

LEAN SIX-SIGMA APPLICATIONS IN AIRCRAFT ASSEMBLY

A Thesis by

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I have examined the final copy of this Thesis for form and content and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science with a major in Industrial & Manufacturing Engineering.

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DEDICATION

To my Family and Friends

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ABSTRACT

To improve the performance of a process and ensure on time delivery there are numerous different approaches available nowadays. Lean offers a unique method that helps identify possible improvement areas on a production line. Also Six-Sigma offers a unique approach that is widely used in industries in order to improve the process and thereby reduce the number of defects.

The lean approach can be used to reduce or even eliminate waste and thereby ensure on time delivery of products. A Value Stream Map (VSM) is one of the main tools of lean manufacturing that can be used to represent the flow of material and information in a production line. It can be utilized to identify areas where improvements can be incorporated for a smooth flow of products. DMAIC (Define-Measure-Analyze-Improve-control) is a five-step approach that utilizes different Six-Sigma tools to generate ideas, collect and measure data, analyze and come up with improvement plans to improve the process under study.

Lean manufacturing concepts can be used to identify waste from the customer point of view and eliminate them. Lean cannot bring a process under statistical control. On the other hand, six-sigma cannot dramatically improve process speed or reduce cost. The integrated lean six-sigma approach maximizes shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed, and invested capital. In aircraft industries, the phenomenal increase in demand has pushed the manufacturers to look for new concepts to stay in business amidst strong competition.

A new methodology of lean six sigma integration was proposed and tested in an aircraft industry. The study involves the assembly of the upper main entry door of a business jet. Improvement opportunities were identified from a high-level value stream map. The DMAIC approach was utilized to address the identified opportunities for improvement. The results indicate that the lead-time was reduced from 26 to 10 days. Using appropriate statistical tools and by incorporating standard engineering changes the occurrence of non-conformance was reduced by 30%. This resulted in a reduction of rework time by 3 hours per aircraft and accounted for close to \$6000 of savings.

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CHAPTER 1

INTRODUCTION

In the contemporary world of manufacturing, due to enormous competition, different companies have started to look for different approaches and practices to improve the quality level of the product at a reduced cost, create a safe and rewarding workplace and eventually achieve higher customer satisfaction. During the early ages of manufacturing, US manufacturers mainly relied on mass production and final stage inspection. The product would be inspected only at the final stages. These practices resulted in increased inventory level, increase in rework and the consequence was loss of time and money. The Japanese counterparts started introducing low cost products with higher quality. Faced with a global competition, the US manufacturers had to change their manufacturing strategies to maintain market share. In the 1980's Motorola launched a process improvement methodology and named it six-sigma. After launching six-sigma initiatives Motorola enjoyed increased customer experience, increased sales, increased stock rate and more profit. Later General Electrics and Allied Signals followed the footsteps of Motorola and they also improved their business [9]. On the other hand, the Japanese were practicing Lean Manufacturing, which has been in use for more than 20 years. They were concentrating on delivering a high quality product in a reduced lead-time. They believed that this would directly affect and improve customer satisfaction. Though General Electrics enjoyed higher Quality product at reduced cost, they were not able to meet their target delivery dates. Their lead-time in delivering the finished goods was much higher. So, General Electrics started using lean manufacturing concepts to overcome lead-time related problems [9]. The integrated

approach of lean and six-sigma explains the connection between shareholder value establishment and precise advancement in the business. Lean six-sigma gives more edge than that could have been attained individually by Lean or Six-Sigma [12].

The following chapter contains a review of literature pertinent to the evolution of lean and six-sigma concepts, their individual approaches towards process improvement and their integration. Chapter 4 represents a case study that was deployed for process improvement using the integrated lean six-sigma approach. Chapter 4 contains the results and conclusions obtained from the case study.

CHAPTER 2

LITERATURE REVIEW

This Literature review will give a basic idea about the evolution of Six-Sigma, what it is about and its methodology. Some case studies to highlight its importance are also discussed in this literature review. While explaining the concept of Lean, case studies of successful Lean implementation are also elucidated. It will also brief about Lean manufacturing's integration with Six-Sigma and how it has helped in process improvement.

2.1 Six-Sigma evolution:

Though Fredrick Taylor, Walter Shewhart and Henry Ford played a great role in the evolution of Six-Sigma in the early twentieth century, it is Bill Smith, Vice President of Motorola Corporation, who is considered as the father of Six-Sigma [22]. Fredrick Taylor came up with the methodology of breaking systems into sub systems in order to increase the efficiency of the manufacturing process [4]. Henry Ford followed his four principles, namely continuous flow, interchangeable parts, division of labor and reduction of wasted effort, in order to end up in an affordable priced automobile [4]. The development of control charts by Walter Shewhart laid the base for statistical methods to measure the variability and quality of various processes [4].

Later during the 1950s, the Japanese manufacturing sector revolutionized their quality and competitiveness in the world based on the works of Dr. W. Edwards Deming, Dr. Armand Feigenbaum, and Dr. Joseph M Juran. Dr. W. Edwards Deming developed the improvement cycle of 'Plan-Do-Check-Act', better known as the PDCA

cycle. Dr Joseph M. Juran gave to the world his 'Quality Trilogy' and it was Dr Armand Feigenbaum who initiated the concepts of 'Total Quality Control' (TQC) [4]. Between 1960 and 1980, the Japanese understood that everyone in an organization is important to maintain quality and so training programs were conducted for almost all employees not considering the department they belong to. Any organization that is dynamically working to build the theme of Six-Sigma and to put into practice, the concepts of Six-Sigma, in its daily management activities, with noteworthy improvements in the process performance and customer satisfaction is considered as a Six-Sigma organization [18].

2.1.1 What is Six-Sigma?

Six-Sigma in general is a fact-driven, disciplined and statistical approach that is followed to eliminate defects and guide processes to reach perfection. Being a versatile system in making business leadership perform better, Six-Sigma doesn't work based on any single theory/strategy. It is based on result driven strategies used in the past century and many important management ideas, which lead the way in today's competitive money making world. There is no one single definition for Six-Sigma. It is a statistical measure of performance of processes/products; a goal that reaches perfection for performance improvement; a management system to achieve business leadership and enhanced performance in a long run [18]. In simple words, Six-Sigma combines best techniques of the recent past with the best management breakthroughs and common sense. Three main areas of Six-Sigma focus are customer satisfaction, reducing defects and eventually reducing cycle time. Team leader's commitment, usage of common language throughout the organization, process reengineering enforced by

aggressive engineering goals, fact based decision making, good communications to keep the interest on Six-Sigma and its continuity on track and maintaining metrics to evaluate past performance and assess future goals are some of the key success factors of Six-Sigma [1].

Six-Sigma is a management language that institutionalizes a precise, closely controlled, fact-based approach to deliver more money to the bottom line through process improvement and process design projects. These design projects are selected by top management and led by highly trained Six-Sigma Black Belts or Master Black Belts with the intention to create ideal processes, products, and services all aligned to delivering what the customers want [4]. From the above discussion it is clear that the management's commitment, which acts as the driving force for both breakthrough and traditional improvements, is very essential in the journey towards successful implementation of Six-Sigma methodology. In general mathematical terms Six-Sigma is the relationship of manufacturing variability and product specifications. In statistical terms, it means that no more than 3.4 DPMO (defects per million opportunities) is possible when a process is at a Six-Sigma level of performance. A defect can be defined as a measurable attribute of the process or its output that is not within the standard acceptable limits, i.e., not conforming to specifications [5].

Customer focus, fact-driven management, process focus, down to business management, boundary-less group effort and drive for excellence are the six critical factors that are required for an organization to attain a quality level of Six-Sigma [19]. The eventual purpose of Six-Sigma is to raise profits by getting rid of variability, discrepancies and wastes that weaken customer trustworthiness. Any organization like

manufacturing, engineering, R&D, sales and marketing, health care and government agencies can utilize Six-Sigma for excellence in quality [4].

2.1.2 Motorola's Six-Sigma Journey

In the 1980s Motorola was the leader in the market of its kind. But during the mid-1980s Japanese high quality products made Motorola lose its feet in the market once conquered by them. Customer discontent was like a pandemic with Motorola. Making profit was out of reach for the reason that the operating costs were very high. Once the head of purchasing from one of the customers was quoted as saying that "Love, love, love the product; hate, hate, hate the company." This ultimately demonstrates that the business was not customer driven. Agreement reviews, responses to demand for quotes, invoicing, response to customer grievances and other administrative areas were in a weak position because of the weary administration of management and disinterested workers. Response times were lengthy and not planned for customer satisfaction. Customers experienced a high level of early-life failures of the products. [16]

Inspired by the Japanese manufacturer's success, Motorola arranged visits to Japan to study the operating methods and product quality levels pursued by the Japanese. What Motorola found was that the quality level of the products should be quantified so as to improve the product's quality. Motorola's CEO Bob Galvin, considered the pioneer of Six-Sigma at Motorola, visited major company sites worldwide to instruct employees about Six-Sigma and encouraged them to integrate it into the day-to-day business activities. The concept of opportunities-for-errors was developed to

account for differing complexities [16]. He along with Bill Smith, Motorola's Vice-President dedicated Motorola to a plan that would decide quality goals for improving the corporation 10 times by 1989, 100 times by 1991. It was with his help that Motorola won its first Malcolm Baldrige National Quality Award in 1989.

2.1.3 General Electric's Six-Sigma Journey

Inspired by the success of Six-Sigma implementation in Allied Signals, Jack Welch, CEO of General Electric (GE), went on to use Six-Sigma as a business improvement strategy. Spending about \$250 million GE educated and trained nearly 4,000 Black Belts and Master Belts and additional 60,000 Green Belts out of a total work force of 60,000 in the year 1997. These trainings added to a \$3,000 million as an operating income for the year 1997. GE adopted Motorola's 'measure-analyze-improve-control' (MAIC) and added to 'define' to it to frame DMAIC approach. Also GE adopted many other concepts and disciplines from Motorola. The improvement measures varied from creating new design for a product from start to finish to saving billions of dollars in a span of three years. GE Medical System used six-sigma principles to manufacture a \$1.25 million diagnostic scanner from start to finish, which ultimately reduced chest-scanning time from 180 seconds to 17 seconds. GE Plastics improved production of plastic by 1.1 billion pounds by implementing Six-Sigma technology. Inventory turns increased from 5.8 to 9.2. During the period from 1996 to 1998, GE incurred \$1 billion in cost and the return on that investment was close to \$1.75 billion [17, 19].

2.1.4 Misapprehensions about Six-Sigma

Though Six-Sigma has been proved to be successful there have always been some misconceptions about it. Many people look upon it as a catchphrase of the month. They fail to keep in mind that it is a strategy, which evolved through Deming's management philosophies and total quality management. It focuses on customer, maintains complete training structure and delineates value from customer's viewpoint considering quality, service, and delivery. Another misconception is that the goal of 3.4 defectives per million is absolute and should be functional to every opportunity, tolerance and specification. The idea is to use Pareto based analysis for selecting projects that are like low hanging fruits, which will provide instant outcomes. The last misconception is that Six-Sigma is only a quality program. From past literature it is evident that Six-Sigma relates quality and customer obligations, meaning that it involves all those who are accountable to deliver a final product to the customer [2].

2.2 Evolution of Lean

The concept of lean has been prevalent in the manufacturing sector for more than 20 years. It is commonly known as a measure to reduce inventory and the number of hands involved in any process. It is also associated with continuous improvement. The main theme in the lean concept is waste reduction. Lean can also be referred to as a production philosophy that foresees the supply chain that consists of receiving raw material to sending out finished goods and from designing a product to customer service. It is an idea of "hundred small improvements every day" than "one home run once a year" [8]. It is a useful tool that helps in reducing waste of time, material, effort

and resources in any industry. The core approach of lean manufacturing is to produce a product in the shortest possible cycle time and streamline the flow of processes. According to the Lean institute, the fundamental objective of Lean is to offer value to the customer through an ideal value added process that has zero waste. Based on a study by the Massachusetts Institute of Technology, lean requires half as much effort in design, development and time than a normal production process [23].

Unlike older manufacturing strategies like, craft manufacturing and mass production, Lean depends on many frequent deliveries of limited quantities with a fewer possible suppliers. The former philosophies resulted in large work in process inventory. Creating value throughout the process stream and therefore eliminating waste is known as 'Lean management'. In mass production, the cost involved in fixing defects is less than the cost the involved in producing defective parts in lots. Lean creates a standardized work environment and minimizes the cycle time and variability in production to meet the variability in demand. The other major variability in today's industrial environment is supplier variability, which can also be overcome by partnering with suppliers and creating a supplier - producer cooperation [2]. The introduction of lean manufacturing has changed the typical ways of measuring performance. Performance measures like cycle time tracking, sales per employee hour and worker participation have replaced measures like equipment utilization and labor variance. Higher quality products can be delivered at reduced rework and inspection. Eliminating excess inventory, excess floor space and unwanted movements result in achieving the shortest possible cycle time. Hence, lean concepts, when implemented successfully, can deliver a product with higher quality in a short period of time.

The main contributors that make designing, redesigning and parts manufacturing simple in a short span of time are factory workforce, suppliers and capacity. Among many, the common Lean practices include standardization, reduced cycle time, built in quality, continuous improvement, and product based streamlined layout [20]. The concept of zero defects in lean manufacturing includes mistake proofing (Poka Yoke), source and automated inspection, production stoppage as soon as a defect is identified and enduring setup conformance. As an essence, Lean production aims at increasing the product flow velocity and throughput by eliminating all possible non-value added activities [2]. The concept of Lean manufacturing relies mainly on manufacturing cells that are capable of producing a variety of products and keeping the production facility flexible enough to produce the exact mix and right quantity of products. Availability of a right product in right quantity at the right time is also one way of describing Lean manufacturing.

Unlike traditional forecast based production, lean manufacturing utilizes a pull system where production is triggered by demand. The rate at which finished goods leave the facility is what determines the rate of supply from suppliers or from a preceding work center in the same facility [24]. Generally the following are termed as the basic principles of lean, define value from customer's standpoint, identify the value stream, eliminate seven deadly wastes, pull the work and not push and pursue the same to perfection [26]. An apt example of Lean implementation would be Toyota, which incorporated Lean under its Toyota Production System. Just in time (JIT), and automation (Jidoka) are considered the two pillars of this system. Value Stream Management is a process by which planning and lean inventiveness through methodical

data collection and data analysis are linked. A value stream identifies all essential members and information of a process or supply chain. Some of the essential members/factors include suppliers, customers, process flow, mode of information flow (electronic or manual) and information about cycle time, lead-time, customer requirement, availability of resources, and net available time per operating period (day or shift). The principle of cost reduction, knowledge about the seven deadly wastes, just in time, automation, 5S and the stages of Lean implementation (demand, flow and leveling) are the key notions and tools used in lean initiatives. These tools actually help in developing an accurate value stream map.

One way to be profitable is to reduce waste from the system by effectively utilizing the value stream and eventually by reducing the cost. This is how the cost reduction principle works. The eventual intention of implementing Lean is to eliminate wastes like overproduction, excessive waiting, excessive transport, unwanted processing, more than required inventory, unwanted movement, and rejections. Just in time and the continuous flow production process provide best value to customer by supplying the required product in required quantity on time. Restocking one piece as the customer pulls out one is an ideal behavior of JIT.

Automation, also known as Jidoka, is not complete automation but automation with a human touch. It simply means using automated mistake proofing for preventing defects and free up workers to perform multiple tasks within a work cell. This strategy maintains a zero defect environment where a defective product is never allowed to flow down the production stream and hence reducing the risk of customers receiving defective parts. 5S (Sort – Set in order – Shine – Standardize - Sustain) is a process

designed for planned organizing and standardizing the workplace. 5S is an important member of the lean implementation process by which the work area is maintained as a neat and safe work place. Generally 5S audits are conducted on a regular basis to maintain the standards of the work place. It promotes cleaning and maintaining the work area, which makes it easy to identify and spot the required tools at the right time [17 & 26].

2.2.1 Misconceptions of Lean

Just like Six-Sigma, Lean also has some misconceptions in spite of its popularity and success. Employee layoff is the most common misconception whenever the word Lean is delivered. The thought that lean manufacturing is successful only in Japanese sectors is another misconception. In fact some of the companies that have implemented lean are non-Japanese. The third misconception is that only manufacturing organizations can benefit from lean initiatives. Lean reflects on each step in the process as a service step, which means that each activity is considered to be adding value to customer's expectation. While processing claims in the insurance industry, evaluating loan applications at a bank would be an apt example [17].

2.3 Lean-Six Sigma integration:

Though both, six-sigma and Lean, have made improvements in organizations individually, together they complimented each other. As a means to having a scientific approach towards quality, lean organizations should make additional use of the data in decision-making process. Companies that have benefited from lean manufacturing lack six-sigma knowledge [13], which is important in training the management about the involvement of people and requirement of resources. Lean techniques like value stream mapping helps in identifying the various value added and non-value added activities involved within a process based on definitions. Identifying Customer Critical-to-Quality characteristics, a six-sigma tool, can further refine this list of value added and non-value added activities. Value stream mapping helps in calculating the actual cycle time, inventory levels and lead-time for any particular process. Six-Sigma, on the other hand, ensures that there is less variation in the process.

General Electrics has considered Six-Sigma as the best initiative they have ever come up with. But even now they accept that they have variance in their deliveries between four to twenty days. Having Six-Sigma alone has not reduced the lead-time for General Electrics. The point to be noted is that Lean and Six-Sigma should be integrated for a combined improvement. Six-sigma does not address the process speed and eventually loses sight of customer due dates. On the other hand, Lean fails to develop cultural infrastructure, which is important for its successful implementation. Lean Six-Sigma is a methodology that maximizes shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed and invested cost [12]. The synthesis of six-sigma and lean production is necessary

because lean cannot bring a process under statistical control, SS cannot reduce lead-time, and both enable the reduction of the cost of complexity [8].

Some questions that seem to be difficult to answer by both lean and Six-Sigma are, which process to consider first? In what order should implementation be carried out? How to attain high quality, improved lead-time and high cost savings quickly? Lean Six-Sigma tends to increase profit by reducing quality costs and the overall invested capital reduces inventory by bringing down the process lead-time. Lean six-sigma's relentless pursuit of high quality and speed lead to corporate success and personal success for those who become part of the lean six-sigma journey [13].

2.3.1 Lean Six-Sigma at Lockheed Martin

Lockheed Martin is rooted in the production of aeronautical and space systems, their integration and technology services. The company put lean six-sigma into practice in the year 1998 under the name "LM21 Best Practices" [24]. This included thorough and careful study of the process, proper differentiation of value-added and non value-added processes, waste elimination and improvement measures. As a top-down approach, the program started with the training of top management and went down in the organizational structure. The company made it mandatory that anyone with incentive compensation has to undergo the training. This includes people holding a position of director or above. As per Lean concepts, the initial step in the process enhancement plan was value stream mapping. It provided information about whether customer expectations are met, presence of any gaps in meeting customer requirements and availability of possible solutions to bridge the gaps. The entire

organization was involved in all the process improvement projects. Improvement methods were a combination of tools from both Lean and Six-Sigma. Lockheed Martin was losing a huge sum of money just on inspection. They worked with critical suppliers to integrate Lean and SS into their plants. By implementing Lean Six-Sigma Lockheed Martin encompassed about 5000 projects, out of which a majority were improvement projects. All started with the aim of reducing the cost by \$3.7 billion over a four-year period, which resulted in close to \$4 billion of reduction in cost [24].

2.3.2 Lean Six-Sigma at Bank One

Lewis Fischer, the Division Executive of National Enterprise Operation (NEO) encouraged the implementation Lean Six-Sigma ideology at NEO before the J P Morgan, NEO merger. Being one among the top 10 banks back in the 1990s, they were struggling hard for basic continued existence. He asserted that, “We were not striving for best in class, just getting control over our operations” [13]. As a part of the improvement process, focus was laid on performance measurement and opportunity identification. Their problem solving approach was divided into different stages. The first stage was to address all possible gaps in their network. The second stage focused more on lean goals such as eliminating complexity and increasing process velocity. It was based on kaizen, a series of continuous improvement events. The objective was to first identify the value stream, spot the problems and resolve them by providing solutions. One of the main and initial hurdles they had was to gain trust of their employees. But eventually by empowering the people to facilitate the processes, the organization managed to gain their trust. This paved the way for providing training for all

employees and creation of project oriented teams. The second stage started with the top management being introduced to key concepts on Lean and Six-Sigma. They listed opportunities, and prioritized projects. Other than forming cross-functional teams, employees who were directly responsible for selected processes were involved in the improvement cycle. Within a span of two years, there was a whole lot of change in the work culture. Also there was a considerable reduction in the overall cycle time. Cycle time improvements ranged from 30 percent to 75 percent, one administrative process went from 20 minutes to 12 minutes, a complaint resolution process dropped from 30 days to mere 8 days [13].

2.3.3 Tools used in Lean Six-Sigma

There are a variety of tools that can be used for lean six-sigma approach. It is not required to use all tools at all times. Based on the nature of the process the selection of tools may vary. Different tools can be used in different phases of the implementation process. The usage of some of the common tools is discussed in the following section.

Flow Diagrams: This is a graphic representation of the series of steps followed in the course of a process. These diagrams help examine the logic; or lack of logic, in the sequence of steps that are used to produce output. It often helps in identifying bottlenecks so that improvement teams working on projects can actually target these areas first. In general it gives a good perspective of the process as a whole. Flow diagrams can also be used to define the scope of a quality improvement project and the boundaries of the team's effort. [19]

Histograms: A histogram is used to graphically summarize and display the distribution of data set. In a typical frequency histogram, the heights of the bars are determined by the class frequency. Given that the bars in a histogram are of equal width, the area of a particular bar is relative to the equivalent class relative frequency [19].

Value Stream Mapping (VSM): Value stream management is a process of planning and linking lean initiatives through systematic data capture and analysis. Value stream mapping is a visual representation of material and information flow for a product family (value stream). It is vital as a tool for visually managing process improvement [26].

Brainstorming: Alex Osborn developed brainstorming technique in 1950s [14]. The success of this technique is based on the quantity of ideas. It is a group technique for generating new ideas and promoting creative thinking. According to Dr. Juran [19], there are four rules of brainstorming such as no idea can be criticized, self-criticism and self-judgment are suspended, team members are instructed to aim for large number of new ideas in the shortest possible time, and team members should expand ideas. This technique may be used to define a project, to develop theories for identifying symptoms of the problem, and for designing solutions after identification of the root causes.

DMAIC

DMAIC stands for Define, Measure, Analyze, Improve and Control. It is a systematic Six-Sigma approach that can be used for process improvement or redesign [20].

In this design phase the problem is identified and defined. The customers who will be benefited by the project and the stakeholders are also identified. Generally a high level SIPOC (Supplier – Input – Process – Output – Customer) [Figure: 1] is developed in order to identify the stakeholders. Sometimes this ‘Define’ phase omitted as management often selects it. The main objectives of the define phase would be to clearly identify the problem that is measurable and to validate and identify team players who will contribute to the project.

Suppliers	Inputs	Process	Outputs	Customers
Upstream providers of all of the inputs needed for the process under study to perform properly.	All of the inputs needed for the process under study to perform properly.	Macro (High-level) description of the process being analyzed – normally a maximum of 5-6 steps.	All of the outputs that are produced by the process being studied.	Downstream users of all of the outputs that are produced by the process being studied.

Figure 1: Supplier-Input-Process-Output-Customer [25]

Measure is a key intermediary phase where the problem is refined and the likely root causes are identified. The plan is first laid out to identify the factor that has to be measured and then the physical data collection is carried out. It is important to make sure that the data collection focuses on the problem defined in the define phase. Two main tools that are often used in this phase are CTQ (Critical to Quality) tree and Cause and Effect diagram [19]. A CTQ tree is used to identify the factors that are critical to

customers. SIPOC plays a major role in developing a CTQ tree so as to identify quality requirements of the customer. After the critical to quality factors are identified the cause and effect (CE) diagram is constructed. A sample CE diagram is shown in Figure 2. Though the CE diagram does not identify the potential causes it helps in understanding the possible causes that contribute to the effect. The most important aspect or characteristic of the CE diagram is that it will depict the relationship between all the factors that may be potential contributors to the targeted problem. [19, 20]

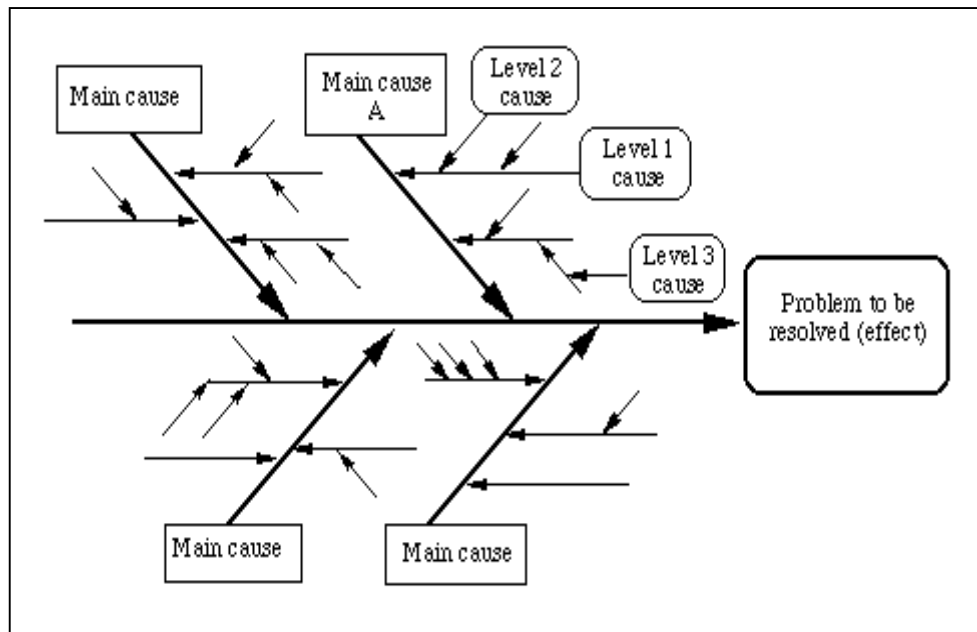


Figure 2: Cause and Effect Diagram [21]

Analysis is generally of two types, process analysis and data analysis. Process analysis is often related with factors that contribute to the out come of the process. Cycle time, down time and rework time are some of the factors that are analyzed in order to improve the process. Data analysis, on the other hand, is used to identify trends and patterns incurred from the process output [19]. Tools like Pareto chart, histogram and scatter plot can be used for such analysis. Figure 3 shows a sample

Pareto chart. A Pareto chart is one form of histogram or bar chart that is developed in the decreasing order of occurrences of categories. It helps in identifying the category that has a higher impact on the problem. A scatter plot helps in identifying the relationship between various factors of significance. The main objective of the scatter plot would be to develop an equation that helps in projecting the value of one variable with respect to the other variable. There are different correlations that can be depicted from a scatter plot.

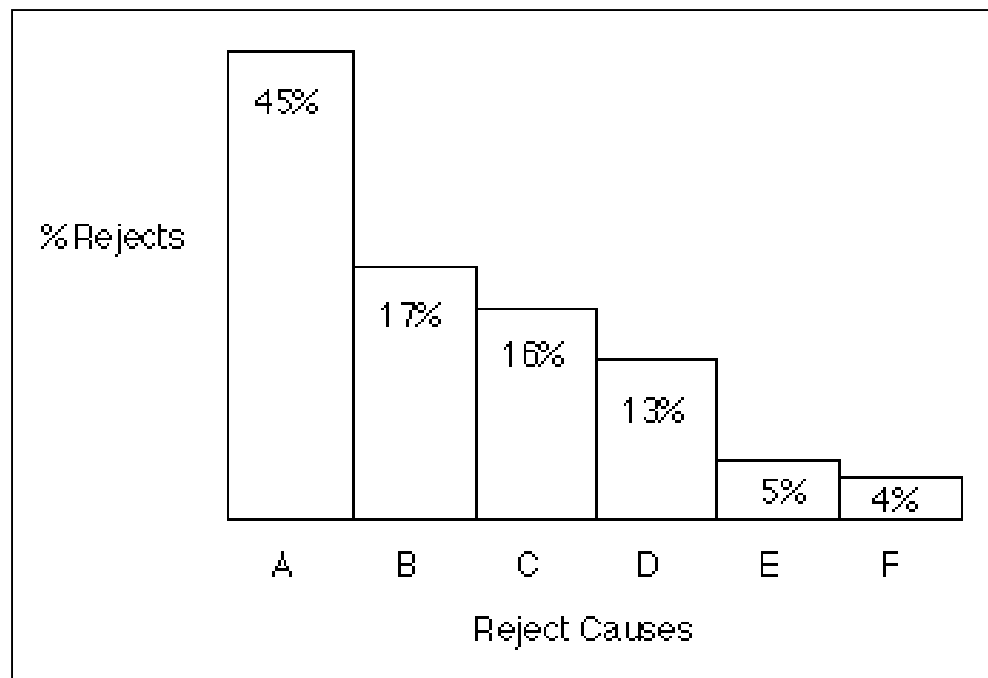


Figure 3: Pareto Chart [7]

In the improve phase, solutions are obtained to improve the factors identified based on the data analysis. Different solutions are documented in this phase and they are tried on the process and the results are documented and analyzed once again to determine any improvements. In the control phase of DMAIC, performance improvements implemented in the improve phase are maintained and suitable measures are taken to sustain them [19].

2.4 Applications in Aircraft industries:

The fundamental concerns bringing down the profit in aerospace segments are industry wide and associated with remarkable demands. Over the past few decades, on the business side of aircrafts, the returns from available-seat-mile have significantly gone down. The capacity for air travel having grown immensely and the competition around the globe has contributed in increased pressure among aerospace companies [11]. Under these circumstances each manufacturer has been pushed to a situation where high production and reduced cost are required to survive the competition.

The military side of aerospace industry is experiencing a different form of pressure [11]. The aircraft manufacturers have to survive competition that may rise due to new sophisticated and technical models. They have to continue controlling cost factors, design factors and also the volume they make in order to meet the needs. The industry can use its available development facilities as a base for the upcoming Lean and Six-Sigma initiatives to generate a profitable quality product and thereby resulting in business enhancement [11].

In 1998, when Boeing started to use their Arizona plant to assemble the AH-64D Apache Longbow Helicopter, they experienced a heavy downfall in the overall operational performance and high cycle time [27]. They decided to use Lean concepts and use statistical tools to reduce cycle time and increase the performance of their assembly operations. Using the Lean techniques the Arizona plant started deploying a number of improvement initiatives. After the deployment, they were able to reduce the number of internal defects by 58% and the cost associated with it by 61%. Since 1999 they have a 100% on-time delivery rate and have reduce the number of hours required

to build an aircraft by 48%. Above all the overall cycle time was reduced by more than 40%. The efforts and success of Boeing's Arizona plant also earned them the prestigious Shingo Prize for Manufacturing in 2005. Since winning the award, they made a change to the layout of the assembly line. They were able to further reduce the cycle time by 8%. Boeing's success story represents a visible evidence of the benefits that can be expected from the implementation of lean initiatives in an assembly unit.

[27]

CHAPTER 3

CASE STUDY

This chapter represents a case study performed at Bombardier Aerospace Learjet, a leading aircraft manufacturing company

3.1 Company overview

It all started in the year 1960. When a Swiss aircraft company ceased all its efforts in developing an unsuccessful fighter jet, Bill Lear and his team saw the effort as a first step towards the development of a world-class business jet. The initial Lear jets had their designs incorporated from a slightly changed one that was used by the prototype aircrafts of the Swiss aircraft Company. By 1962, the base for developing the aircraft and the tooling required for it were moved to Wichita, KS, U.S.A. the very next year the company incurred its new name, "Lear Jet Corporation". The next year, in 1963, the first flight of the Learjet 23 (six to eight seats) was recorded.

In 1967, the Gates Company acquired Bill Lear's 60% shares of the company and later in 1969 it was merged with its aviation partner and was renamed as 'Gates Learjet Corporation'. After launching different models with series numbers 25, 35, 54, 55 and 56 in 1987 Integrated Acquisition, Inc, acquired it and renamed it to Learjet Corporation.

After going through different acquisitions, finally the Learjet Corporation was acquired by 'Bombardier Aerospace' in the year 1990. After acquisition, future aircrafts were promoted as 'Bombardier Learjet Family'. The latest additions to the Learjet fleet

were the models 60 and 45. Recently the extended range versions of these two models have also been launched.

3.2 Objectives

A case study was conducted in the Upper Door of Learjet Model 40/45 to analyze the problems of late delivery and frequent occurrences of non-conformance in the final aircraft assembly line. The Door Shop has two separate lines, one for the upper door and another for the lower door assembly. The upper door has to go through 4 positions in order to be ready for installation. Positions 1, 2 and 4 are at the door shop while position 3 is at the foam shop where sealing and foaming is carried out. Each manufacturing line has a specified move time that is associated with the move time of the final assembly of the aircraft. Model 40/45 has a move time of four days. Therefore, every four days, a completed door should leave the door shop and be installed on the fuselage at the final assembly line.

In order for the door to be completed as per schedule, parts should be readily available. Parts for this door assembly are delivered as kits. All the parts required for the assembly of the door are collected together as a kit and supplied to the shop floor for assembly. Material Control agents (Stock Room) provide the complete kit for production. Each kit contains parts that are either made in house or purchased from an outside vendor. When the purchased parts are short in supply, Procurement department is notified for appropriate action. The final assembly of the Model-40/45 aircraft has 6 positions with a move time of 4 days. As per production schedule, the doors should be installed in position 3. The doors were delivered to the final assembly

line only when the aircraft was in its position 5, which would be after 8 manufacturing days. Even after the doors were available for installation, there were occurrences of non-conformance on the upper door. At least 8-10 man hours were required to rework the upper door assembly.

3.3 Problem Statement:

The Model 40/45 upper door is delivered late to the final assembly line after 2 move cycles (8 days) and in turn 8 to 10 hours are spent on the doors to rework non-conformances.

3.4 Proposed Methodology

The methodology proposed here is an integrated approach of lean and six-sigma. To start with, a high level should be developed for the process under study. Possible improvement opportunities can be identified from this value stream map. All possible opportunities should be identified here, irrespective of the nature of the problem. DMAIC should be used for working on these opportunities. Since DMAIC is a systematic approach it keeps the project on track. Based on the nature of the problem, any of the available six-sigma tools or lean tools or both together can be used to analyze and improve the problematic processes. Based on the nature and size of the problem the usage of lean and six sigma tools could vary. For example, if the problem is process based tools like Control charts, Pareto charts can be used and if the problem is workplace related tools like 5-S and Kaizen can be used. A schematic representation of the proposed methodology is shown in Figure 4.

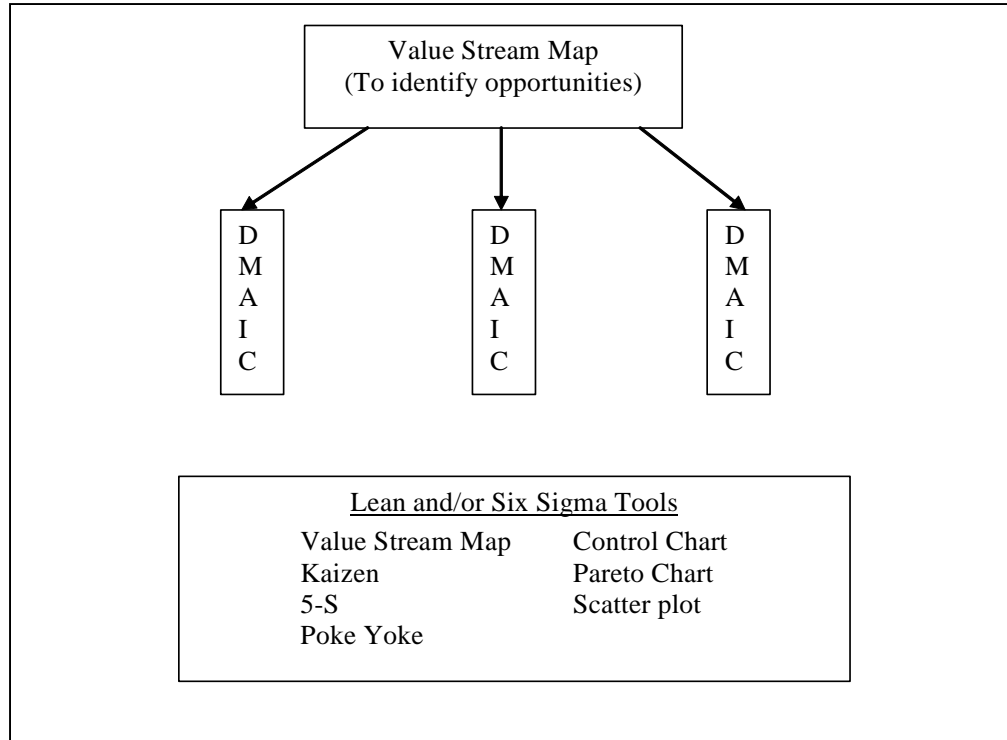
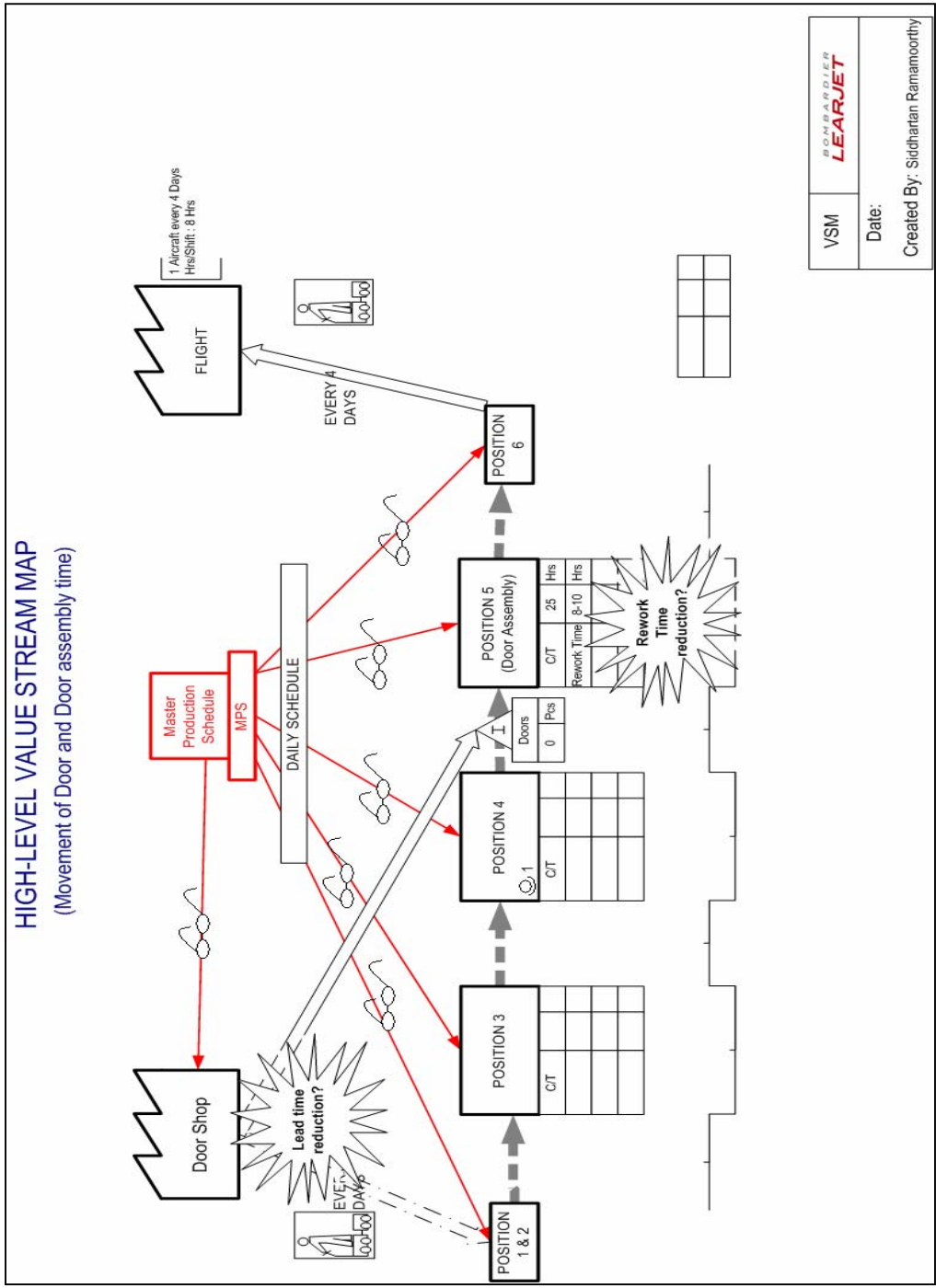


Figure 4: Schematic representation of methodology

3.5 High Level Value Stream Map

As an initial step, a high-level value stream map was developed so as to prove that there are lead-time related issues and non-conformances with the door delivered by the door shop. The high-level value stream map in Figure 5 indicates when and in which position the completed door is delivered at the final assembly line. The cycle time and rework time recorded in assembling the door with the fuselage is also documented and shown. As shown, the time taken to mount both the upper and lower doors and perform some functional tests before the aircraft is moved to the sixth position is 25 hours.



VSM

BOMBARDIER
LEARJET

Date:

Created By: Siddhant Ramamoorthy

Figure 5: High Level Value Stream Map

From the value stream map, two opportunities were identified. One was to ensure on-time delivery of the upper door to position 3, which is lead-time reduction. The other was to reduce rework hours associated with the installation of the upper door assembly on the fuselage. Having identified the improvement opportunities the next step was to work on the two opportunities identified using DMAIC approach.

The entire project was divided into two phases. The first phase was to work on lead-time reduction and the second phase was to work on and reduce the non-conformances occurring due to the upper door when mounted on the fuselage. Lead-time reduction was selected first in order to follow the order in which the opportunities were identified.

3.6 Phase I: Lead-Time Reduction:

Define

It was reported by the final assembly crew that the completed doors have been reaching the floor only when the aircraft reaches position 5. As per the master production schedule, the doors have to be available when the aircraft is in position 3. In order to define and quantify the issue with lead-time a current state value stream map (VSM) [Figure: 6] was developed for the assembly of the upper door. The VSM included the staging time and lead-time of the parts required for the assembly of the door. The VSM also includes different positions (stages) in the assembly and their corresponding cycle times. The VSM shows that there are kits waiting in between positions. Based on the data on inventory level, the lead-time that resulted from this VSM is 26 days. These 26 days are inclusive of the 10 days of parts' staging period in the stock room.

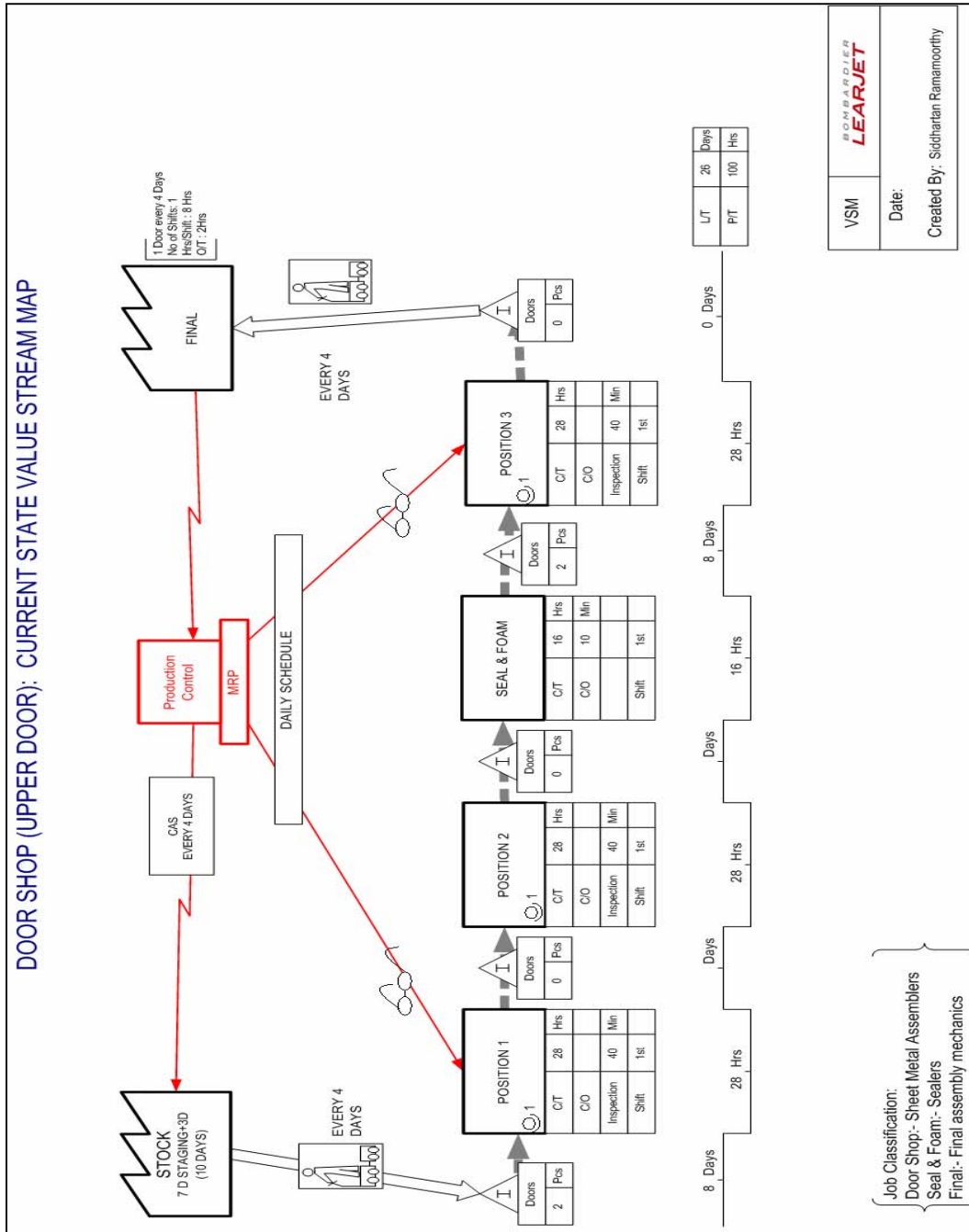


Figure 6: Current State Value Stream Map

Since the doors are assembled as per the master production schedule, the door assembly line is already in a pull environment. In a pull environment there should be no inventory in between positions. There are 4 kits waiting in between positions. Since the

move rate is 4 days, it is 16 days of inventory, which means that each kit spends at least 16 days more than the actual 12 days. Whenever a part is missing from a kit, the whole kit is set aside and the next available is taken and used. Hence, the kits are waiting in between positions because of shortage of parts. Since part shortages were a main player in late delivery of doors, the next step was to measure the shortage of parts.

Measure

Data was collected on parts shortages. Every four days a kit full of parts was delivered to the floor. The list of shortages from every kit was collected and tabulated. This data collection extended to include twenty kits. A closer look at the data indicates that thirteen parts were missing from each kit on the average. Table 1 gives a detailed description of the number of parts missing in each of the 20 kits that were included in the study.

	# of Shortages			# of Shortages
A/C 1	9		A/C 11	11
A/C 2	7		A/C 12	19
A/C 3	8		A/C 13	15
A/C 4	15		A/C 14	11
A/C 5	11		A/C 15	13
A/C 6	14		A/C 16	15
A/C 7	15		A/C 17	18
A/C 8	17		A/C 18	9
A/C 9	14		A/C 19	9
A/C 10	16		A/C 20	9
			Average	13

Table 1: Initial shortage list

Analyze

Apart from the frequency of parts missing from each kit, the trend of individual missing parts was also considered. The make of the part, that is, whether the part was made in-house (Learjet) or purchased from an outside vendor was also recorded. Using these three different measures, namely number of parts missing in a kit, parts that were missing repeatedly and the make of the part, the list of parts was sorted out and a chart was plotted [Figure 7]. It is apparent from figure 7 that there is only one in-house part which was found missing in 4 of the 20 kits. In order to get corrective action from the vendors that supply the parts, the vendor names were retrieved from the database. From the Pareto chart in Figure 8, it is evident that 8 parts were missing for at least 50% of the time. Hence, these 8 parts were considered for corrective action. Out of the 8 parts that were considered for corrective action, the same vendor supplied four parts.

Improve

The improve phase was nothing but identifying appropriate corrective actions to reduce the shortage issues. Shortages were mainly with vendor parts. In order to get corrective actions from the vendors, a team of material logistics agents from the Work Material & Planning (WMP) department was formed. The team came up with the corrective action of demanding the vendor to supply the parts on time failing which the vendor might be replaced. With these data as evidence corrective actions were demanded from the vendors with high shortage history. The vendor that supplied 4 of the 8 parts was eventually replaced. After 3 move cycles (12 manufacturing days) the

same shortage data was collected for another 20 kits. These second set of shortage list was not blank. On an average only three parts were missing from each kit [Table 2].

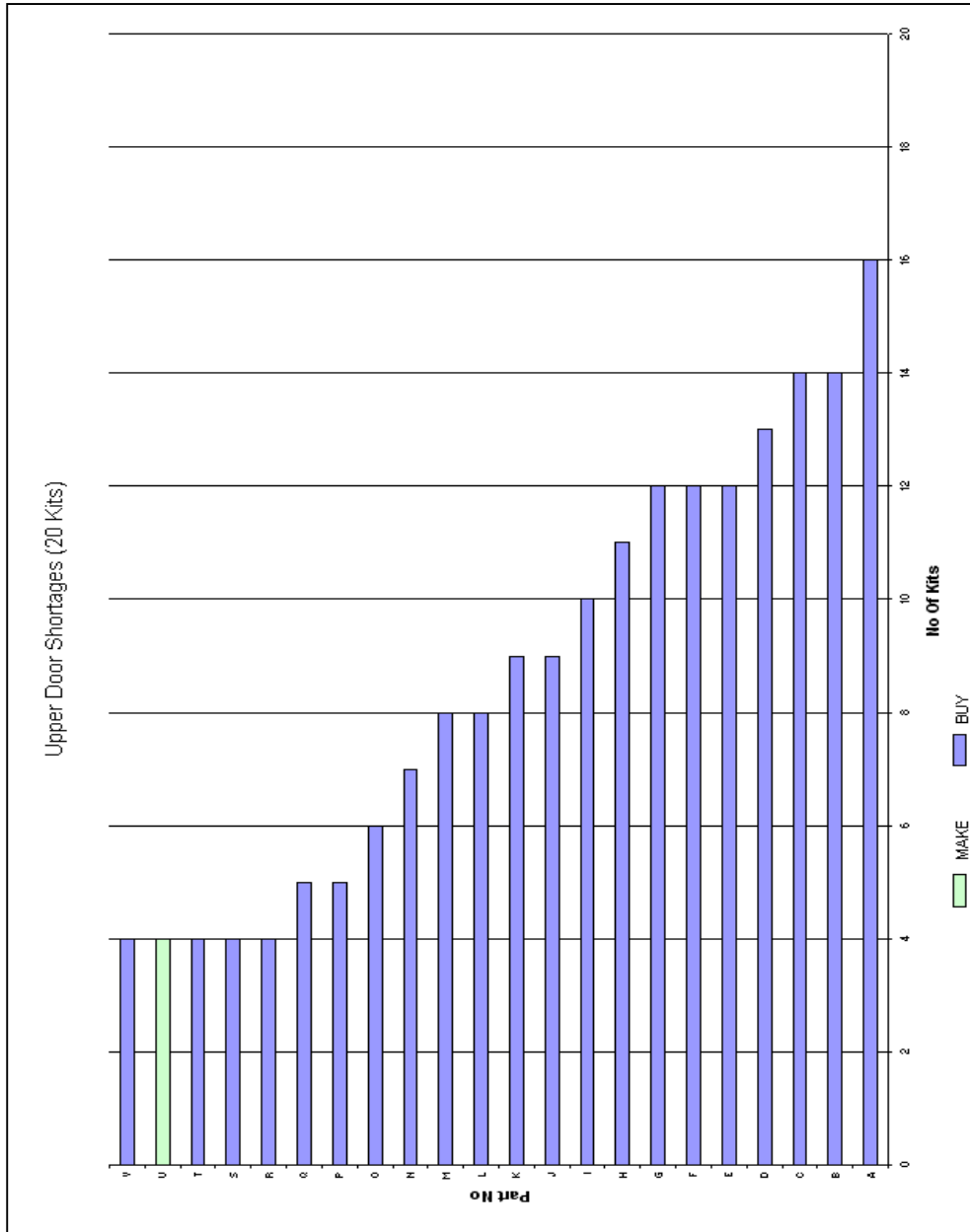


Figure 7: Shortage list by part number and number of occurrences

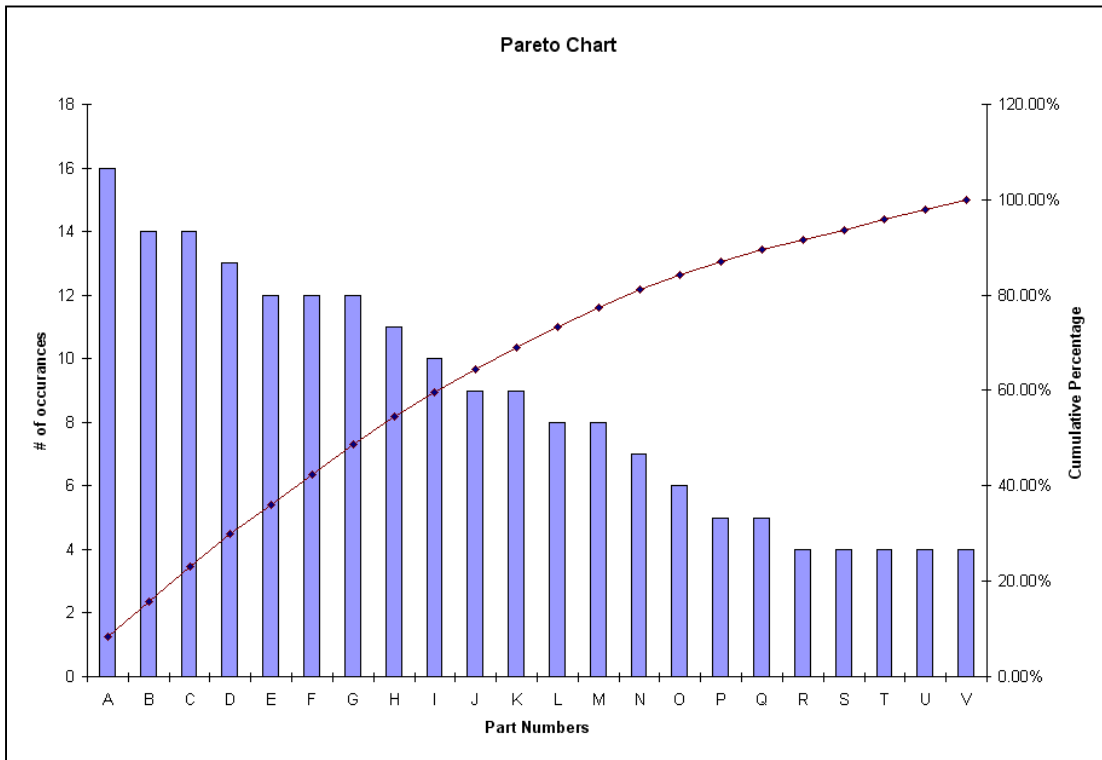


Figure 8: Distribution of part shortages

Though there were parts missing from the kits, it didn't affect the assembly line, as the missing parts were required only in either position 2 or position 4 of the assembly line. The missing parts were filled in before the door assembly even reached position 2 or position 4. For these 20 kits that were monitored, there was no extra lead-time from the assembly line and the doors were delivered to the final assembly line of the aircraft on time to meet the 4 day move rate. A new VSM was once again constructed. From the VSM it was evident that the total lead-time for the door to hit the final assembly line had gone down to 10 days from 26 days [Figure: 9]. These 10 days were due to the staging time taken by the stockroom

	# of Shortages			# of Shortages
A/C 1	2		A/C 11	3
A/C 2	3		A/C 12	4
A/C 3	3		A/C 13	4
A/C 4	4		A/C 14	5
A/C 5	4		A/C 15	3
A/C 6	2		A/C 16	3
A/C 7	2		A/C 17	2
A/C 8	3		A/C 18	3
A/C 9	3		A/C 19	3
A/C 10	4		A/C 20	2
			Average	3

Table 2: Shortage list after improvement

Control

The corrective actions taken were documented for future reference. The corrective actions are controlled and monitored by the WMP department using the Consolidated Applications System (CAS), a mainframe application that is used to monitor the lead-time of the parts supplied by vendors. By monitoring the lead-time, the WMP department would be able to demand corrective action from the suppliers whenever their supply lead-time crosses the required production lead-time.

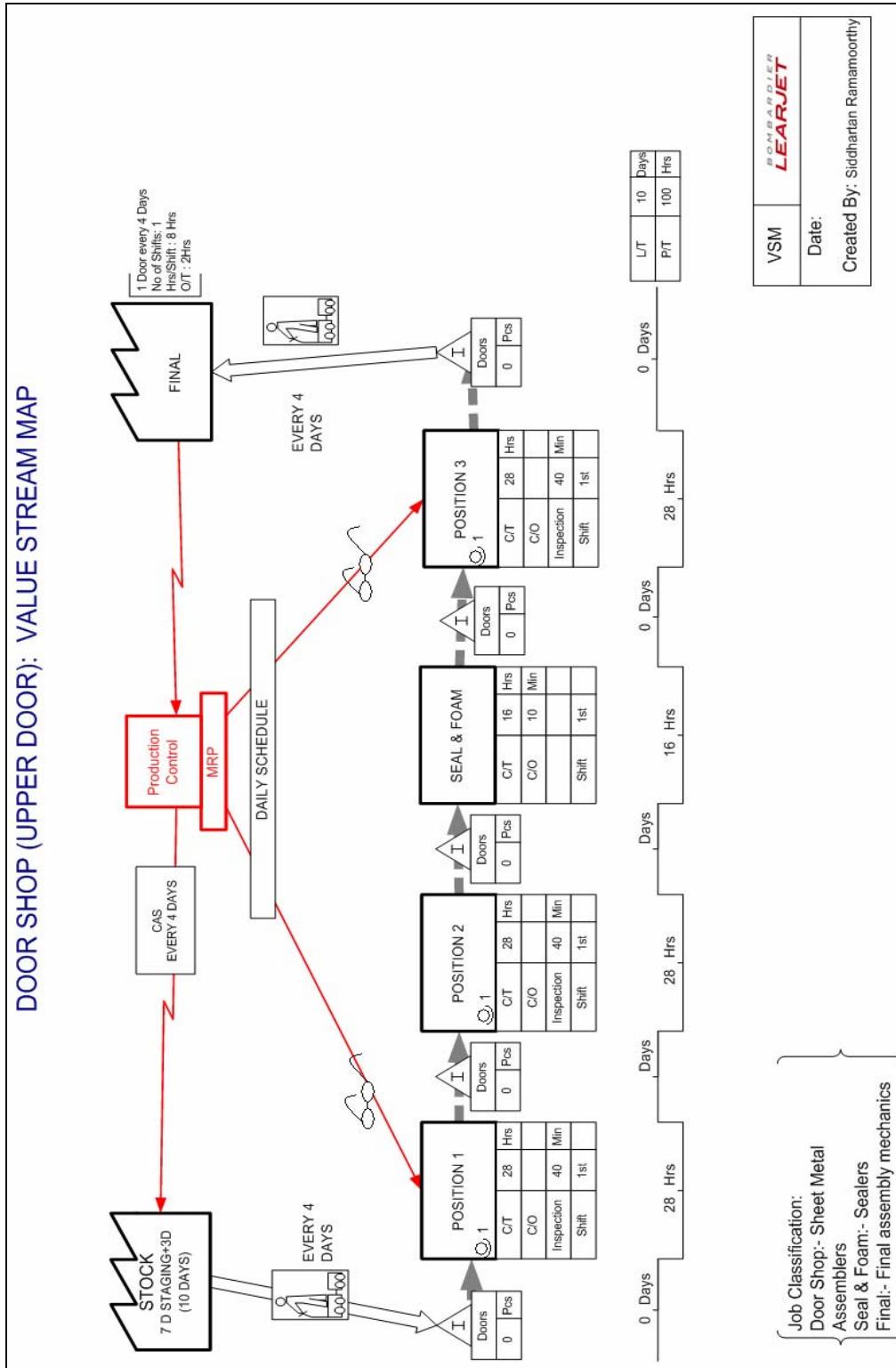


Figure 9: Value Stream Map after Improvement

3.7 Phase II: Non-conformance reduction:

Having reduced the lead-time associated with the delivery of completed Model 40/45 Upper Door, the next phase was to study the non-conformance from the doors and reduce the rework hours associated with it. In the final assembly line, the wing, which arrives from a different facility, is mated with the fuselage. Then the wind shields, doors, flight controls and avionics equipments would be installed and the Aircraft would be ready for a flight test.

Define

One of the most frequently noted non-conformances at the final assembly was the deviation in the contour of the upper door. The completed door when installed on the fuselage always had a deviation in contour with that of the fuselage. Each time this deviation in contour was encountered, the door had to be reworked for alignment with the fuselage. This contour issue was only noted with the Upper door and not the Lower door. Since this was a repeating issue, this non-conformance was chosen for study and analysis.

Measure

As a first step in the measure phase, 'Defect Concentration Charts' (DCC) were used. A DCC is used to identify the area on a particular part where defect occurs the most and also repeatedly. For this case study, the DCC chart was designed and provided to the assembler. He was instructed to mark the DCC every time he encounters a defect corresponding to the contour of the upper door. DCC was used for

five upper doors. One of the DCC's marked by the assembler is shown in Figure 10. The DCC has the front and the side views of the door. It also shows the different marks to be used for different deviations. The date refers to the date on which the chart was marked and the A/C No is the aircraft number. This DCC indicates the existence of deviation on the upper forward edge. From the defect concentration data collected for 5 doors the upper front edge of the door was identified to be the defective area

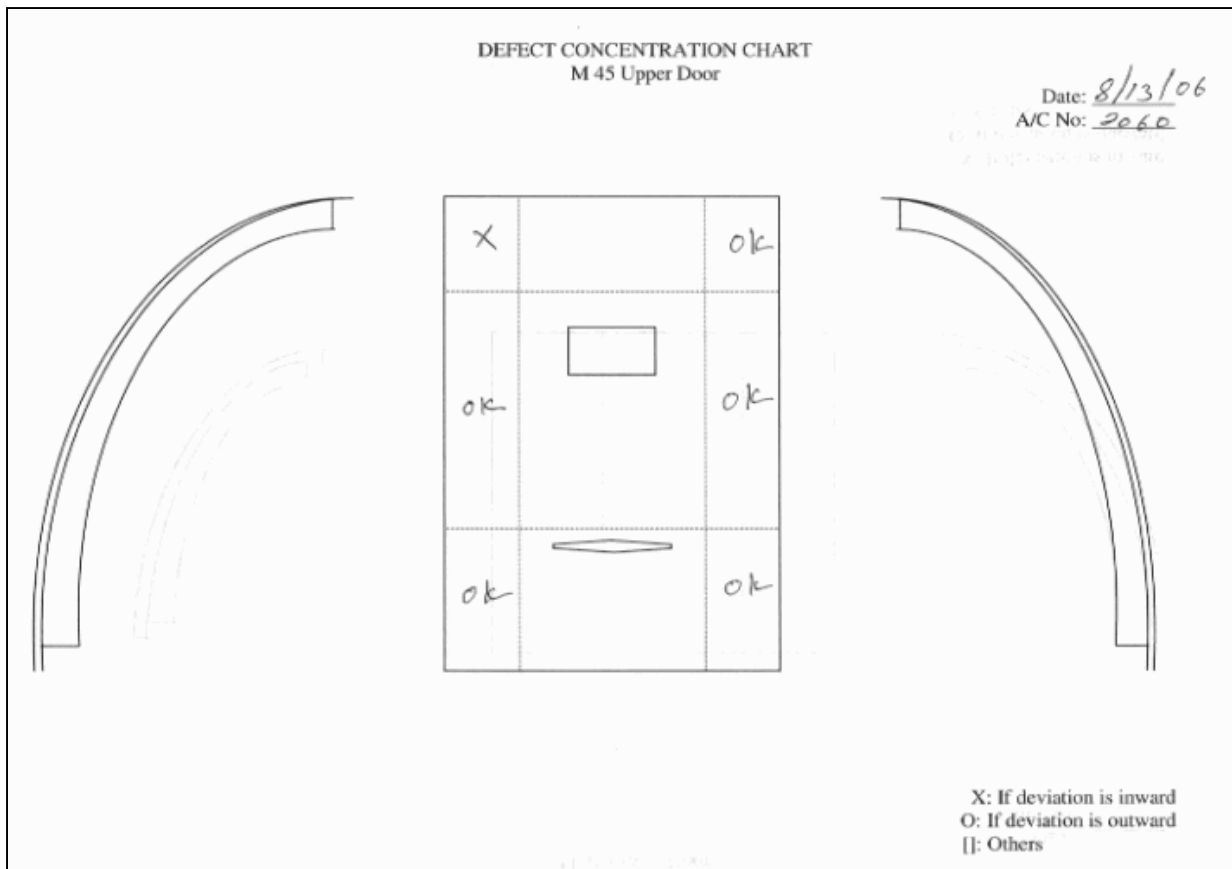


Figure 10: Defect Concentration Chart

To identify possible causes for these deviations a cause and effect diagram was constructed. The categories considered in the cause and effect diagram were Man, Components and Methods [Figure: 11]

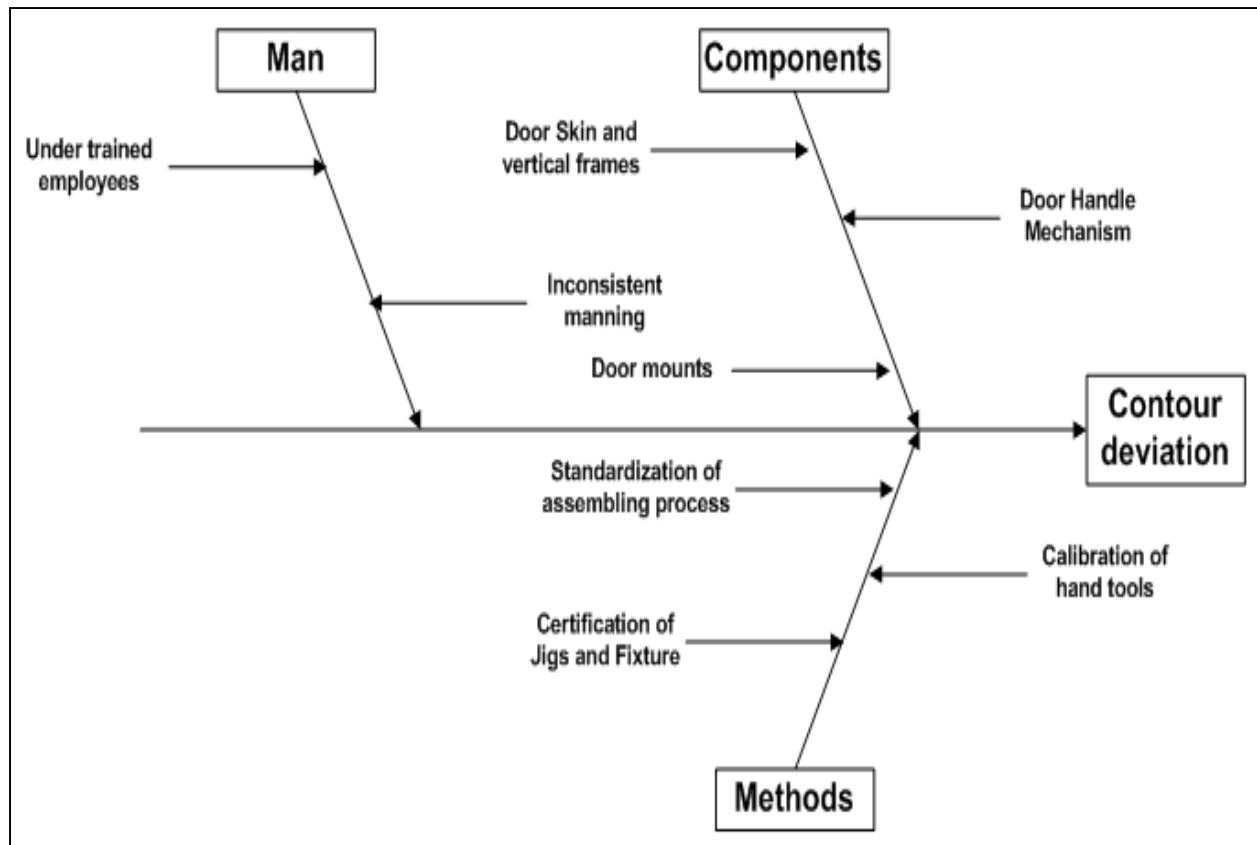


Figure 11: Causes for deviation in contour

Under trained employees and inconsistent manning were considered as possible causes. When enquired they were found to be skilled and experienced assemblers. They have been working on doors in the door shop for at least eight years and thus the cause of operators was ruled out. For Method, the standardization of work being carried out was questioned. The entire process of assembling the upper door was observed and documented. When compared with the engineering standards and work instructions the operators appeared to be following the standard work instructions. It was also evident that the process was not different from what was followed before contour problems were experienced.

The jigs, fixtures and hand tools used for assembling the doors were considered as a possible cause. Improper maintenance and out of calibration could be key factors. The three different tools used in three different positions of the upper door assembly were considered for dimensional check. Since the tools were being used for many years there were possibilities for wearing out of the tools that might be the cause for defective outputs. The certification history of the tools was collected. From the data it was found out that the tools, jigs and fixtures were certified once every 16 door deliveries by the tooling department as required by the FAA. Similarly all the hand tools were up to date on calibration and certification. Hence the question of the tools being defective was also ruled out.

The final inspection for the contour of the doors involved a contour template. This contour template was a replica of the template that is used to measure the contour of the fuselage. The contour template was checked for accuracy and found to be within specifications. The main components that might contribute to the contour of the door are the frames and the door skin. The stock room was requested to measure the parts that were already in the stock for dimensional accuracy. As expected there were 3 sets of these parts in stock. They were measured and found to be within engineering tolerance limits. In order to measure the contour of the door, a portable CMM was used. In this case a FARO Arm was used to measure the contour of the door. [Figure: 12]



Figure 12: Faro Arm – G08 – 02

Analyze

The procedure that was followed was to match the contour of the completed door with the engineering drawing of the door. The output from the FARO arm is a digitized image file. The IMAGE WARE – BUILD IT software was used as a medium of matching the two files, namely one from the FARO arm and the other from the drawing. The engineering drawing was available as a CATIA model. Both the CATIA model and the .SAT file were imported to the IMAGE WARE software as IGES files. These two files

were matched and the results were used to calculate the average deviation from the engineering. Four doors were used for this study. The output of this contour matching procedure is shown in Figure 13.

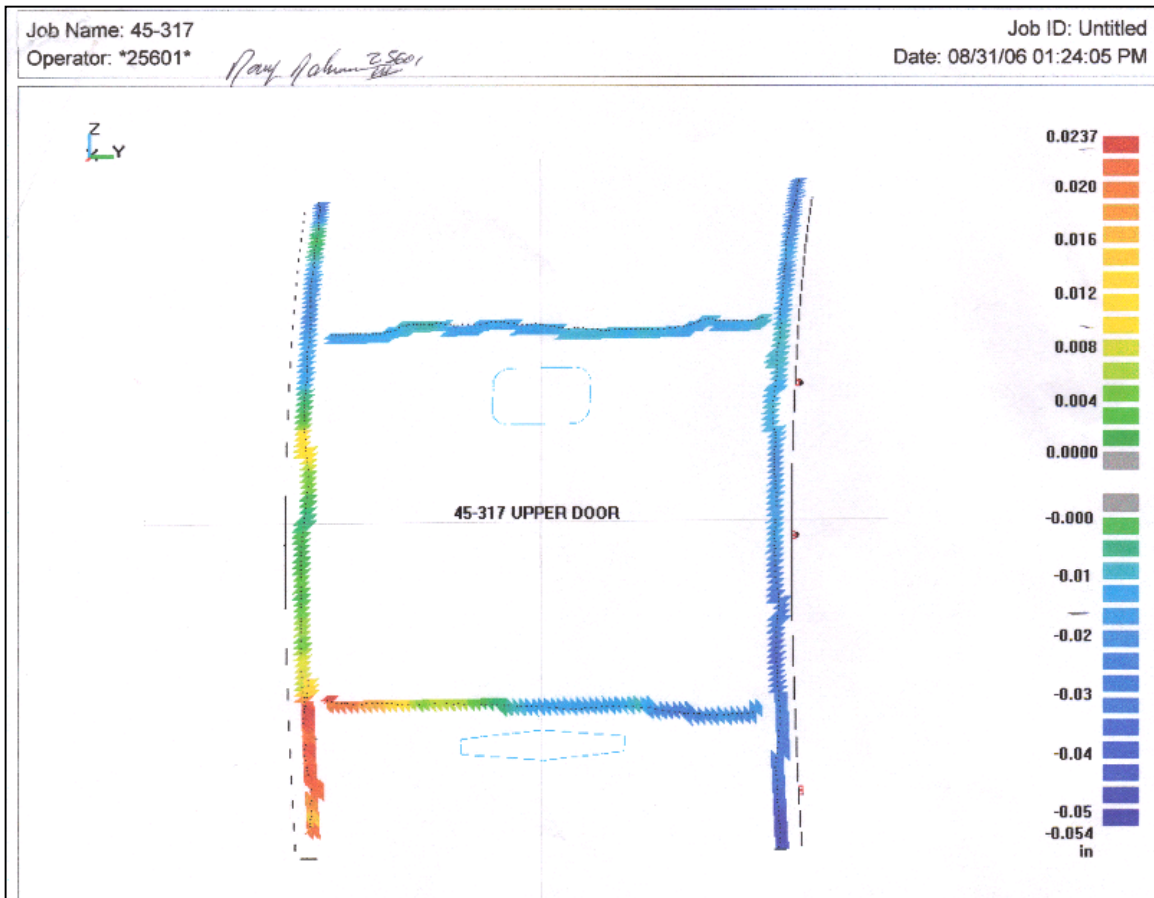


Figure 13: Sample output from IMAGE WARE

An average value was computed from the measurements made as shown in Figure 14. The aero dynamical tolerance limit for contours is ± 0.06 inches. From figure 16 it is evident that the average values of all the four contours are well within the tolerance limits.

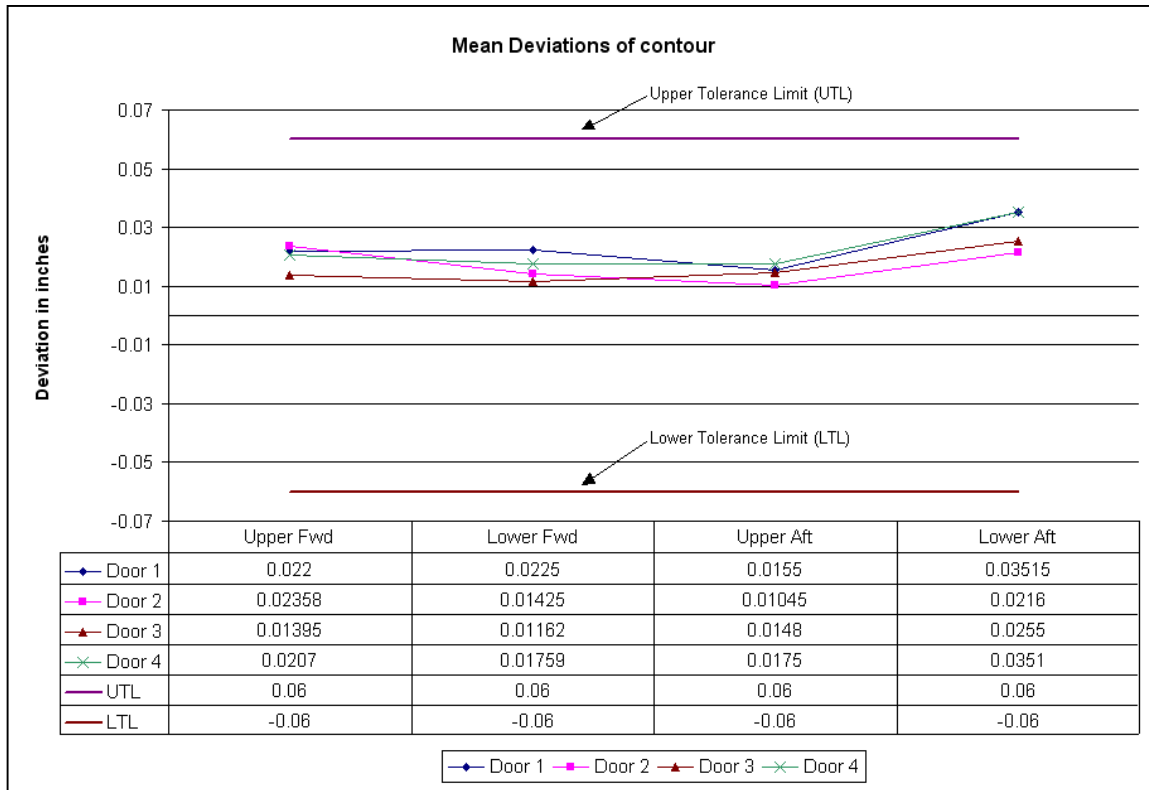


Figure 14: Mean Deviations on sample

In order to identify the other causes, the non-conformances reported during the assembly of the door with the fuselage were collected. Interestingly, there was one non-conformance that was repeatedly reported along with the contour deviation. It was the force requirement in operating the door handle mechanism. As per Learjet engineering standards, the maximum force that can be applied in operating the door handle mechanism is 35 lbs. After assembling a complete door, the force requirement is inspected at the final assembly line. When the door was mounted on the fuselage and the force requirement was functionally tested, often more than 35 lbs was required to operate the door handle. A 0-100 lbs spring gauge was used to measure the force requirements in operating the door handle. The spring gauge is attached to the inner

handle of the upper door while it is in the locked and latched position. The spring gauge is then pulled in the direction to unlatch and unlock the door (counter clockwise). The reading on the spring gauge is the force requirement for operating handle of that door. The force requirements were measured for six doors. All the doors required more than 35 lbs to operate [Figure: 15].

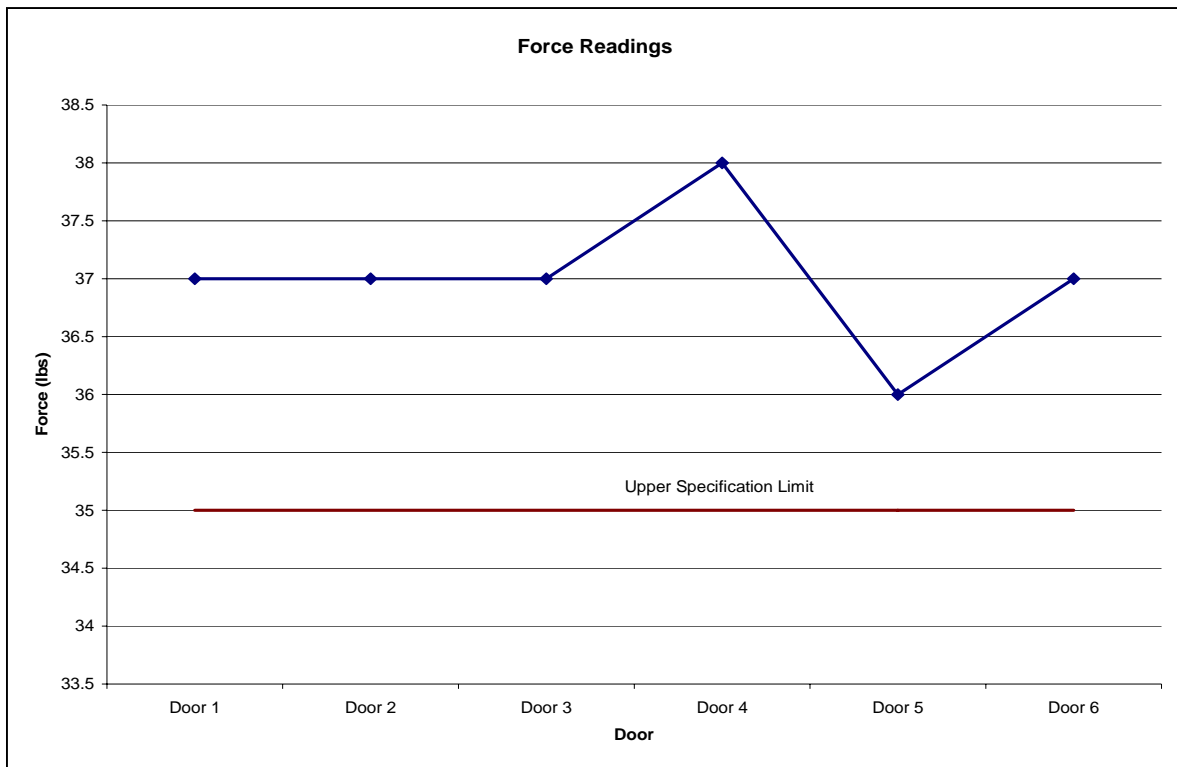


Figure 15: Force measurements on sample

When this issue on force requirement occurred, the door locking mechanism was studied in detail. A schematic drawing of the bell crank assembly is shown in Figure 16.

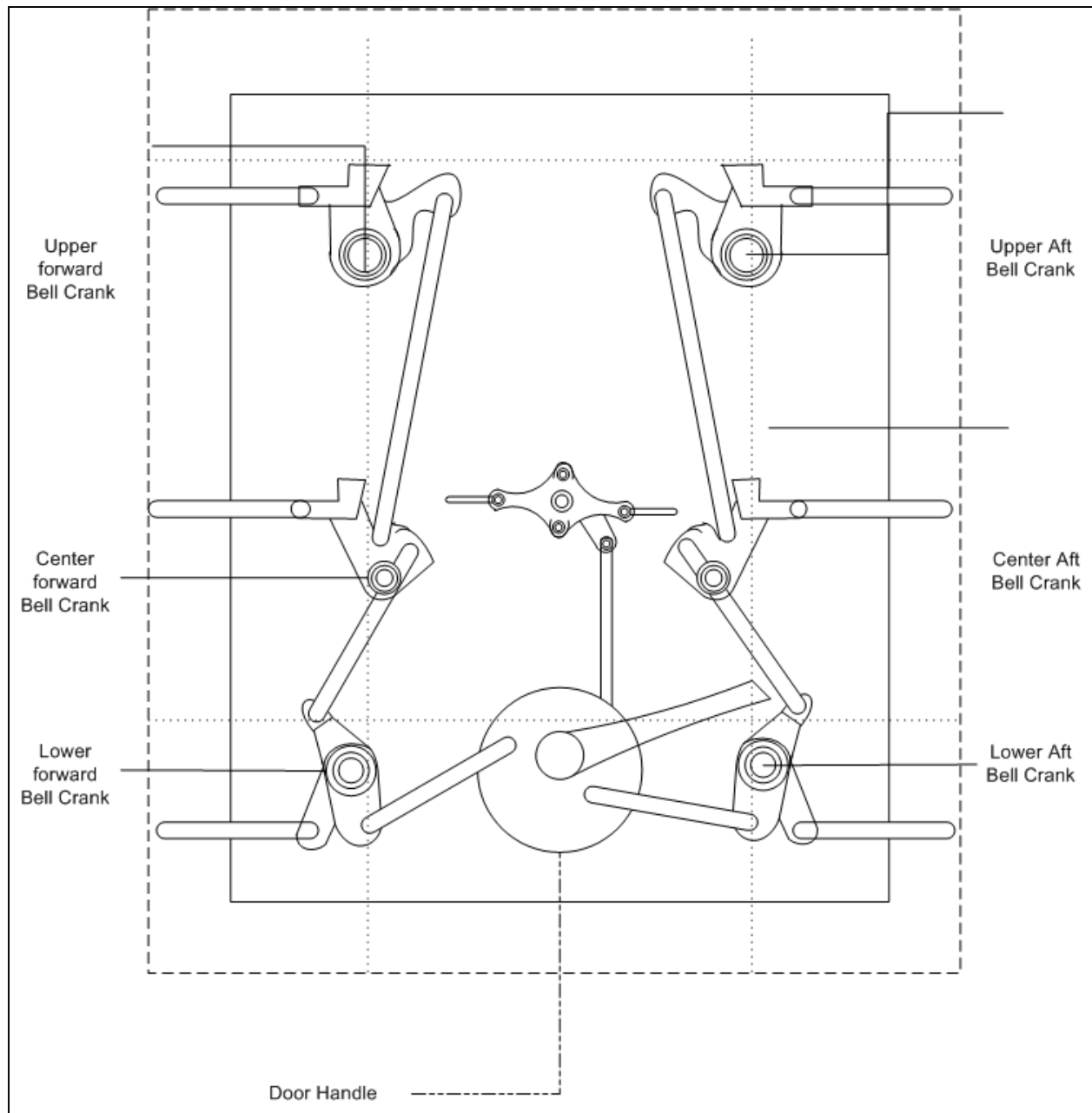


Figure 16: Bell Crank Assembly

Improve

A team of process engineers and quality engineers was formed to identify the root cause for the high force requirement in operating the door handle. The bell crank pin not sliding into the bush at a straight angle was identified as the root cause by the

team. Interestingly, since the pin was not aligned with the bush, more force was required to be applied on the door, which in turn aided in the door deviating from its normal position. After a thorough study on the bell crank and the engineering specifications it was decided by the team to move the center bell crank assembly up by 0.190, along with the other geometry, so as to ensure that the pin slides into the bush at a straight angle. This was a small design change and the cost associated with it was non-recurring. Force readings were collected again for another six doors and they were found to be within the maximum limit of 35 lbs [Figure: 17].

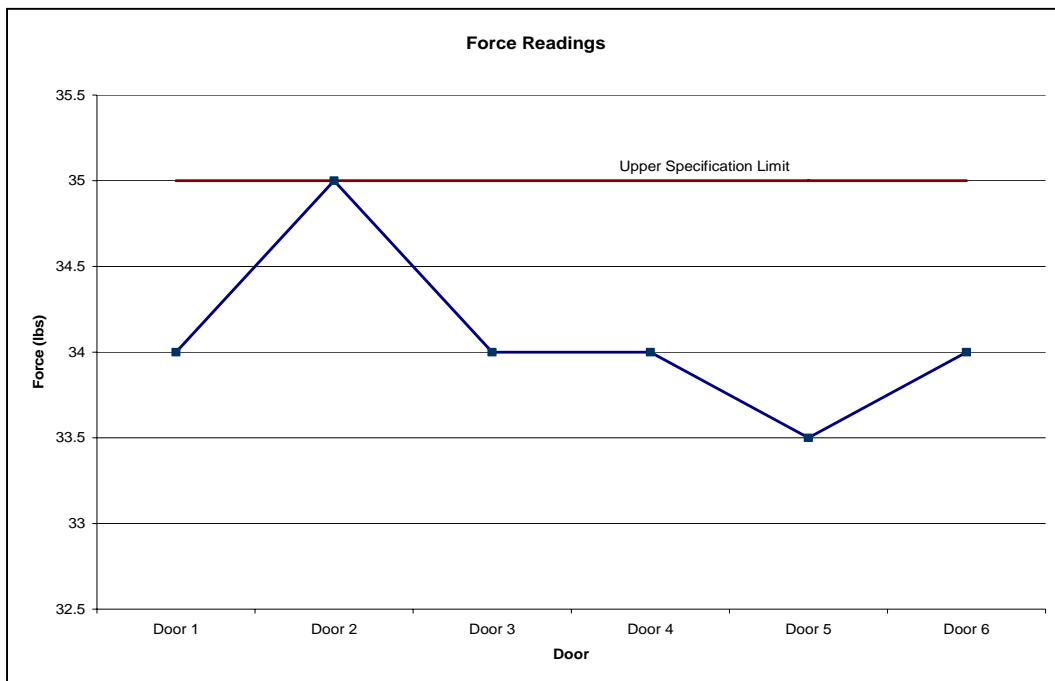


Figure 17: Force measurements after design change

Control

The change that was implemented on the door handle assembly played a vital role in minimizing the handle force requirement and thereby reducing defects due to

contour mismatch. This change in design was documented as a DCN (Drawing Change Notification). Figure 18 shows the drawing of the bell crank assembly after the design change. This DCN would be used for future references. Since a DCN was issued the future doors would be having the bell crank installed as per the new design change and there wouldn't be non-conformances related to force requirements.

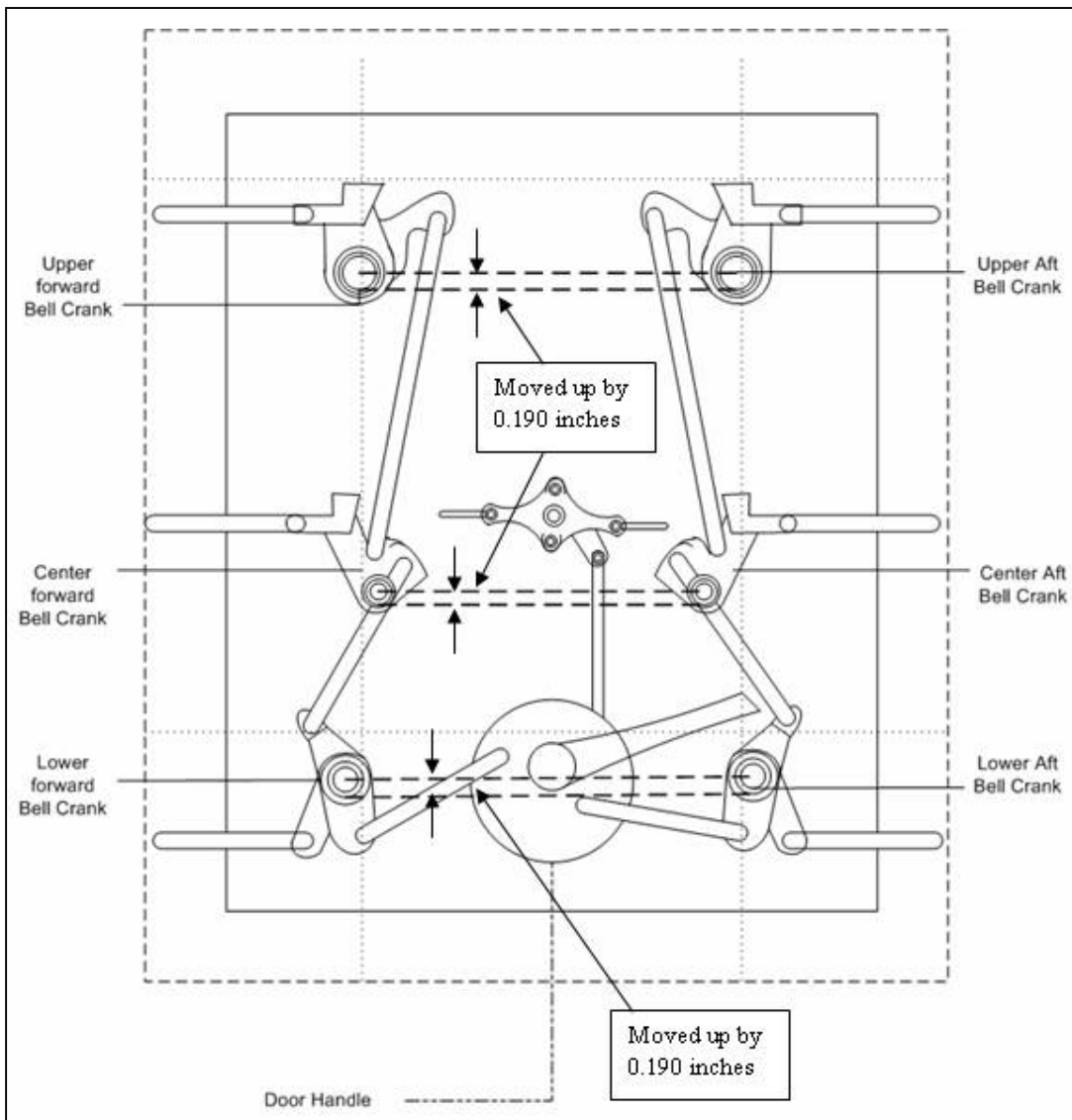


Figure 18: Bell crank assembly after design changes

CHAPTER 5

RESULTS AND CONCLUSIONS

Lean Six-Sigma has evolved from individual practices of lean and six-sigma that focus on reducing waste and variability to deliver a high quality product. The effectiveness of this integrated approach has been tested in many occasions. Success in most of the cases is evident from cited literature and case studies. Value stream mapping, considered as a strong and effect lean manufacturing tool is often used to visualize the flow of information and material involved in a certain process. Value stream map also helps identify the possible improvement opportunities. The DMAIC, a six-sigma approach, gives a finite sequence of steps to be followed in improving a process.

This integrated approach of using lean and six-sigma tools was proposed and evaluated through a case study. Using a high level value stream map two opportunities for improvement were identified, namely lead-time and non-conformance reduction. The first phase of the improvement, lead-time reduction, was actually a lean goal where a detailed current state value stream map was utilized to calculate lead-time. Part shortage was found to be the reason for high lead-time. After utilizing the DMAIC procedure, corrective actions were taken the lead-time was reduced from 26 days to 10 days.

The next phase involves non-conformance reduction. Once again, DMAIC was used as a systematic approach to reduce the non-conformances and thereby further reduce the cycle time involved in assembling the fuselage.

The tools to be used in the DMAIC approach is not limited to what was used in this case study. Depending on the nature and type of the application a suitable lean and, or six-sigma tool can be utilized. As in this case study, engineering knowledge and team approach are essential in identifying the root causes for defects. Without engineering knowledge the actual cause of the defect might be either missed or misinterpreted. While working on defects from assembly lines the actual cause of the defect might be from another department. So forming a cross functional team with members from departments that are affected by the defect would add value and reduce the effort in identifying root causes. This Lean Six-Sigma integration was found to be an effective problem solving approach. If used repetitively, more improvement opportunities can be identified and studied. Systematic use of the proposed integrated approach can ensure savings in terms of time and money.

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