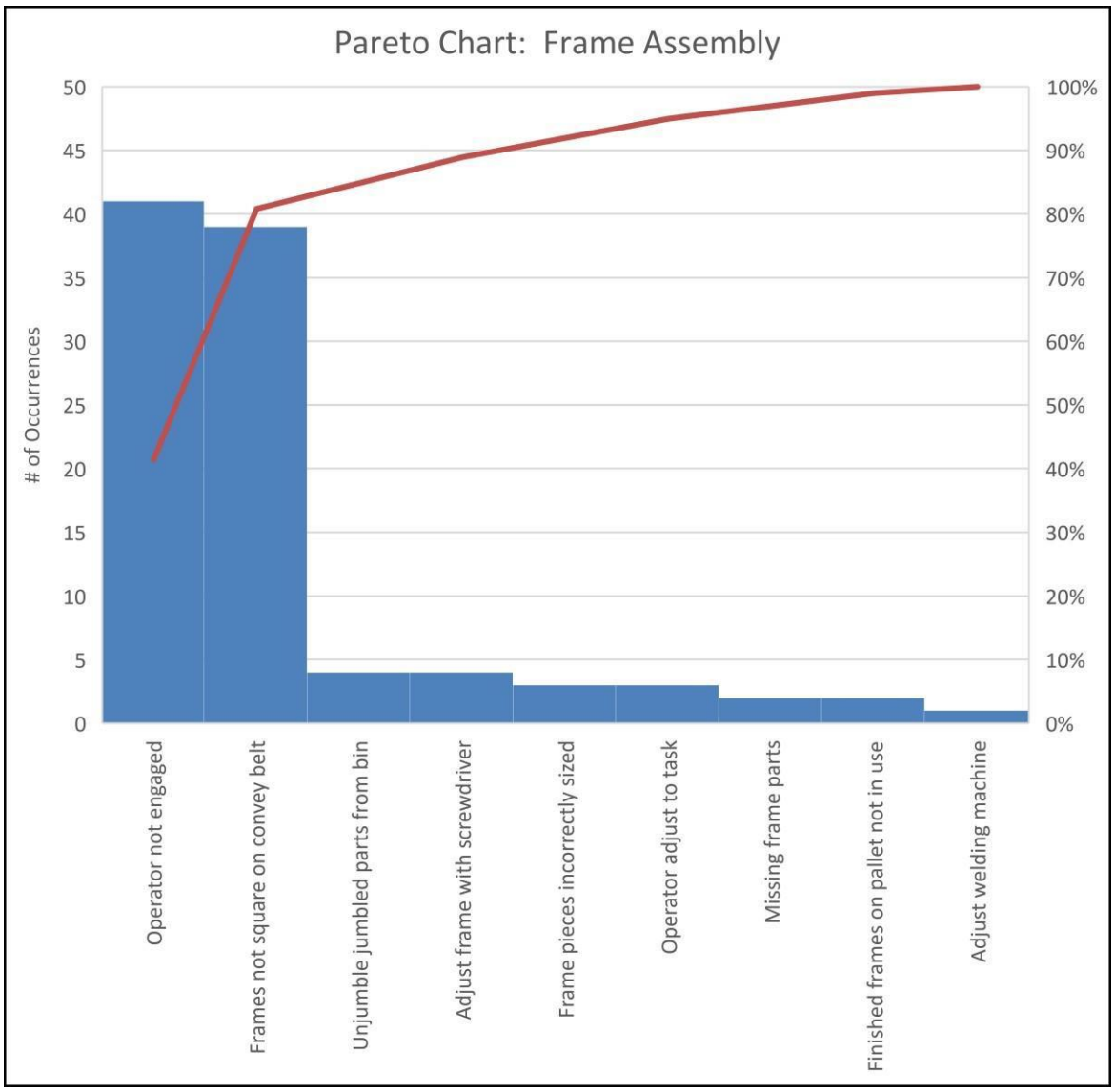

Figure 4-2. Pareto Analysis of Frame Assembly

The steps for the Door-to-Frame Assembly process were as follows:

1. Operator placed frame hinges on the assembled frame into the hinge slots on the door.
2. Operator aligned the holes on the frame hinges with the holes on the door.
3. Operator attached door to frame with mechanical fasteners (rivets) using a rivet gun.
4. Operator placed Door-to-Frame Assembly on a pallet.

Steps 1 through 4 were repeated until the work order was completed. As mentioned in Chapter 1, Door-to-Frame Assembly required one operator.

Figure 4-3 illustrates a Pareto Analysis of the Door-to-Frame Assembly at Work Center 24. Results revealed that the most recurrent issues were operator not engaged and operator required to hammer the frame so door would easily close and open once attached to the frame.

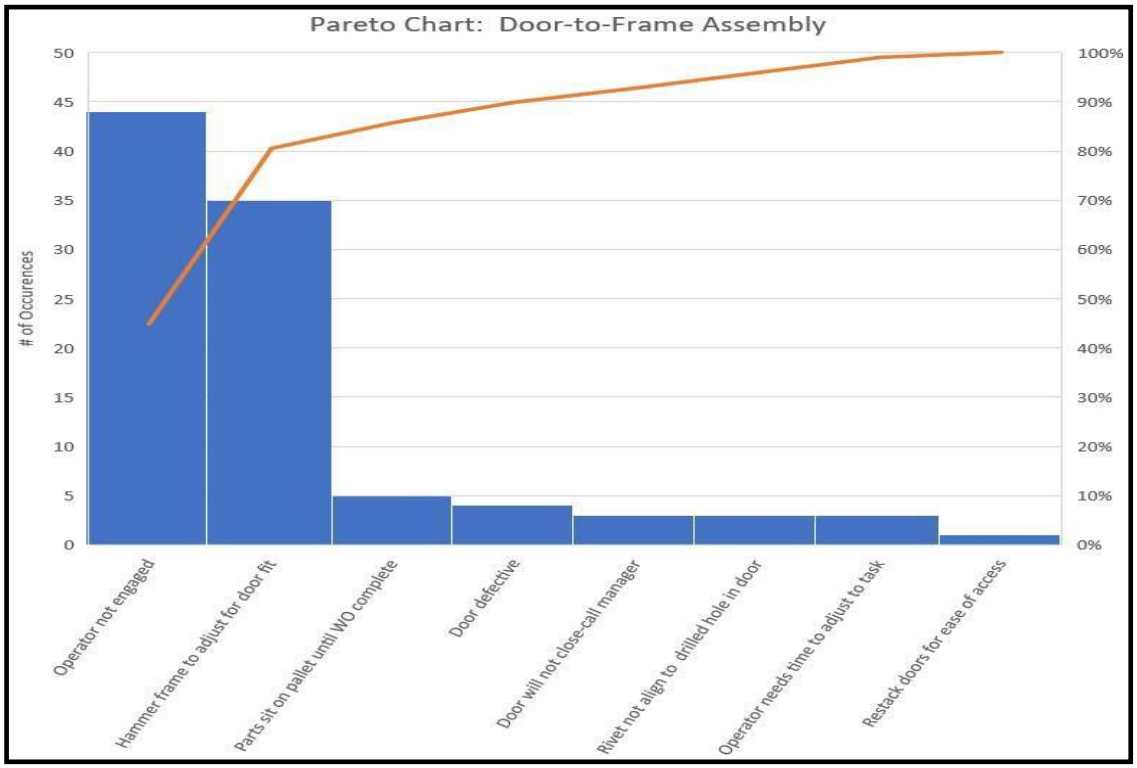

Figure 4-3. Pareto Analysis of Door-to-Frame Assembly

Although Frame Assembly and Door-to-Frame Assembly were the two processes that occurred at Work Center 24, they were performed concurrently. Thus, data collection on each process was easily segregated. Efficiency data collected from the SAP was separated into Frame Assembly and Door-to-Frame Assembly. After a thorough discussion with management, the decision was made to focus solely on Frame Assembly process improvement.

In addition to completing time studies and Pareto charts to determine the frequency of issues during the process and identify potential root causes, additional efficiency data

was collected through May 2019 on the Frame Assembly process before the process improvement was implemented. An additional PCA shown in Figure 4-4 on the Frame Assembly process was performed to include data from December 2018 to May 2019. Results from this analysis revealed that the data were normal and the Ppk value was -0.93, indicating that the process was not meeting the company's specifications. A boxplot of the data is shown in Figure 4-5.

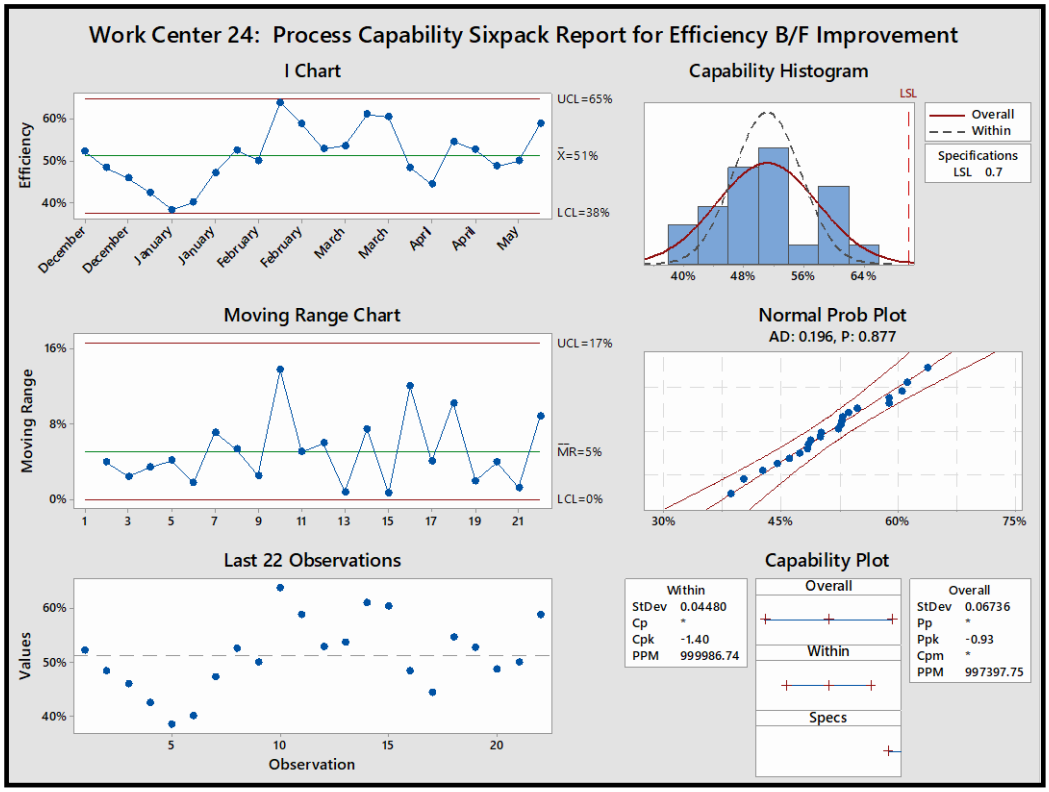

Figure 4-4. PCA for Frame Assembly (Dec – May)

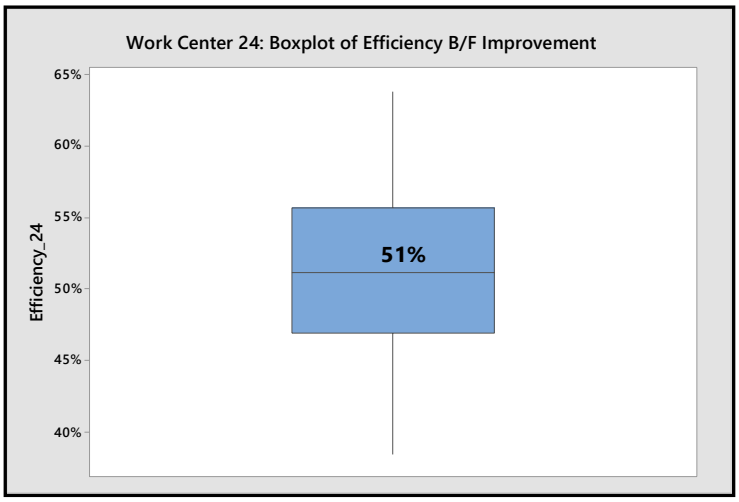

Figure 4-5. Boxplot of Data for Frame Assembly (Dec – May)

To confirm the management's analysis of cost variance, data was collected from the SAP system for the 2019 Fiscal Year (May 2018 to April 2019). As shown in Table 4-1, gross sales for 2019 were $61 million and the percentage of unfavorable cost variance out of gross sales represented 8.11%. Table 4.1 also shows the breakdown of the different types of monetary variances, which include labor and overhead variance, purchase price variance, material usage variance, and scrap variance.

Table 4-1. Cost Variance Breakdown for the 2019 Fiscal Year

May 2018 to April 2019			
Gross Sales	**Monetary Variances**		**Percent of Total Variance**
$ 61,000,000	**Labor and Overhead (Efficiency)**	$ 2,200,000	44.46%
	Purchase Price	$ 2,300,000	46.48%
	Material Usage	$ 500,000	10.11%
	Scrap	$ (52,000)	-1.05%
	Total	**$ 4,948,000**	
	Percentage of Unfavorable Variance out of Gross Sales	**8.11%**	

Of the different types of variances, labor and overhead variance (efficiency) represented 44.46% of the total variance. Figure 4-6 further emphasizes labor and overhead and purchase price variance as significant sources of unfavorable cost variance, which answers **Research Question 1: What are the significant sources of manufacturing**

variances at *XYZ Industry*?. With regard to **Research Question 2: Is variance controllable**

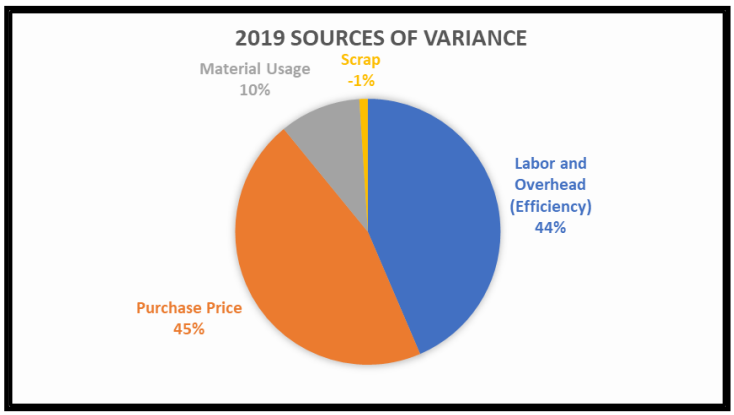

Figure 4-6. Pie Chart of Sources of Variance

for a given source?, the only variance that could be reduced with regard to the scope of this Praxis was labor and overhead variance.

A thorough understating of the relationship between labor and overhead cost variance and efficiency is vital to this research. As shown in Figure 4-7, there is an inverse relationship between variance and efficiency. As noted in earlier in Equation 4-1, efficiency is determined by run earned hours divided by run actual hours. Equation 4-2 calculates labor and overhead cost variance using run earned hours and run actual hours.

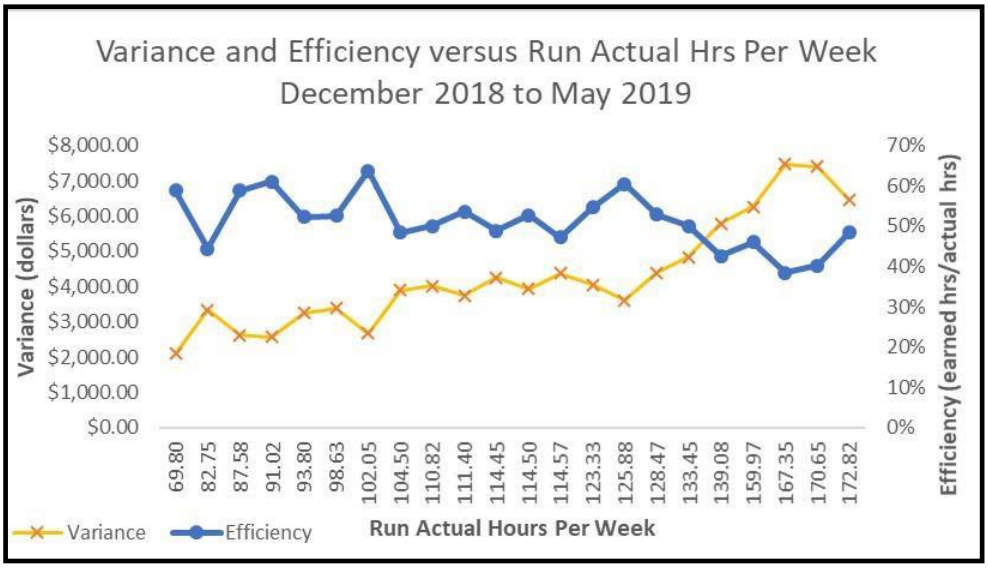

Figure 4-7. Inverse Relationship between Efficiency and Variance

Equation 4-2. Cost Variance for Labor and Overhead

$$CV = (RAH - REA) * DLR + (RAH - REA) * (RAH - REA) * OR$$

where, CV = Cost Variance

RAH = Run Actual Hours

REA = Run Earned Hours

DLR = Direct Labor Rate

OR = Overhead Rate

DLR and OR are specific monetary amounts set by the corporate office and are determined based on the fiscal year budget. Each Work Center has a specific DLR and OR. A positive CV indicates an unfavorable variance while a negative CV indicates a favorable variance. Hypothesis 1 states labor is a significant contributor to unfavorable cost variances. The results of these analyses indicate labor is a significant contributor to unfavorable cost variances.

Because the Frame Assembly Process for Work Center 24 was the initial scope of the project, in order minimize concern that process improvement of this Work Center alone would reduce overall labor variance by 10%, other Work Centers with a history of low efficiency outputs were identified. Based on historical efficiency data and Gemba Walks of four Work Centers upstream to Work Center 24, Work Center 1KPUNCH - *Blank Locker Doors* was chosen as another Work Center to implement a process improvement plan. The Gemba Walks took place to gain a more thorough understanding of the manufacturing process at Work Center 1KPUNCH by observing the process, identifying potential sources of waste, determine possible areas of improvement, and obtain verbal feedback from the operators.

During the measure phase of Work Center 1KPUNCH, data collected from the SAP system from December 2018 to May 2019 on a weekly basis was used to perform a PCA to determine whether the current process was capable of sustaining management requirements. Based on the results in Figure 4-8, the efficiency data showed a slight departure from normality, but not to an effect that would significantly

affect the Ppk analysis because the majority of points fell within the confidence lines. However, the Ppk value for this data set was -1.11, indicating that the process was not meeting the company's specifications. A boxplot of the data is shown in Figure 4-9.

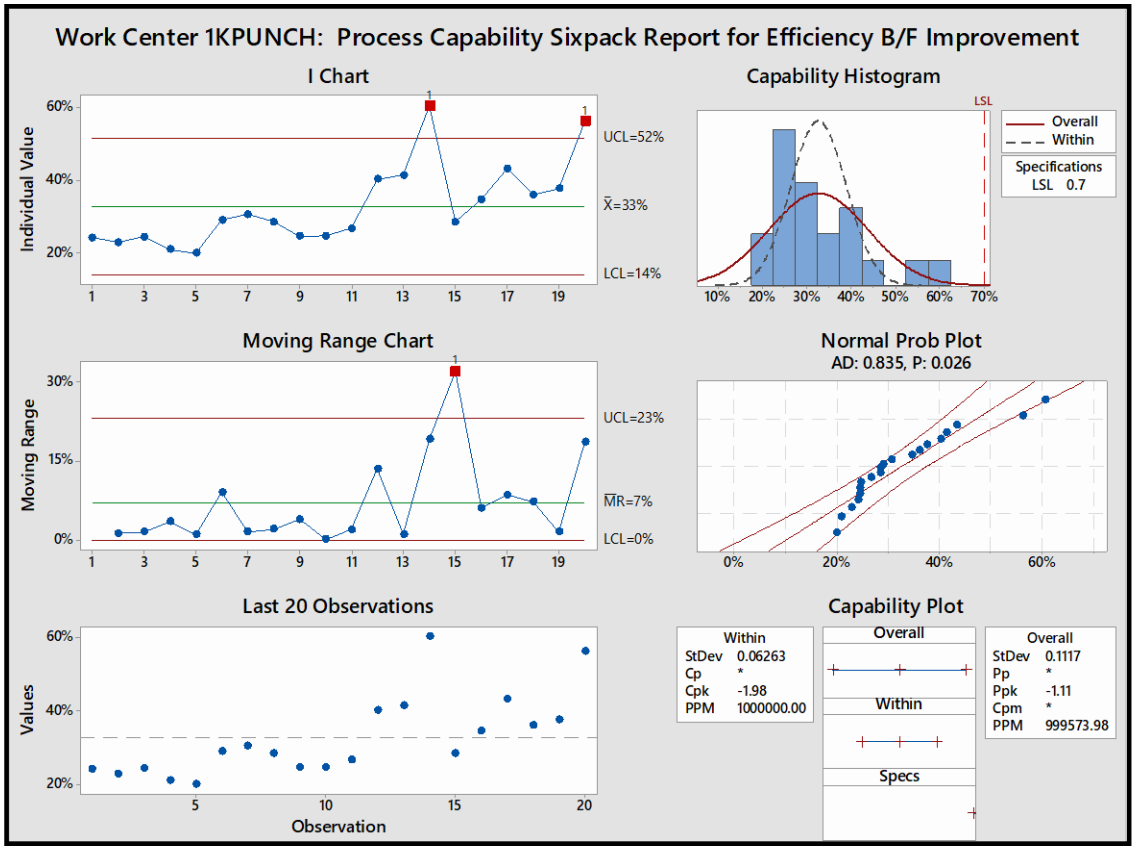

Figure 4-8. PCA for 1KPUNCH (Dec – May)

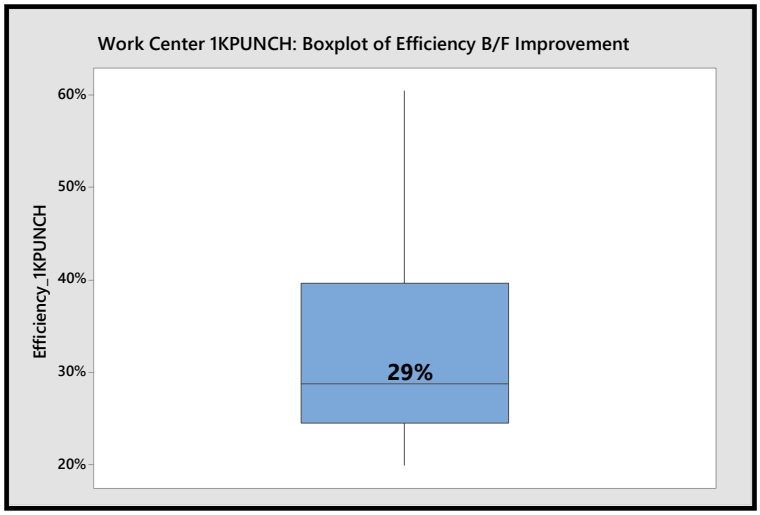

Figure 4-9. Boxplot of Efficiency Data for 1KPUNCH (Dec – May)

Because Work Center 1KPUNCH was not chosen as another Work Center for process improvement until May 2019, time studies were conducted during May to determine potential root causes. The breakdown of the steps for the 1KPUNCH process are as follows:

1. A large coil of steel is loaded onto a machine that feeds into a punch press machine that creates the blank doors.
2. The de-coiler machine is set a specific speed and a specific distance from the punch press.
3. The operator starts the de-coiler and punch press machines.
4. As the punch press machine produces each blank door, the operator stacks the blank doors on a pallet.

The standard rate at which the blanks can be produced in an hour varies depending on the size of the door. For example, the SAP rate to form blank doors that become 12 inch by 15 inch doors downstream is 840 parts per hour. Based on time study data, on average, the number of parts that were actually formed per hour was 270 parts. A sample time study is shown in Table A-4 in Appendix A.

4.4 Analyze Implementation

Based on the data measured for Work Center 24, a cause and effect diagram mapped the potential root causes of labor variance, as shown in Figure 4-10. An additional tool used was the 5 Whys method to identify opportunities for process improvement, as shown in Figures 4-11 and 4-12. Conclusions drawn from the 5 Whys method were that a countermeasure for low efficiency output was to redesign the process such that only one operator was required and that a countermeasure for frames not being square after manual assembly and welding was to add jigs and fixtures to hold each piece of the frame in place during assembly, thereby eliminating operator error during assembly.

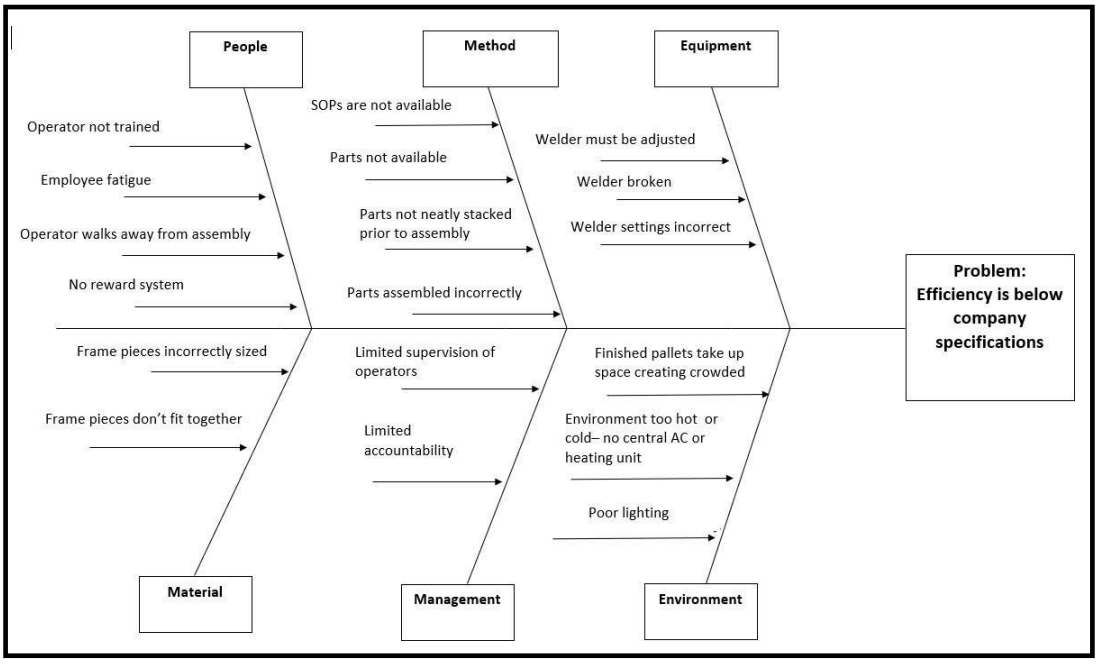

Figure 4-10. Cause and Effect Diagram for Frame Assembly

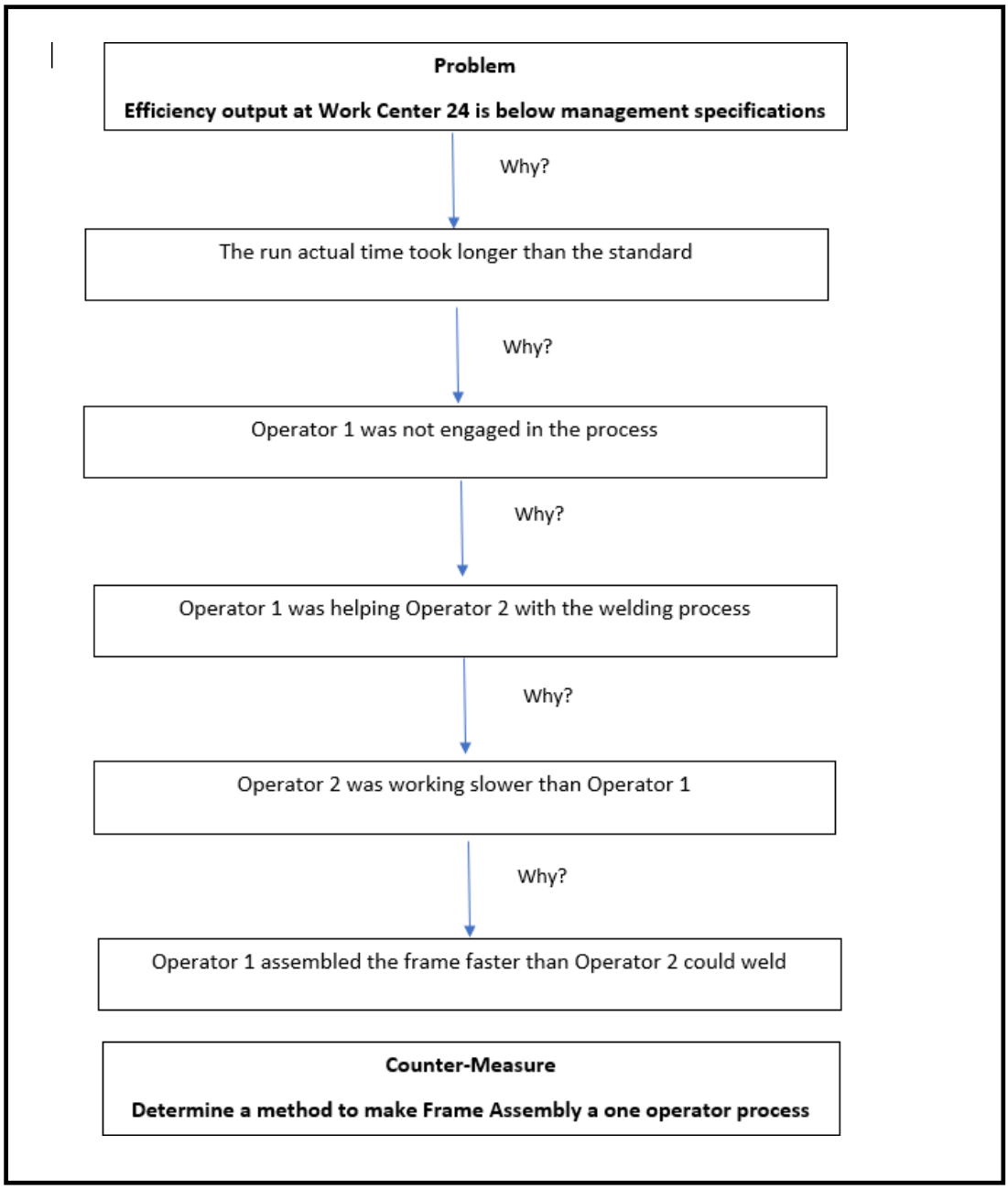

Figure 4-11. 5 Whys for Frame Assembly – Attempt 1

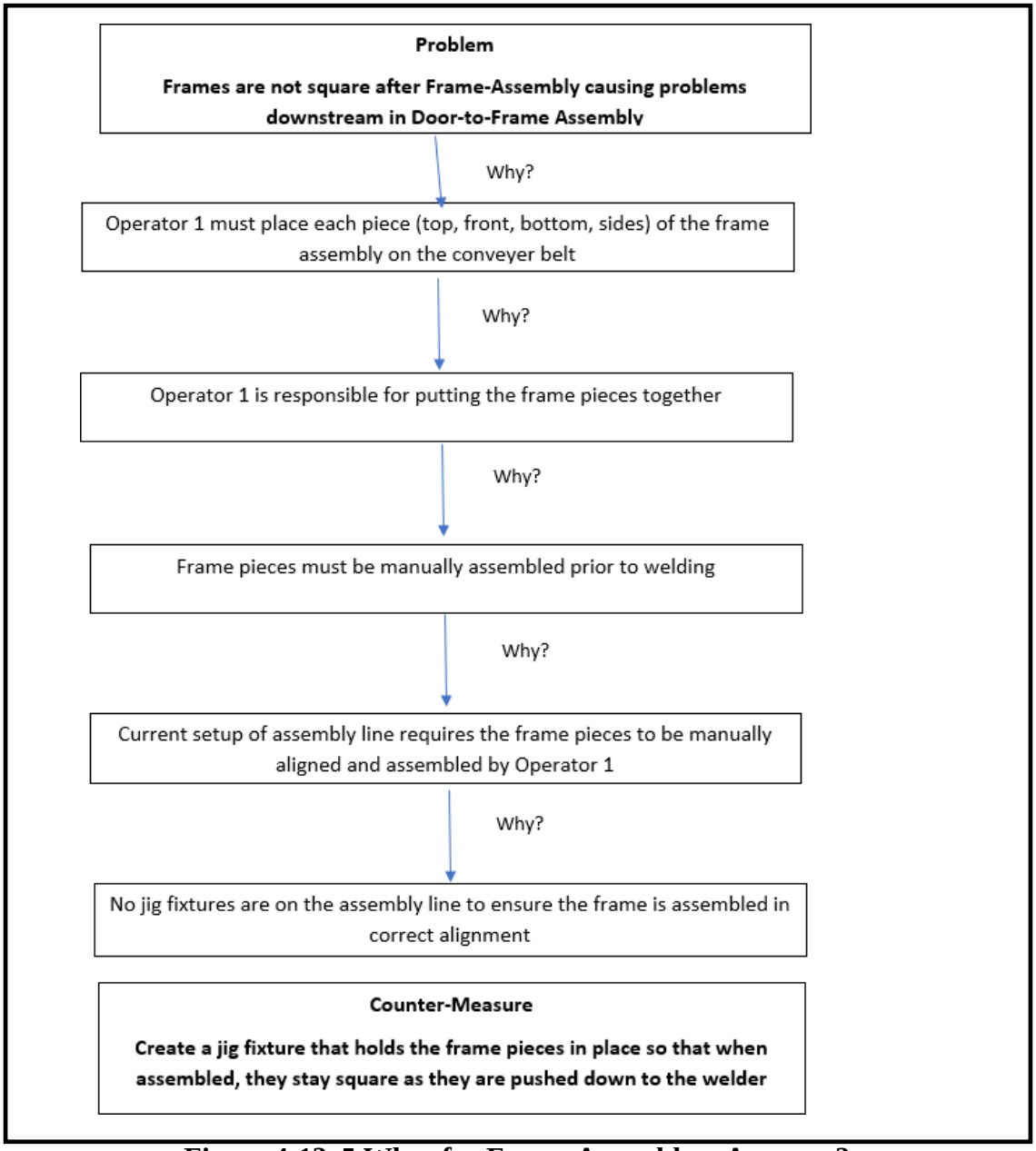

Figure 4-12. 5 Whys for Frame Assembly – Attempt 2

The issues that had the highest frequency of occurrence were operator not engaged and frames not square on the conveyer belt. In order to accept or reject the identified potential root causes, time studies were conducted to determine the amount of time each issue added to the process. Results showed that on average, operator 1 spent an additional 20 seconds of time per run leaving the manual frame assembly station to assist operator 2

with the welding process, which represented 29 percent of the frame assembly process time. In addition, on average, operator 1 spent an additional 7 seconds of time adjusting the pieces of the frame to check that the manually assembled frame was square, which represented 7 percent of the frame assembly process time. Thus, both of these issues were accepted as potential root causes.

For Work Center 1KPUNCH, observations of the process were used to identify the root cause. Because the de-coiler machine was set at too low a speed, there was not enough vertical slack in the steel prior to reaching the punch press to allow the process to run at the SAP rate, which is the standard in the SAP system that states the number of blanks that should be produced in an hour. The steel would stay taut between the two machines, slowing down the process.

4.5 Improve Implementation

Prior to implementing the process improvements, a Failure Modes and Effects Analysis (FMEA) was performed to determine and address possible issues that could arise implementation. FMEA is a DMAIC tool that lists the potential failure modes of the new process and the effects of those failures. Metrics are assigned to the severity, occurrence, and detection and recommendations for decreasing the occurrence of failures or increasing the detection of failures. A detailed FMEA is shown for Work Center 24 is shown in Appendix B. The outcome of the analysis revealed that by addressing potential failure modes and their effects, the Risk Priority Number (RPN) for each process improvement were considerably decreased.

Using the tools for the analyze phase, the following process improvements were put in place and approved by management for the Frame Assembly Process:

1. The layout of Frame Assembly was changed such that only one operator was required
2. The new set-up incorporated jigs for the top, bottom and intermediate(s) pieces of the frame and fixtures for left and right side pieces of the frame keep each piece of the frame in place during manual assembly. Note: Because there are different size frames, there are several differently sized fixtures to hold the left and right side pieces of the frame.
3. Instead of pushing the assembled frame down to the welding stations, the fixtures were on a roller system such that the frame could be pushed down to the welder while being stabilized by the jigs.
4. As the operator pushed the frame down to the welder, the welder was set up on automatic sensor so that when the roller system engaged with the welder, the welder would automatically weld the top, middle and bottom pieces of the frame to the sides of the frame.

Using similar tools for the analyze phase of Work Center 1KPUNCH, the following process improvements were put in place and approved by management:

1. The de-coiler machine was set at a new speed that allowed enough vertical slack between the de-coiler machine and punch press so that the steel did not get taut and increase process time.

4.6 Control Implementation

The goal of a quality improvement initiative was to collect data-driven evidence that corrective actions or process improvements resulted in improved efficiency, and thus a reduction of cost variance. During the Implement phase, changes and improvements were

put in place at *XYZ Industry*. These process improvements were monitored to determine if a statistically significant improvement in processes could be documented. It was essential to maintain and sustain the changes to achieve the objectives of improvement; otherwise, the company may not benefit from the changes because it could return to practices that were in place before the improvements that resulted in a condition of unwanted variances negatively impacting profits.

Time study data, SAP efficiency data, and observational data were collected and analyzed after improvements were implemented for Work Centers 24 and 1KPUNCH. A two-sample T test compared time study data before and after improvements to determine the level of significance of improvements in efficiency.

For Work Center 24, data was collected on a daily and weekly basis from June 2019 to July 2019 with sample size n equal to 24. A table of the data sample is shown in Appendix C. The first six efficiency data points were collected using time studies. The remaining data points were collected from the SAP system. Results of the PCA in Figure 4-13 show the efficiency data were normal and the Ppk value for this data set was 1.60, indicating that the process was meeting the company's specifications. A process control chart (PCC) of the efficiency data before and after improvement is shown in Figure 4-14. To determine if improvements to the process had a significant effect on efficiency, a two sample T-Test was performed on the data. The results of the statistical test, shown in Figure 4-15, revealed that there was a significant difference between the two data sets with a p-value less than 0.01. Figure 4-16 illustrates a boxplot of the data before and after improvement.

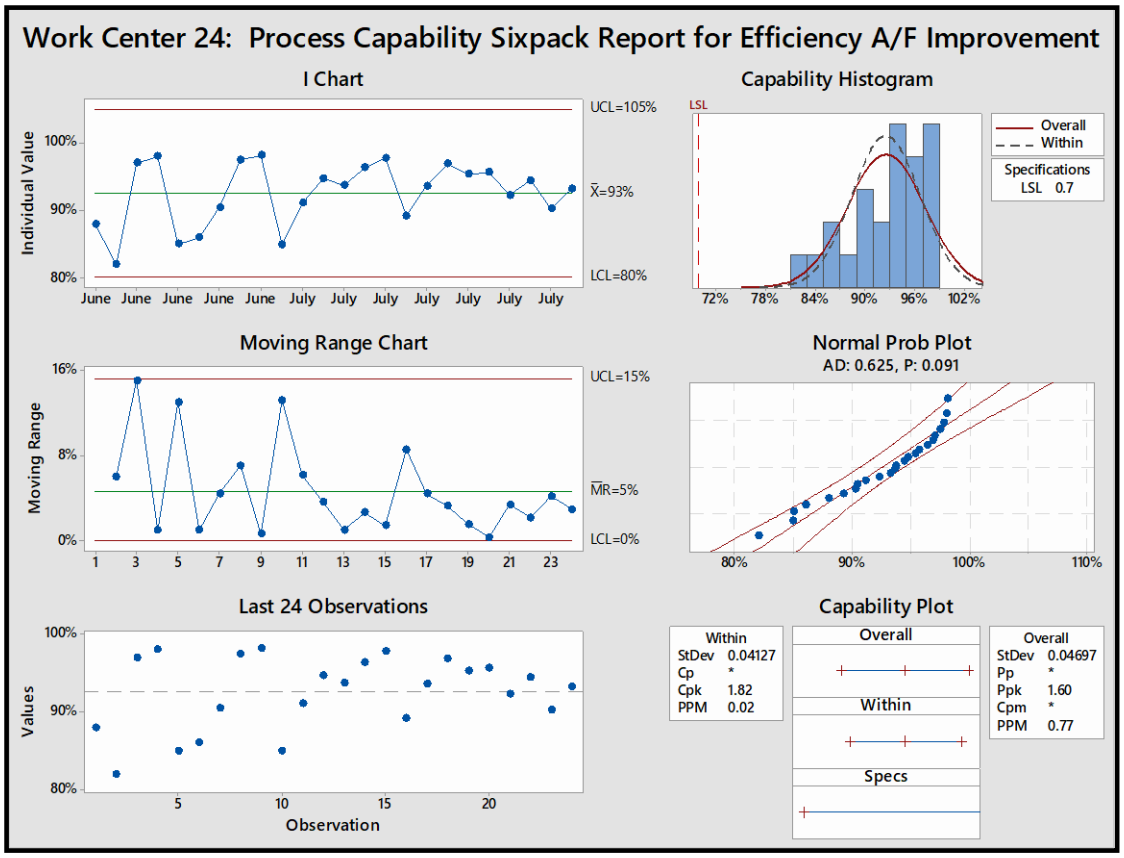

Figure 4-13. PCA for Frame Assembly After Improvement

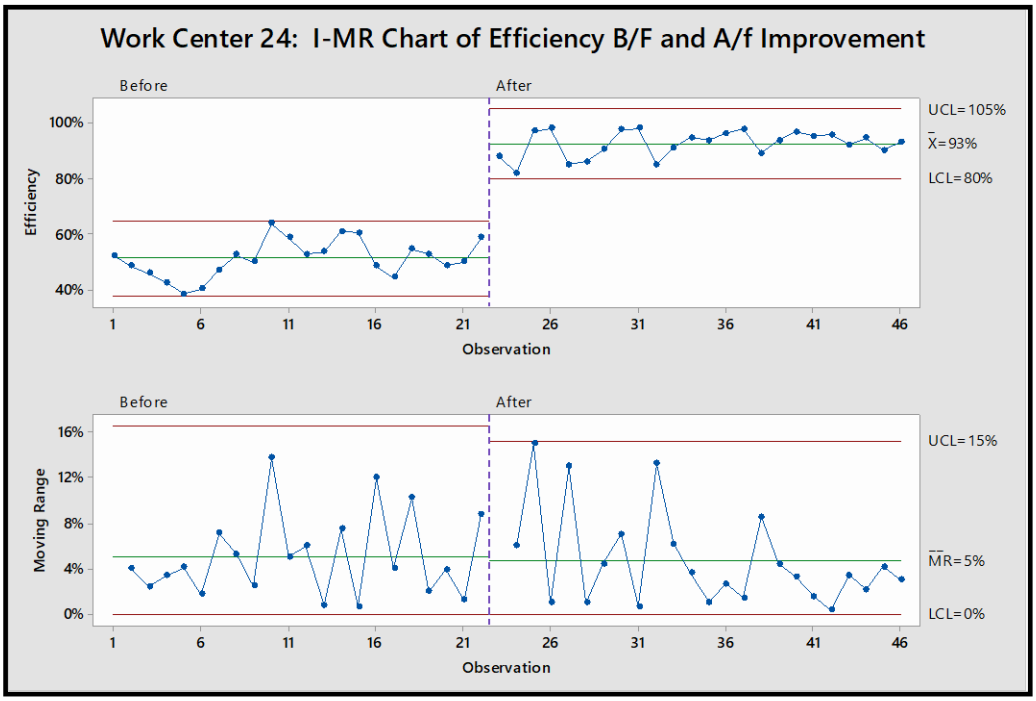

Figure 4-14. PCC: Before and After Improvement (WC 24)

Two-Sample T-Test and CI: Efficiency_24, Time Method

- μ_1: mean of Efficiency_24 when Time = After
- μ_2: mean of Efficiency_24 when Time = Before
- Difference: $\mu_1 - \mu_2$
- Equal variances are not assumed for this analysis.

Descriptive Statistics: Efficiency_24

Time	N	Mean	StDev	SE Mean
A/f	24	0.9255	0.0472	0.0096
B/f	22	0.5118	0.0674	0.014

Estimation for Difference

Difference	95% CI for Difference
0.4137	(0.3787, 0.4488)

Test

Null hypothesis $H_0: \mu_1 - \mu_2 = 0$

Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
23.92	37	0.000

Figure 4-15. Two-Sample T-Test (WC 24)

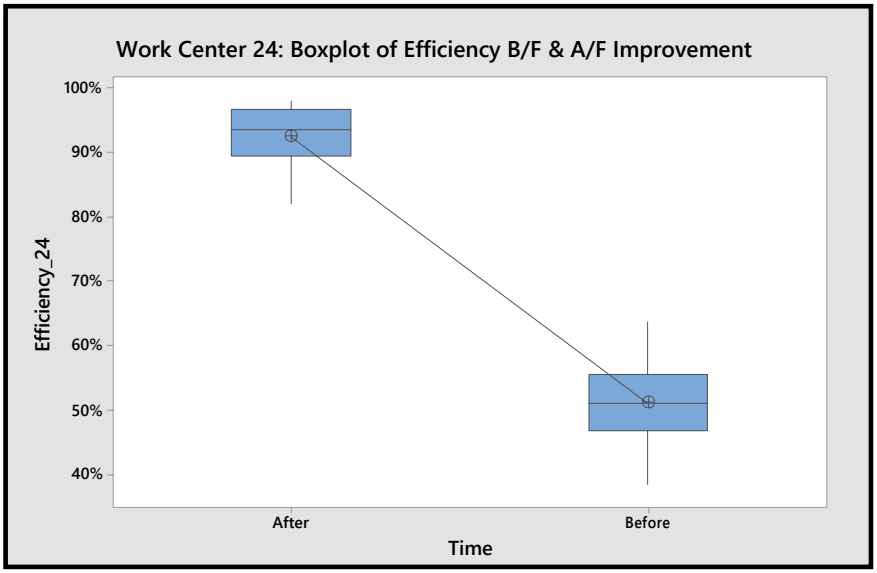

Figure 4-16. Two-Sample T-Test Boxplot (WC 24)

The results of the implementing the process improvement plan for Work Center 1KPUNCH are shown in are shown in Figure 4-17. Data was collected from the SAP system on a daily and weekly basis from June 2019 to July 2019 with sample size n equal to 14. Results of the PCA showed the efficiency data efficiency data showed a slight departure from normality, but not to an effect that would significantly affect the Ppk analysis because the majority of points fall within the confidence lines. were normal and

the Ppk value for this data set was 1.23, indicating that the process was meeting the company's specifications.

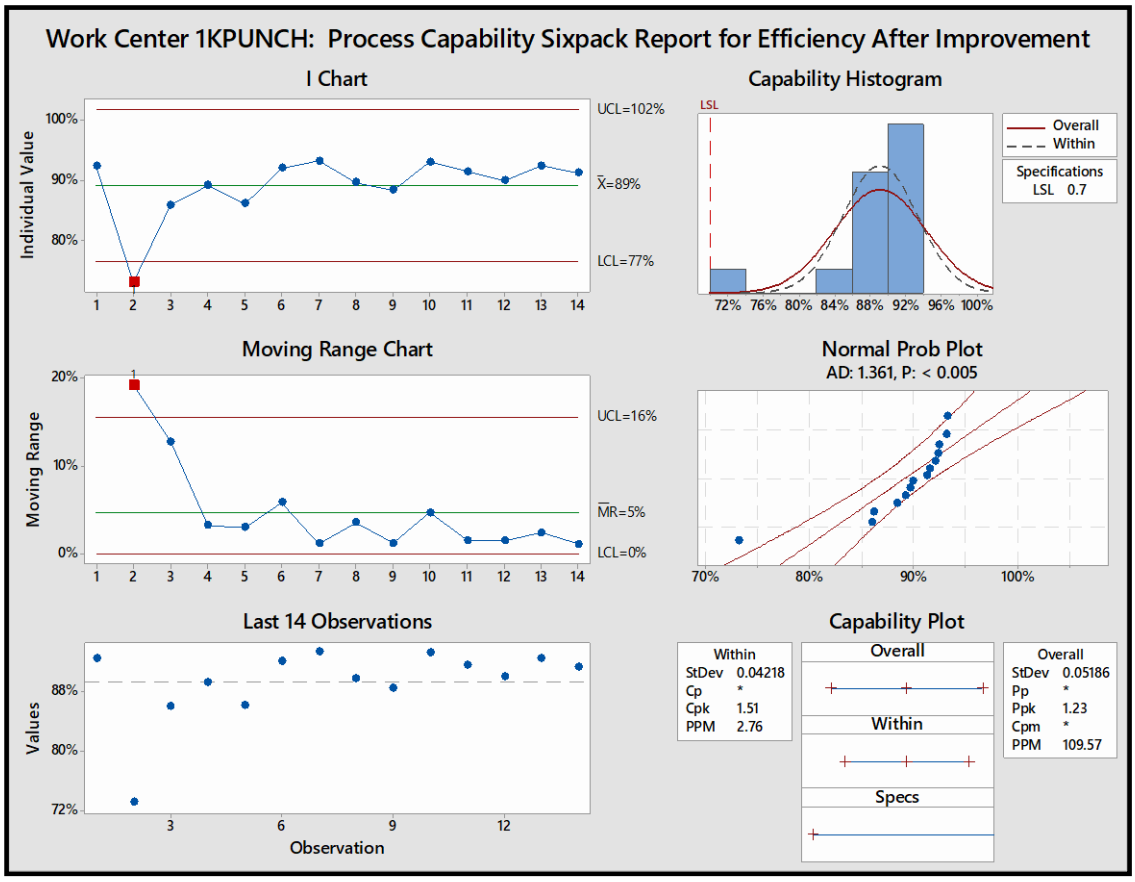

Figure 4-17. PCA for IKPUNCH After Improvement

It is important to note data point 2 on the PCA with an efficiency value of 73%. Upon further investigation, the de-coiler machine had been set to an incorrect speed, thus the process was not running properly. Operator error in programming the de-coiler speed was a potential failure mode listed in the FMEA. Because the management control plan was in place, the error was caught on day two of that week and the speed was placed on the correct setting. Because measures were in place to prevent this error, the PCA analysis was performed again on the data set with point 2 removed. Results of the PCA in Figure 4-18 show the efficiency data were normal and the Ppk value for this data set was 2.77, indicating that the process was meeting the company's specifications.

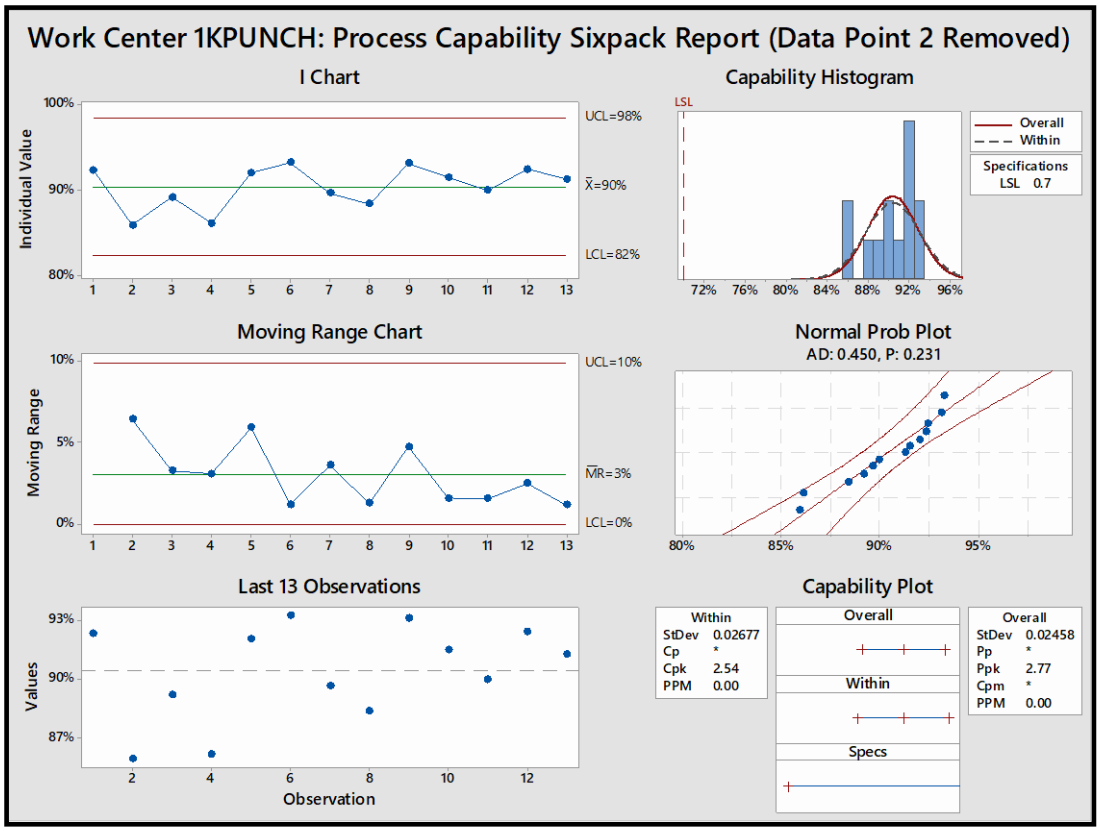

Figure 4-18. PCA for IKPUNCH A/F Improvement (Data Point 2 Removed)

A process control chart (PCC) of the efficiency data before and after improvement is shown in Figure 4-19. To determine if improvements to the process had a significant effect on efficiency, a two sample T-Test was performed on the data. The results, shown in Figure 4-20, of the test revealed that there was a significant difference between the two data sets with a p-value less than 0.01. Figure 4-21 illustrates a boxplot of the data before and after improvement.

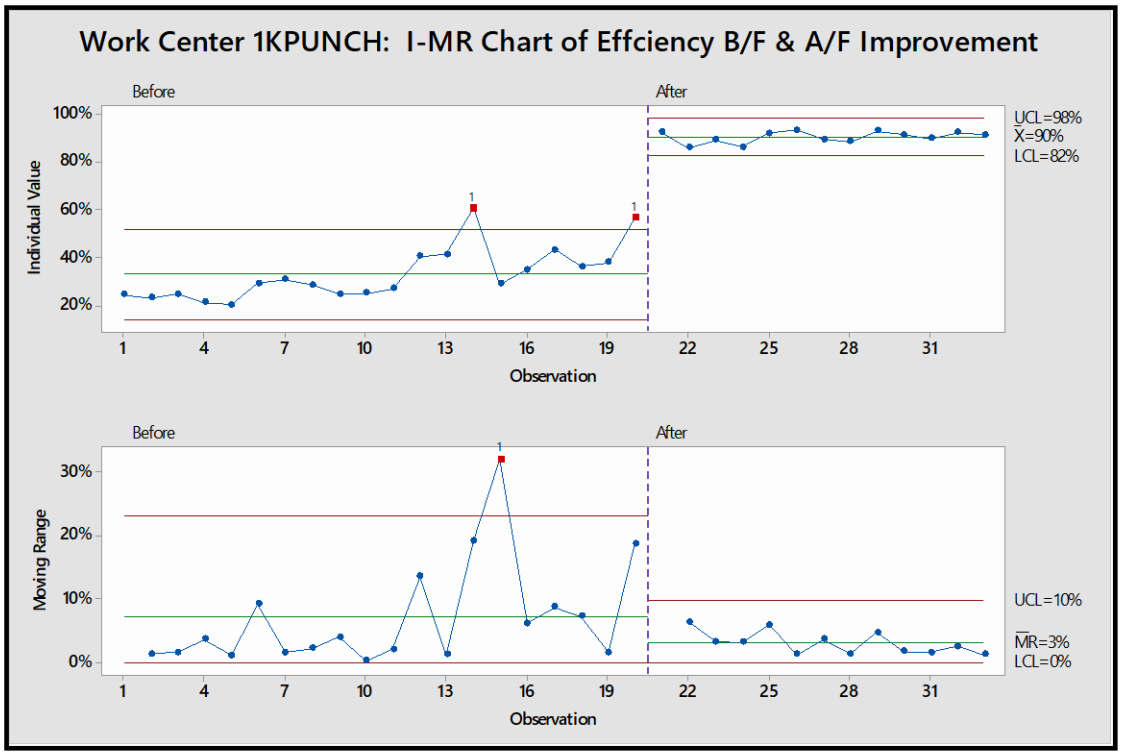

Figure 4-19. PCC: Before and After Improvement (WC IKPUNCH)

Two-Sample T-Test and CI: Efficiency_1KPUNCH_B/F & A/F Method

- μ_1: mean of Efficiency_1KPUNCH_B/F
- μ_2: mean of Efficiency_1KPUNCH A/F
- Difference: $\mu_1 - \mu_2$
- Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
B/F	20	0.327	0.112	0.025
A/F	13	0.9040	0.0246	0.0068

Estimation for Difference

Difference	95% CI for Difference
-0.5766	(-0.6304, -0.5227)

Test

Null hypothesis

$H_0: \mu_1 - \mu_2 = 0$

Alternative hypothesis

$H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-22.27	21	0.000

Figure 4-20. Two-Sample T-Test (WC IKPUNCH)

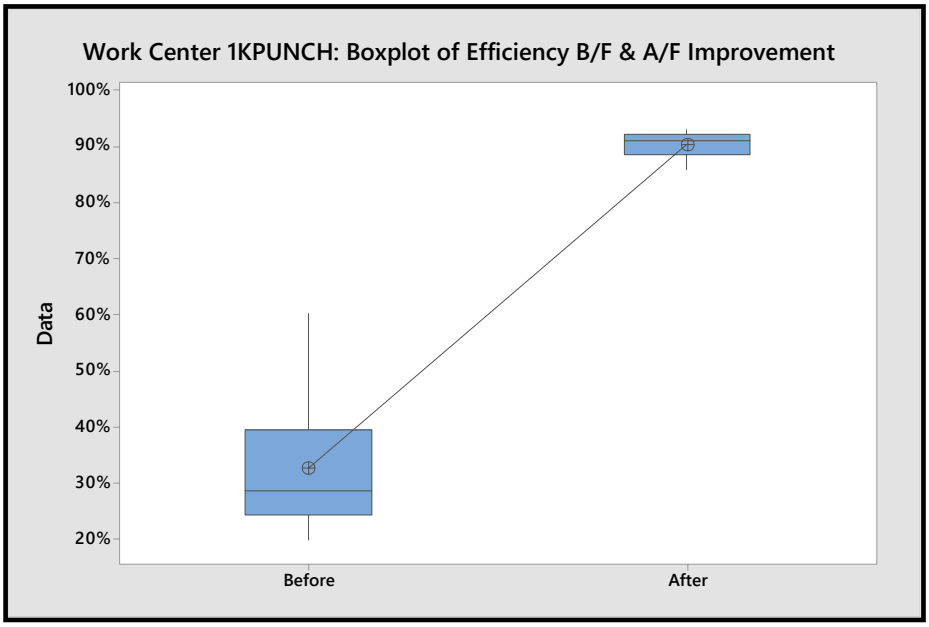

Figure 4-21. Two-Sample T-Test Boxplot (WC 1KPUNCH)

Because there was a slight departure from normality in the 1KPUNCH data set before improvement, a nonparametric analysis was also performed, specifically the Mann-Whitney test, to verify the results of the two-sample T test. Figure 4-22 shows a p-value of less than 0.01, indicating that there is sufficient evidence to conclude that there is significant difference between the efficiency data before and after process improvement.

Mann-Whitney: Efficiency_1KPUNCH_B/F & A/F Method

η_1: median of Efficiency_1KPUNCH_B/F

η_2: median of Efficiency_1KPUNCH A/F

Difference: $\eta_1 - \eta_2$

Descriptive Statistics

Sample	N	Median
Efficiency_1KPUNCH_B/F	20	0.287822
Efficiency_1KPUNCH A/F	13	0.912700

Estimation for Difference

Difference	CI for Difference	Achieved Confidence
-0.612123	(-0.650323, -0.531337)	95.13%

Test

Null hypothesis: $H_0: \eta_1 - \eta_2 = 0$

Alternative hypothesis: $H_1: \eta_1 - \eta_2 \neq 0$

W-Value	P-Value
210.00	0.000

Figure 4-22. Mann-Whitney Test (WC 1KPUNCH)

Hypothesis 2 stated that by implementing a management control plan, efficiency (earned hours/actual hours) will improve and overall cost variance will decrease by 10%. Based on the data analyses for Work Center 24 and 1KPUNCH, there was sufficient evidence to suggest that efficiency did improve. In order to determine if variances will decrease by 10%, Equation 4-2 was used to relate efficiency data before and after improvement to cost variance. The Direct Labor and Overhead Rates for Work Centers 24 and 1KPUNCH are shown in Table 4-2. Per Equation 4-2, the cost variance for

Table 4-2. Direct Labor and Overhead Rates for WC 24 and WC 1KPUNCH

Work Center	D/L Rate	Overhead Rate
24	$ 13.96	$ 58.49
1KPUNCH	$ 14.07	$ 58.53

Work Center 24 is calculated by multiplying the direct labor rate times the difference between the run actual hours and run earned hours and adding it to the overhead labor rate times the difference between the run actual hours and run earned hours. A positive cost variance means the variance is unfavorable (profit loss) while a negative cost variance means the variance is favorable (profit gain).

Figure 4-23 illustrates the yearly efficiency and labor and overhead cost variance for the 2019 Fiscal Year (May 2019 to April 2019) for Work Centers 24 and 1KPUNCH.

		Fiscal Year 2019			Fiscal Year 2020 (Projected)		
Work Center	Run Hours	Run Hours	Efficiency	Cost Variance	Run Hours	Average Efficiency	Cost Variance
24	•Earned	5,542.01	39.55%	$ 613,789.88	5,542.01	90.00%	
	•Actual	14,013.92			6,157.79		$44,613.18
1KPUNCH	•Earned	386.72	28.69%	$ 69,778.04	386.72	86.46%	
	•Actual	1,347.85			447.28		$4,396.80
			TOTAL	$ 683,567.92			$49,009.98
					Difference in Variance	$634,557.94	
					Overall Decrease in Cost Variance	12.82%	

Figure 4-23. Analysis of Reduction in Cost Variance Overall After Improvement

The efficiency (Run Earned Hours/Run Actual Hours)*100 was approximately 40% for Work Center 24 and 29% for Work Center 1KPUNCH. The total unfavorable variance for both work centers was calculated to be $683,567.92. Through implementation of a management control plan for process improvement at Work Centers 24 and 1KPUNCH, the average efficiency for Work Center 24 and Work Center 1KPUNCH is 90% and approximately 86%, respectively. Assuming the total run actual hours for the two work centers remain approximately the same for the 2020 Fiscal Year, the projected run hours should decrease to the values shown in Figure 4-23. It is important to note that the Chief Financial Officer (CFO) confirmed that the direct labor and overhead rates for each work center are based on yearly budgets, thus they are not affected by efficiency improvements. The projected total unfavorable variance for both work centers was calculated to be $49,009.98. Using this data, the total unfavorable labor and overhead cost variance decreased by $634,557.94. Table 4.1 showed that the 2019 Fiscal Year overall unfavorable cost variance, including labor and overhead variance, purchase price variance, material usage variance, and scrap variance, was $4,948,000. Thus, the overall cost variance decreased by approximately 13% [($634,557.94/$4,948,000)*100].

Additionally during the Control phase, a Management Control Plan was designed to guide the company in sustaining the improvements over long periods to maintain a high level of product quality. The plan included a checklist to assist management in identifying whether corrective action or process improvement was or was not being sustained. The company incorporated its previously established process checklist for verifying customer-driven quality requirements into the Management Control Plan.

The Management Control Plan was formatted in Excel. It included input cells for

the type of process improvement, a process improvement identification number, the projected date for initiating the process improvement, the actual start date of the process change, a description of the process improvement, contact information of the individual or team responsible for the process improvement, dates of any revisions to the process improvement plan, description of the revision, a listing of any tools or equipment or machines required to make the revision, key characteristics of any process revised, the revised plan for collecting data and controlling the process, and the cost associated with the revision. The dynamic form included a set of instructions for managers that simplified the process of updating the form such that minimal training was required.

4.7 Summary

Through implementation of the DMAIC method, all four research questions were answered and by implementing a management control plan, efficiency was significantly improved at two Work Centers and overall variance decreased by at least 10%.

Chapter 5—Discussions and Conclusions

5.1 Discussion and Conclusions

The purpose of this research was to implement a management control plan to decrease manufacturing variances at *XYZ Industry* to provide an opportunity to increase profit without making relatively large capital investments. By identifying, categorizing and quantifying sources of manufacturing variances, the goal to decrease overall variance by 10% to improve company profitability was accomplished.

Hypothesis 1 stated that labor was a significant contributor to unfavorable cost variances. Hypothesis 2 stated that by implementing a management control plan, efficiency (earned hours/actual hours) will improve and overall cost variance will decrease by 10%. The data analyses provided sufficient evidence to support both hypotheses.

5.2 Contributions to Body of Knowledge

This Praxis research developed a Management Control Plan to enable a manufacturing company to determine, control, and eliminate potential root causes of cost variances in the production of more than 12,000 products. The research served as a pilot study on two specific fabrication Work Centers. The company can now expand this study to additional fabrication Work Centers to continue to improve process efficiency, reduce unfavorable cost variance, increase profitability.

The presence of high unfavorable variances at any company indicates problems that should be addressed for quality and financial purposes. Root cause analysis proved to be a vital tool for identifying the sources of variance. Process control charts can also be utilized to establish and analyze process performance. Time series data can be collected and analyzed on manufacturing processes. Implementation of a similar Management Control

Plan could prove useful to other manufacturing plants.

5.3 Recommendations for Future Research

Recommendations for extending this research entail implementation of the Management Control Plan at other Work Centers at *XYZ Industry* as well as other manufacturing plants with significant unfavorable cost variances and loss in profitability. Process improvement can not only improve efficiency, but can also improve product quality, making companies more competitive and increasing customer satisfaction. Efficiency improvement cuts costs, which could allow companies to lower product prices.

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Appendix A. Sample Data for Work Centers Before Improvement

Table A-1. Before Improvement: Data collection for WC 24

Month	Week	Day	Run Actual Hr	Run Earned Hr	Efficiency	Time
December	1	N/A	93.8	49.0	52%	Before
	2	N/A	172.8	83.5	48%	Before
	3	N/A	159.9	73.4	46%	Before
	4	N/A	139.0	59.2	43%	Before
January	1	N/A	167.3	64.3	38%	Before
	2	N/A	170.6	68.5	40%	Before
	3	N/A	114.5	54.1	47%	Before
	4	N/A	98.6	51.8	53%	Before
February	1	N/A	110.8	55.4	50%	Before
	2	N/A	102.0	65.0	64%	Before
	3	N/A	87.5	51.4	59%	Before
	4	N/A	128.4	67.8	53%	Before
March	2	N/A	111.4	59.7	54%	Before
	3	N/A	91.0	55.5	61%	Before
	4	N/A	125.8	76.0	60%	Before
April	1	N/A	104.5	50.6	48%	Before
	2	N/A	82.7	36.7	44%	Before
	3	N/A	123.3	67.4	55%	Before
	4	N/A	114.5	60.3	53%	Before
May	1	N/A	114.4	55.8	49%	Before
	2	N/A	133.4	66.7	50%	Before
	3	20,21	69.8	41.0	59%	Before

Data was collected on a weekly basis from December 2018 to May 2019 with sample size n equal to 22 from the SAP system.

Table A-2. Before Improvement: Time Study Sample for WC 24

Time Study Sheet

ORDER NO.			WORK CENTER & DESCRIPTION						START TIME		10:32 AM			START QTY		0	DATE	
MATERIAL	670600X																	
DESCRIPTION	1278, FRAME ASSEM 2Tier		24: FRAME ASSEMBLY						STOP TIME		10:53 AM			FINISH QTY		17	3/13/2019	
OBSERVATION NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	DATA SUMMARY		
TIME (SEC)	56.00	84.00	63.00	59.00	57.00	64.00	73.00	58.00	63.00	81.00	62.00	58.00	77.00	59.00	58.00	AVERAGE (SEC)	60.72	
OBSERVATION NO.	16	17														MAXIMUM (SEC)	84.00	
TIME (SEC)	60.00	61.00														MINIMUM (SEC)	56.00	
																SAP RATE	129	
																STUDY RATE	56	
COMMENTS																EFFICIENCY	43%	
																STANDARD	8.54	
PROCESS	OPERATOR 1: THE RIGHT HAND SIDE CHANNEL IS PLACED ONTO THE ASSEMBLY TABLE. THE LEFT HAND SIDE CHANNEL IS TAKEN FROM A BIN PLACED ONTO THE TABLE. THE TOP, INTERMEDIATE, & BOTTOM HORIZONTAL CHANNELS ARE PLACED ONTO THE TABLE. THE HOOKS ON THE BOTTOM & INTERMEDIATE HORIZONTAL CHANNELS ARE INSERTED INTO THE VERITCALS & TWISTED TO LOCK INTO PLACE. ONCE EVERYTHING IS MANUALLY ASSEMBLED, THE FRAME IS SLID ONTO A CONVEYR BETLT TO OPERATOR 2. OPERATOR 2: THE FRAME IS SPOT WELDED MANUALLY (FOOT PEDAL) ON THE TOP, INTERMEDIATE, AND BOTTOM HORIZONTAL CHANNELS TO THE RIGHT AND LEFT HAND SIDE VERTICAL CHANNELS. AFTER ALL WELDS ARE COMPLETE, OPERATOR 2 REMOVES THE COMPLETED FRAME & PLACES IT ONTO THE COMPLETED PARTS PALLET.																	

NOTES
SAP RATE IS THE NUMBER OF FRAMES THAT SAP SAYS CAN BE PRODUCED IN AN HOUR.
STUDY RATE REFLECTS THE NUMBER OF FRAMES THAT CAN ACTUALLY BE PRODUCED IN AN HOUR BASED ON THE AVERAGE TIME DURING THIS TIME STUDY.

Table A-3. Before Improvement: Data collection for WC 1KPUNCH

Month	Week	Day	Run Actual Hr	Run Earned Hrs	Efficiency	Time
December	1	N/A	N/A	N/A	N/A	
	2	N/A	24.6	5.9	24%	Before
	3	N/A	31.5	7.2	23%	Before
	4	N/A	16.7	4.0	24%	Before
January	1	N/A	2.6	0.5	21%	Before
	2	N/A	6.5	1.3	20%	Before
	3	N/A	9.2	2.6	29%	Before
	4	N/A	25.4	7.7	31%	Before
February	1	N/A	17.1	4.8	28%	Before
	2	N/A	28.1	6.9	25%	Before
	3	N/A	N/A	N/A	N/A	
	4	N/A	31.7	7.8	25%	Before
March	2	N/A	26.0	6.9	27%	Before
	3	N/A	21.9	8.8	40%	Before
	4	N/A	10.6	4.3	41%	Before
April	1	N/A	6.7	4.0	60%	Before
	2	N/A	11.2	3.2	29%	Before
	3	N/A	12.8	4.4	35%	Before
	4	N/A	16.0	6.9	43%	Before
May	1	N/A	12.5	4.5	36%	Before
	2	N/A	15.2	5.7	38%	Before
	3	N/A	28.0	15.7	56%	Before

Data was collected on a weekly basis from December 2018 to May 2019 with sample size n equal to 20 from the SAP system

Table A-4. Before Improvement: Time Study Sample for WC 1KPUNCH

Time Study Sheet

ORDER NO.			WORK CENTER & DESCRIPTION						START TIME		8:17AM			START QTY		0	DATE	
MATERIAL	62560rxb																	
DESCRIPTION			1KPUNCH: BLANK LOCKER DOORS						STOP TIME		8:21AM			FINISH QTY		15	5/7/2019	
OBSERVATION NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	DATA SUMMARY		
TIME (SEC)	12.2	12.1	12.2	12.3	12.1	12.4	12.3	12.3	12.3	12.2	12.3	12.2	12.3	12.3	12.1	AVERAGE (SEC)	12.24	
																MAXIMUM (SEC)	12.40	
																MINIMUM (SEC)	12.10	
																SAP RATE	840	
																STUDY RATE	294	
COMMENTS																EFFICIENCY	35%	
																STANDARD	0.09	
PROCESS	LARGE COIL OF STEEL IS LOADED ONTO A MACHINE THAT FEEDS INTO A PUNCH PRESS MACHINE. OPERATOR STARTS THE MACHINES. AS THE PUNCH PRESS MACHINE PRODUCES EACH BLANK DOOR, OPERATOR STACKS THE BLANKS ON A PALLET.																	

NOTES
SAP RATE IS THE NUMBER OF BLANKS THAT SAP SAYS CAN BE PRODUCED IN AN HOUR.
STUDY RATE REFLECTS THE NUMBER OF BLANKS THAT CAN ACTUALLY BE PRODUCED IN AN HOUR BASED ON THE AVERAGE TIME DURING THIS TIME STUDY.

Appendix B. Failure Modes and Effects Analysis (FMEA)

Work Center 24

Process Step/Input	Potential Failure Mode	Potential Failure Effects	SEVERITY (1 - 10)	Potential Causes	OCCURRENCE (1 - 10)	Current Controls	DETECTION (1 - 10)	RPN	Action Recommended	Resp.	Actions Taken	SEVERITY (1 - 10)	OCCURRENCE (1 - 10)	DETECTION (1 - 10)	RPN
What is the process step, change or feature under investigation?	In what ways could the step, change or feature go wrong?	What is the impact on the process if this failure is not prevented or corrected?		What causes the step, change or feature to go wrong? (how could it occur?)		What controls exist that either prevent or detect the failure?			What are the recommended actions for reducing the occurrence of the cause or improving detection?	Who is responsible for making sure the actions are completed?	What actions were completed (and when) with respect to the RPN?				
Addition of jigs	jigs too loose	frames not square	7	operator does not verity jigs tightened properly	5	visual inspection	3	105	operator performs quality check to ensure jigs correctly tightened	operator	operator trained on SOP with jig specifications	7	2	1	14
Addition of fixtures	incorrect fixture used for differently sized left and right side channels	time wasted replacing correct fixture	7	operator does not check work order to see what size fixture is required	10	visual inspection	6	420	operator verifies correct fixture is in place by checking it against the work order prior to starting the process	operator	operator trained on the different sized fixtures; fixtures clearly labeled with size	7	3	1	21
Addition of Roller system	roller wheels blocked and cannot move down the line	time wasted adjusting the wheels	5	tools get placed in the tracks	10	visual inspection		2	operator checks tracks to verify they are clear of obstruction	operator	Instructions in SOP to perform a quality check of equipment	5	2	1	10
Automatic Welder	welder sensor malfunction	roller system not fully engaged with sensor	8	operator does not push the roller system all the way down the track to activate the sensor	5	visual inspection; welder does not weld	1	40	operator	operator	Instructions in SOP to verify roller system engages welding sensor	8	2	1	16
		welder sensor broken	10	machine malfunction	2	visual inspection; welder does not weld	1	20	welder regularly inspected by maintenance	maintenance; operator	Instructions in SOP to change welder to manual foot pedal welding setting; in addition, contact maintenance if welder does not weld with roller system fully engaged	3	2	1	6

Severity Scale		Occurrence Scale		Detection	
Effect	**Ranking**	**Probability of Failure**	**Ranking**	**Detection**	**Ranking**
Hazardous - Without Warning	10	Very High: Failure is almost inevitable	10	Almost Impossible	10
Hazardous - With Warning	9		9	Very Remote	9
Very High	8	High: Generally associated with processes similar to previous processes that have often failed	8	Remote	8
High	7		7	Very Low	7
Moderate	6	Moderate: Generally associated with processes similar to previous processes which have experienced occasional failures, but not in major proportions	6	Low	6
Low	5		5	Moderate	5
Very Low	4		4	Moderately High	4
Minor	3	Low: Isolated failures associated with similar processes	3	High	3
Very Minor	2	Very Low: Only isolated failures associated with almost identical processes	2	Very High	2
None	1	Remote: Failure is unlikely. No failures associated with almost identical processes	1	Almost Certain	1

*The template used for the FMEA Analysis was obtained from the following website: https://goleansixsigma.com/failure-modes-effects-analysis-fmea/
impedance

Appendix C. Sample Data for Work Centers After Improvement

Table C-1. After Improvement: Data collection for WC 24

Month	Week	Day	Run Actual Hrs	Run Earned Hrs	Efficiency	Time
Time Study Data: June	Dates of Time Studies Listed on "Time Study A/F Improvement"		N/A	N/A	88%	After
					82%	After
					97%	After
					98%	After
					85%	After
					86%	After
June	1	N/A	120.8	109.3	90%	After
	2	N/A	137.5	134.0	97%	After
	3	N/A	143.0	140.3	98%	After
	4	N/A	148.7	126.3	85%	After
July	1	N/A	134.3	122.4	91%	After
	2	N/A	171.8	162.8	95%	After
	3	15	39.4	36.9	94%	After
		16	49.3	47.5	96%	After
		17	40.2	39.3	98%	After
		18	41.6	37.1	89%	After
		19	36.9	34.5	94%	After
		20	29.4	28.5	97%	After
	4	22	37.6	35.9	95%	After
		23	52.2	50.0	96%	After
		24	51.8	47.8	92%	After
		25	45.3	42.8	94%	After
		26	42.9	38.7	90%	After
		27	32.4	30.2	93%	After

Data was collected on a daily and weekly basis from June 2019 to July 2019 with sample size n equal to 24. The first six efficiency data points were collected using time studies. The remaining data points were collected from the SAP system.

Table C-2. After Improvement: Time Study Sample for WC 24

Time Study Sheet

ORDER NO.		WORK CENTER & DESCRIPTION							START TIME		11:00 AM			START QTY		0	DATE	
MATERIAL	617780K																	
DESCRIPTION	1260, FRAME ASSEM 1Tier	24: AUTOMATED FRAME WELDER							STOP TIME		11:18 AM			FINISH QTY		15	6/11/2019	
OBSERVATION NO.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	DATA SUMMARY	
TIME (SEC)		51.51	51.71	52.92	52.93	50.06	51.37	52.08	53.73	55.89	55.49	58.44	58.40	52.47	53.51	50.94	AVERAGE (SEC)	53.43
																	MAXIMUM (SEC)	58.44
																	MINIMUM (SEC)	50.06
																	SAP RATE	83
																	STUDY RATE	67
COMMENTS																	EFFICIENCY	82%
																	STANDARD	2.48
PROCESS		THE TOP, INTERMEDIATE, & BOTTOM HORIZONTAL CHANNELS ARE PLACED INTO THE JIG. THE RIGHT HAND SIDE CHANNEL IS WIPED DOWN & PLACED INTO THE JIG. THE LEFT HAND SIDE CHANNEL IS WIPED DOWN & PLACED INTO THE JIG. THE HOOKS ON THE BOTTOM & INTERMEDIATE HORIZONTAL CHANNELS ARE INSERTED INTO THE VERITCALS & TWISTED TO LOCK INTO PLACE. ONCE EVERYTHING IS ALIGNED, THE JIG IS SLID INTO THE WELDER & WELDED MANUALLY (FOOT PEDAL). AFTER ALL WELDS ARE COMPLETE, THE OPERATOR REMOVES THE COMPLETED FRAME & PLACES IT ONTO THE COMPLETED PARTS PALLET.															

NOTES
SAP RATE IS THE NUMBER OF FRAMES THAT SAP SAYS CAN BE PRODUCED IN AN HOUR.
STUDY RATE REFLECTS THE NUMBER OF FRAMES THAT CAN ACTUALLY BE PRODUCED IN AN HOUR BASED ON THE AVERAGE TIME DURING THIS TIME STUDY.

Table C-3. After Improvement: Time Study Process Breakdown for WC 24

ORDER NO.		START TIME	9:15 AM	START QTY	0	WORK CENTER	24 AUTO	SAP RUN RATE (PPH)	83
MATERIAL	617780K	STOP TIME	9:30 AM	STOP QTY	15	# OPERATORS	1	STUDY RUN RATE (PPH)	
DESCRIPTION	1260, FRAME ASSEM 1TIER	OBSERVATIONS MEASURED IN SECONDS						DATA SUMMARY	

	PROCESS:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AVG	MAX	MIN	STDE
1	PLACE FRAME COMPONENTS INTO JIG	23.38	22.50	23.52	25.56	24.33	24.00	25.20	22.07	22.62	25.55	26.50	21.75	23.66	19.43	21.03	23.41	26.50	19.43	1.84
2	WELD	13.46	12.34	15.05	13.17	12.64	13.04	13.33	12.25	13.82	12.31	12.75	13.30	13.93	12.37	11.91	13.04	15.05	11.91	0.79
3	REMOVE FRAME & PLACE ON PALLER	6.54	7.38	10.55	6.63	8.59	10.88	8.95	6.74	7.37	7.20	9.38	7.54	7.00	9.00	6.59	8.02	10.88	6.54	1.39
4	MOVE JIG BACK TO STARTING POINT	3.62	5.05	3.83	4.58	4.89	4.50	4.68	4.93	5.06	4.68	5.58	4.35	5.39	4.88	5.13	4.74	5.58	3.62	0.51
	TOTAL TIME	47.00	47.27	52.95	49.94	50.45	52.42	52.14	45.99	48.87	49.74	54.27	46.94	49.98	45.66	44.66	49.22	54.23	44.69	2.81
COMMENTS		THE "WELD" PORTION OF THE PROCESS STARTS WHEN THE JIG BEGINS BEING PUSHED THROUGH THE WELDER AND ENDS WHEN THE FRAME IS REMOVED.																		

NOTES
SAP RATE IS THE NUMBER OF PARTS THAT SAP SAYS CAN BE PRODUCED IN AN HOUR.
STUDY RATE REFLECTS THE NUMBER OF PARTS THAT CAN ACTUALLY BE PRODUCED IN AN HOUR BASED ON THE AVERAGE CYCLE TIME DURING THIS TIME STUDY

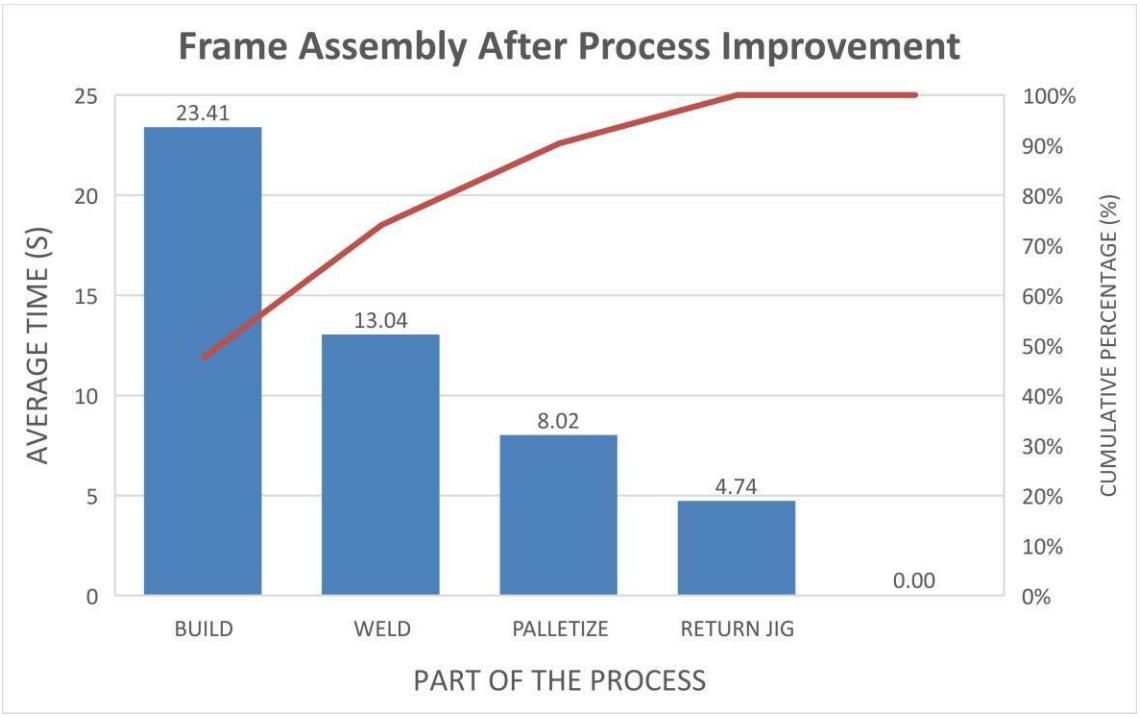

Figure C-1. Pareto Analysis of Frame Assembly After Improvement

Table C-4. After Improvement: Data collection for WC 1KPUNCH

Month	Week	Day	Run Actual Hrs	Run Earned Hrs	Efficienc	Time
	1	N/A	9.5	8.7	92.35 %	After
	2	N/A	12.5	9.1	73.13 %	After
	3	N/A	14.5	12.5	85.94 %	After
June	4	N/A	11.5	10.2	89.20 %	After
	1	N/A	12.1	10.4	86.13 %	After
	2	N/A	15.4	14.2	92.03 %	After
		15	5.1	4.7	93.23 %	After
		16	5.7	5.1	89.64 %	After
	3	17	9.4	8.3	88.38 %	After
		18	4.6	4.3	93.11 %	After
		19	N/A	N/A	N/A	
July		20	N/A	N/A	N/A	
		22	8.8	8.1	91.52 %	After
		23	8.5	7.7	89.96 %	After
		24	5.8	5.3	92.44 %	After
	4	25	N/A	N/A	N/A	
		26	4.8	4.3	91.27 %	After
		27	N/A	N/A	N/A	

Data was collected on a daily and weekly basis from June 2019 to July 2019 with sample size n equal to 14. N/A for days July 19, 20, 25, and 27 indicates that Work Center 1KPUNCH was not running those days.

Table C-5. After Improvement: Time Study Sample for WC 1KPUNCH

Time Study Sheet

ORDER NO.			WORK CENTER & DESCRIPTION						START TIME		8:17AM			START QTY		0	DATE
MATERIAL	62560rxb																
DESCRIPTION			1KPUNCH: BLANK LOCKER DOORS						STOP TIME		8:21AM			FINISH QTY		15	5/7/2019
OBSERVATION NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	DATA SUMMARY	
TIME (SEC)	5.3	5.2	5.1	5.3	5.1	5.2	5.2	5.1	5.2	5.2	5.1	5.2	5.2	5.2	5.2	AVERAGE (SEC)	5.19
																MAXIMUM (SEC)	5.30
																MINIMUM (SEC)	5.10
																SAP RATE	840
																STUDY RATE	694
COMMENTS																EFFICIENCY	83%
																STANDARD	0.06
PROCESS	LARGE COIL OF STEEL IS LOADED ONTO A MACHINE THAT FEEDS INTO A PUNCH PRESS MACHINE. OPERATOR STARTS THE MACHINES. AS THE PUNCH PRESS MACHINE PRODUCES EACH BLANK DOOR, OPERATOR STACKS THE BLANKS ON A PALLET.																

NOTES
SAP RATE IS THE NUMBER OF BLANKS THAT SAP SAYS CAN BE PRODUCED IN AN HOUR.
STUDY RATE REFLECTS THE NUMBER OF BLANKS THAT CAN ACTUALLY BE PRODUCED IN AN HOUR BASED ON THE AVERAGE TIME DURING THIS TIME STUDY.