

Lean Six Sigma Implementation in an Automobile Axle Manufacturing Industry

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# Glossary

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| --- | --- |
| Acronym | Definition |
| VSM | Value Stream Mapping - Lean management technique for optimizing materials and information flow to the customer. |
| LSS | Lean Six Sigma - Business management strategy for quality improvement and waste elimination. |
| PCE | Process Cycle Efficiency - Measure of process efficiency calculated as value-added time divided by total cycle time. |
| SOP | Standard Operating Plan - Document outlining step-by-step instructions for performing a task in a standardized manner. |
| SMED | Single Minutes Exchange of Die - Lean technique to reduce equipment changeover time and increase productivity. |
| CNC | Computerized Numerical Control - Manufacturing technology using computers to control machine tools and automate processes. |

# Overview

The papers discussed the application of Lean Six Sigma methodology and the DMAIC approach in different industries and processes to improve efficiency, reduce waste, and increase profitability. These studies highlight the importance of identifying problem areas, measuring process performance, analyzing the root causes of problems, implementing process improvements, and establishing control measures to sustain the improvements. The authors used statistical process control tools and digitized real-time data to identify the sources of waste and implement process improvements to reduce costs. The papers provide insights into the application of Lean Six Sigma methodology and the DMAIC approach for organizations looking to improve their operations and profitability.

These papers collectively demonstrate the application of Lean Six Sigma methodology in various industries and processes to improve efficiency, reduce waste, and increase profitability. The DMAIC approach, which stands for Define, Measure, Analyze, Improve, and Control, is a problem-solving methodology used in Lean Six Sigma that is employed in all these papers. Each paper focuses on identifying problem areas, measuring performance metrics, analyzing root causes, implementing process improvements, and establishing control measures to sustain improvements. The industries and processes in which the methodology is applied vary, ranging from railcar assembly to automobile axle manufacturing to printing operations. However, the common thread across all these papers is the effectiveness of the Lean Six Sigma methodology and the DMAIC approach in driving process improvements and increasing profitability.

## **Case study 1: Application of lean Six Sigma methodology using DMAIC approach for the improvement of bogie assembly process in the railcar industry.**

### **Background:**

Railcars have always played a vital role in transportation. The smooth operation of bogie assembly processes is crucial for the railcar industry to achieve success. Bogie assembly is the process of constructing a railcar's chassis, suspension, and braking system, which are all critical components for ensuring a railcar's safe and dependable operation. However, the bogie assembly process can be difficult and time-consuming, resulting in quality concerns and manufacturing delays. Using a DMAIC approach, the railcar industry can improve its bogie assembly process by applying lean Six Sigma methodology.

### **Problems and bottlenecks:**

Many problems and bottlenecks are encountered in railcar bogie assembly, including quality issues, high lead times, excessive rework, and waste. The industry's overall performance can be negatively affected by these issues, as they can increase costs and decrease productivity.

### **Six Sigma tools and applications:**

The DMAIC (Define, Measure, Analyze, Improve, and Control) approach is a widely used Six Sigma tool that helps organizations identify and solve problems. A DMAIC approach is appropriate for the assembly of bogie components in the railcar industry, as follows:

#### Define Phase:

The define phase involves identification of key performance indicators and their assistance in identifying areas to improve, such as:

1. Problem: The problem has been identified as labor delays during the construction phase of the railcar bogie, resulting in an increase in the lead time and a decrease in the efficiency of the process.
2. Business case: Troubleshooting the assembly process, identifying the root cause of the waste generated and improving the assembly process using the Lean Six Sigma approach. Improving process efficiency, reducing delay, and improving productivity are the objectives.
3. Critical to Quality (CTQ): The CTQ for this problem is lowering job tardiness throughout the assembly process, which results in a shorter lead time and greater process efficiency.
4. Process Map: The VSM approach provides an overview of the assembly process, including value-added and non-value-added operations, and criteria to meet benchmarks. It shows the flow of information, labor, and materials, and identifies areas for improvement. Eq. (1) states the current PCE at 19.9%, below the 25% benchmark. LSS installation is expected to reduce waste and non-value-added time.

The present PCE of the assembly line is expressed as Eq. (1)

Present Lead Time = Value Added Time + Non-Value-Added time (1)

Process Cycle Efficiency = Value-added / Leadtime x 100%

#### Measure phase:

This phase collected data on lead times and process cycles for design, parts procurement, jigs development, under frames, bogies, and components assembly, preassembly, overall assembly, finishing, and inspections. Descriptive statistical analysis of the period was done to assess variation and deviation from the mean lead time. Interviews with selected personnel provided further data on value contributed, non-value-added, and equipment up and down times (Table 1). A Pareto chart compares PCE for several assembly operations to 85%. A continuous improvement method will measure the percent improvement needed.

#### Analysis phase:

The assembly process is being analyzed to find the cause of low cycle efficiency and lead time changes. Low process cycle efficiency and lead time variations are identified using a fishbone diagram. The five-why iterative interrogative method is used to find the root and cause-effect relationship. Recorded are the issues and potential primary causes, including operator behavior and materials. Inefficient process flow, non-value-added time, and production lag time are also present. Modularity is suggested to make the process of assembly more flexible, cost-effective, and simplified. A low level of technology and process automation is a significant element; highly automated systems are suggested to improve assembly operations by increasing human capacity.

#### Implementation phase:

The Kaizen Approach was used to enhance assembly process by systematically managing material and part movement to reduce inventory and faults. The study implemented Single Minutes Exchange of Die (SMED) and 5S to reduce inventory and improve poor PCE. SMED separated value-added and non-value-added production, assembly, and machine setup to save waste and setup time. 5S involved organizing equipment and parts, cleaning and safeguarding the workplace, standardizing work processes, and maintaining the standard. These methods have significantly increased value-added time and decreased nonvalue-added time. The study replaced 50% of human operators with robots, which boosted assembly speed, precision, and accuracy and reduced cycle time.

#### Control phase:

During control, the system's performance is monitored and compared to the benchmark to prevent compromising long-term goals. Deviations were corrected to ensure continued progress. The underframe, bogie frame, and components are built using SOP controls. Employees are also taught 5S and SMED for continuous improvement. LSS Tool improved this procedure by 3.95 sigma, as shown by histograms (Figure 1). It is not normally desirable that the level of Sigma be below 3.

### **Results and conclusion:**

Kaizen and work standardization increased PCE from 19.9% to 66.7%, increasing assembly process productivity by 46.8%. From 623,519.97 minutes to 450,280 minutes, the lead time has decreased by 27.9%. The study also found a 59.3% increase in value-added time from 125,87.8 minutes to 309,600 minutes and a 71.9% reduction in nonvalue-added time from 497,661.17 minutes to 139,680 minutes.

The study concludes that LSS's successful implementation in this case has shown its potential for waste elimination and improved manufacturing processes when applied to other process metrics like quality and turnaround time. The study shows that the LSS can be used to achieve process improvements and operational excellence in an organization by integrating lean and six sigma techniques, which can also achieve zero defects, optimum production performance, improved product quality, or rapid delivery at optimal cost.

## **Case study 2: Process improvement for printing operations through the DMAIC Lean Six Sigma approach, Nicholas Roth, and Matthew Franchetti**

### **Problem Statement:**

At present, the printing company utilizes only two digital printing machines to create sample boards. This year's production capacity is limited to about 75%, which is unlikely to satisfy the anticipated printing demand.

### **Goals and Objectives:**

The project's objective is to minimize process waste and enhance production capacity to fulfill the expected market demand for the new sample board product line. Implementing Six Sigma and lean practices will help ensure efficient and long-lasting improvements.

### **Six Sigma tools and applications:**

#### Define:

##### Improve Efficiency and Effectiveness:

Operators should inspect incoming materials used for producing sample plates. Interruptions caused by quality issues reduce the process's capacity. Operators need to spend time examining the boards for scratches, discoloration, or warping.

##### Eliminate Waste/Rework:

The primary downtime the machine can avoid is ink replacement, an unstable factor in the current printing process. One solution is to create specific instructions to optimize machine usage without compromising operator efficiency and decrease non-value-added activities.

#### Measure:

##### Time Study:

Time studies were carried out for both the first and second-shift operators, utilizing the collected data to pinpoint and simulate various scenarios. It was discovered that Steps 3 and 4, as well as Steps 6 and 1, required the operator to restart the machine, indicating a greater potential for variation. (Figure 2)

##### Work Sampling Study:

A work sampling study was conducted on the operator to gain a better understanding of the distribution of tasks they performed. One analysis method involves determining which activities add value and which do not. This is crucial for identifying opportunities for improvement and reducing wasted time. The analysis results revealed that operators spend over 30% of their time on non-value-added tasks. The primary causes of this are the back-and-forth movement to the printer and waiting for a batch to be completed.

#### Analyze:

##### Layout Evaluation, Material Storage, and Material Handling:

The primary objective of this research is to minimize inventory and non-value-added work. The measurements obtained are used to create floor plans that accommodate three or four machines within the current workspace, reducing the operator's required movement between the machine, raw materials, and packaging areas. (Figure 3). A chart depicting the collaboration between humans and machines can be used to identify the tasks that require the machine operator's involvement in the process, as well as the time required for each task. This chart can establish a standardized workflow by specifying the order in which tasks should be completed by the operator. By scheduling the operator's activities during the process, short breaks can be identified, thereby minimizing downtime.

##### Standardized work:

A plan for standardized work can be developed based on the data collected, which can regulate the movement of materials throughout the process. The machining time, movement of raw materials, facility layout, and operator actions are all considered when creating the standardized work plan. By reducing the amount of time, the operator spends traveling between machines, raw materials, the computer, and the packaging area, the amount of time wasted during fabric transport can be minimized.

#### Improve:

##### Production configuration

The calculations in Figure 4 indicate the highest possible output that can be achieved based on the equipment cycle time and its reliability. By using this formula, investors can comprehend that to meet the demand, the company must increase its workforce or equipment. E-Kanban systems offer a simpler and more reliable approach, where stockkeepers do not have to manually enter values but can instead scan them using a barcode scanner. This method saves time and ensures promptness in handling stocks.

#### Control

Standard Operating Procedures (SOPs) provide the policies, processes, and standards required for success, reducing errors, increasing efficiencies, and profitability while establishing guidelines for resolving issues and overcoming obstacles. A check sheet can be used to mark unplanned delays in the process, enabling operators to predict which parts of the machine are prone to breakdowns.

### **Conclusion of the improvement of the printing process**

By applying Six Sigma methods, the root cause of the printing process problem can be identified and improved. This project has offered the company manager improved methods to achieve their printing demand for the following year. The proposed improvement methods can reduce production defects, improve overall product quality, and ensure sustainability using standardized methods.

## **Case study 3: Lean six-sigma implementation in an automobile axle manufacturing industry - Prateek Guleria, Abhilash Pathania, Shubham Sharma, José Carlos Sá**

### **Background:**

The case study addresses the use of Lean Six Sigma (LSS) in the manufacturing sector to address the issue of high rejection rates and waste in the production of a specific axle component. The team discovered and removed waste by using historical data, modified the shop floor layout, and applied 5S to improve accessibility. The effective adoption of LSS resulted in considerable gains such as lower rejection rates, reduced shop floor area and material transit distance, higher sigma level, and shorter lead time. These enhancements boosted the organization's profitability.

### **Problems and bottlenecks:**

#### A vehicle's transmission system relies on axle shafts, which are forged in one piece using expensive machines. With 1.3 billion vehicles produced annually, the manufacturing industry struggles to meet consumer demand. Rejections and rework result from inadequate training programs, poor materials, machine deterioration, and vendor inspections. The team used Lean Manufacturing and Six Sigma methods to improve productivity, decrease costs, and remove waste. Methods used were Value Stream Mapping,5s and DMAIC to improve material and information flow, while Six Sigma targets 3.4 failures per million chances. LSS contributed to the elimination of process variance and the reduction of waste, resulting in increased productivity and profitability.

### **Six Sigma tools and applications:**

#### VSM:

#### For the VSM study, the team chose the product with the greatest rejection rate over a three-month period, the M & M Rear Axle 1914C1. The rejection data for 33 different axle types was collected, and a graph showing the average rejection rate for each product was generated to determine which product had the highest rejection rate. (Figure 5)

#### Current State Mapping:

Historical data was used to create the Current State Map (Figure 6). The industry produced 3,976 axles every month, 394 of which were eliminated. Measurements included step cycle time and WIP. The lead time was 12:1, and the entire procedure for this product took approximately 30 minutes and 38 seconds. According to the Current State Map, the rear axle went through ten stages and was 4,050 meters from raw material to completed product. The industry had not implemented 5S, resulting in unstructured waste and work-in-progress on the shop floor. The expected line efficiency was 56.97%.

#### Analyze with 5s:

After identifying the three main wastages—transportation, additional inventory, and defects—from the Current State Map, the team changed the layout to reduce transportation, applied 5S to make room for supplies on the shop floor, and post management approval. The machines were altered to process 90-meter squares while freeing 162-meter squares. The material distance dropped from 4050 m to 809 m, and 5S was implemented on the shop floor. (Figure 7)

#### DMAIC –

##### Define:

A Project Charter (Table 2) was prepared that provides the necessary information to set the rear axle improvement goal. A SIPOC (Supplier, Input, Process, Output, Customer) diagram (Figure 8) has also been prepared to map out the entire business process of the rear axle, from supplier to customer, outlining essential processes and parties involved.

##### Measure:

During DMAIC Measure, rear axle rejections averaged 10.4% every month. The Pareto chart (Figure 9) showed that bearing diameter undersize and dent caused 78.8% of rejection. The monthly cost of poor quality was calculated to be Rs. 7,33,000/- (8,968.54 USD). The process capability for the undersize bearing diameter was 1.33 z-bench with a failure rate of 10.4%. However, low Cp (0.63) and Cpk (0.55) levels indicated a non-steady process. The red marks on the X Bar-R chart (Figure 10) showed that the axle diameter was above and below the UCL (Upper control limit) and LCL (Lower control limit), needing rework or rejection.

##### Analyze:

The team used a Fishbone diagram (Figure 11) to identify potential axle bearing diameter variation sources during the analysis phase. The Fishbone diagram considered the factors: Man, Material, Measurement, Machine, Method, and Environment. After brainstorming to confirm the causes, the team decided to attach an in-process gauge system to the CNC (computerized numerical control) Grinding machine to indicate diameter during the operation. This fix addresses the CNC grinding process's lack of bearing diameter control.

##### Improve:

During the improvement phase, the team added a Marposs gauge system on the machine (Figure 12) to monitor the shaft diameter and alert when the proper diameter was attained, eliminating the bearing diameter undercut issue. The manufacturer employed a trolley system (Figure 13) and damping material between axle layers to prevent rear axle dents during shipping and storage. (Figure 14)

##### Control:

Bearing diameter undersized and dents accounted for 78.8% of control phase rejections. After these issues were resolved, 125 samples were collected for capability analysis (Figure 15). The bearing diameter was within the prescribed range and the rejection rate was lowered to 3.20%. Six-sigma level rose to 3.94 from 3.34. SOPs and 5S were applied and displayed on the shop floor. Using a future state map (Figure 16) and one month of data, lead time was reduced from 12 days to 11 days.

### **Conclusion and results:**

The purpose of this research was to improve production by using Lean Six Sigma (LSS) in the automotive transmission parts manufacturing business. Due to shipping, inventory, and flaws, one of the rear axles had the greatest rejection rate. The shop floor layout was improved, and 5S was implemented. The gauge system and trolley system were designed to address the issues of undersized bearings and dents on the back axle. As a result, the rejection rate dropped from 10.4% to 3.20%, and the sigma increased from 3.34 to 3.94.

## **Case study 4: Manufacturing conversion cost reduction using quality control tools and digitization of real-time data by Veer Shivajee, Rajesh KR Singh and Sanjay Rastogi**

### **Problem statement:**

Indian two-wheeler vehicle producers face the challenge of reducing production expenses to remain competitive globally. However, manufacturers are concerned about various manufacturing conversion expenses, making it a difficult task. This problem sets the foundation for further research to understand this complex issue.

### **Goals and objectives:**

Indian two-wheeler vehicle producers are analyzing conversion cost factors and using quality control methods like DMAIC and QC tools to reduce manufacturing expenses. They aim to showcase the benefits of these methods through case studies and encourage others to focus on minor improvements for significant cost savings.

### **Lean Six Sigma Tools and applications:**

#### Define:

XYZ Ltd has three divisions: frame manufacturing, component machining, and engine assembly. The frame manufacturing process involves press, weld, and paint shops (as shown in Figure 4). The press shop shapes and welds the gasoline tank using MIG, spot, and seam welding, with brazing securing small pieces. The welded tank is inspected and leak tested before painting. Welding consumables are inputs, and real-time data records rejections. Pre-treatment, including degreasing, water washing, surface conditioning, and phosphating, is done before painting.

Measure:

The research conversion costs and identified ways to reduce them using quality control tools and digitization processes. Table 3 summarizes the 18 cost factors in the frame plant, three in machining, and two in assembly, scaled to maintain confidentiality. The frame plant accounts for over 57% of the total conversion cost, followed by machining (37%) and assembly (5.5%). The company uses real-time data capture with quality control tools and digitalization technologies to optimize the process.

#### Analyze:

#### Research shows that digitalization and real-time data collection have improved industrial operations. The team at XYZ Ltd. has integrated cutting-edge HMI technology into their system for real-time cost factor data. Data is stored in the cloud and observed through various methods, with automated processes fixing any aberrations. The team has also reduced conversion costs through quality control and digitalization tools, with the frame plant accounting for the majority of the conversion cost.

#### Improve:

#### XYZ Ltd used Pareto Analysis to prioritize cost factors and reduce manufacturing conversion costs. Welding and painting processes accounted for over 52% of the overall cost, followed by the machine shop. To cut production costs and eliminate waste, the company focused on the main contributors, identified tool costs and gas usage as significant cost considerations, and examined the possibility of a real-time data recording system. The company also investigated the causes of high gas consumption and determined a lack of real-time data monitoring and substitute low-cost gasses were contributing factors. XYZ Ltd is committed to reducing manufacturing conversion costs through various methods and achieving sustainable production.

#### Control:

### Through the use of Pareto charts and cause-and-effect diagrams, XYZ Ltd identified and addressed the main causes of high manufacturing conversion costs. They implemented natural gas and low-temperature chemicals, optimized processes, and improved worker training. These efforts resulted in significant cost savings, reduced contamination, and decreased waste. Notably, their pricing strategy saved them USD 2.2 million annually, and they saw advancements in their machine shop and frame assembly.

### **Conclusion:**

A recent study developed a framework to analyze manufacturing conversion costs in the automotive industry. The report found that the frame plant accounted for over half of the conversion expenses. The study highlighted various advancements and improvement activities that have effectively reduced costs, resulting in annual savings of 2.2 million USD and making the company more competitive. The study suggests that future research should prioritize cost reduction and sustainability. Overall, the study provides valuable insights for the automotive industry and instructors interested in manufacturing operations and continuous improvement programs.

# Learnings:

### **Key Takeaways:**

The four case studies used the DMAIC method to optimize their manufacturing processes. The Lean Six Sigma technique was used in all the studies to eliminate waste, improve quality, and increase efficiency. They emphasized the need of using data to detect and fix problems in industrial processes.

### **Bottlenecks and problems:**

Case Study 1 revealed insufficient personnel, delayed component delivery, and faults in the bogie frame as bottlenecks in the bogie assembly process. Case study 2 noted printing process difficulties such as ink smearing, unnecessary downtime, and high scrap rates. Bottlenecks in the automotive axle manufacturing process were discovered in Case Study 3, such as material flow difficulties, high cycle durations, and product faults. Case study 4 met difficulties due to high production conversion costs and data accuracy concerns.

### **Synergy:**

To accomplish process improvement, all four case studies used the DMAIC technique and Lean Six Sigma methodologies. The studies showed that combining a data-driven strategy with cross-functional collaboration can result in considerable gains in process efficiency and quality.

### **Human Aspects:**

The importance of human elements in process development was underlined in all four case studies, including communication, teamwork, and training. They emphasized the necessity of incorporating employees in the process of improvement, developing a culture of continuous improvement, and offering training to improve skills and knowledge.

### **Commonalities and differences:**

The DMAIC approach and Lean Six Sigma methodology were shared by all four case studies, however the specific tools and techniques employed differed depending on the industry and process being improved. The research' objectives ranged from decreasing waste to enhancing quality and lowering conversion costs. The case studies demonstrated that the DMAIC approach and Lean Six Sigma methodology may be used to enhance operations in a variety of sectors and processes.

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# Appendix

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Table 1: The value added and the non-value-added time of the assembly operations.

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Figure 2: The average time using for each process.

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Figure 3: Activities of value added and non-value.

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Figure 4: The formula of Production configuration

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Figure. 5. Median of 3 months for axle rejection and the rear axle selected for LSS implementation.

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Figure 6: Current state map for the rear axle.

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Figure 7. Shop floor before and after new layout with 5S.

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Table 2: A project charter for rear axle process improvement

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Figure. 8. SIPOC diagram for the rear axle.

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Figure. 9. Pareto Chart for the rear axle.

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Figure 10. Capability Analysis, X Bar- R Chart for the rear axle.

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*Figure 11: Fishbone diagram for axle bearing diameter undersize.*

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Figure 12: CNC grinding machine before and after the in-process gauge system.

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Figure 13: Storage and transportation of axles before LSS implementation.

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Figure 14: Storage and transportation of axles after LSS implementation.

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Figure 15. Capability Analysis, X Bar- R Chart for axle after LSS.

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Figure 16: The Future State Map for rear axle after LSS.

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Figure 17: Welding process and its consumables

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Figure 18: Realtime data recording system.

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Figure 19: Pareto analysis for manufacturing conversion cost.

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