CHAPTER 124

Six Sigma in Linear Project Delivery

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ABSTRACT

This study seeks to understand the implementation of Six Sigma in linear projects delivery such as roads and railways. It explores the potential of Six Sigma methodology applied to Garage repairing operations. The garage project selected for the study undertakes massive vehicle repairing activities, which are essentially linear activities. Thus, we undertaken a case study of Garage repairing operations for process improvement using six sigma. The current operations of the garage facility before application of six sigma were evaluated. We measured operations such as service delays, diagnostic errors, inventory shortages, customer complaints. The garage processes were found to be operating at 3 sigma levels. We suggested process improvements to attain 6 sigma levels. We collected vehicle repair data for process improvement. The activities were ranked in the descending order of six sigma potential (1. Inventory shortages, 2. Diagnostic errors, 3. Unorganized workplace, 4. Undefined repair protocol and scrutiny). By adapting data driven approach the research identifies key inefficiency through root cause analysis, process capability indices and pare to analysis. The garage is currently operating at Sigma Level 3 which leads to various delays and errors. To overcome those challenges a structured Six Sigma framework is proposed focusing on workflow optimization, inventory management, and standardized operations. Adapting these strategies can reduce defects and enhance reliability. This study shows the importance of adapting Six Sigma into linear projects for the continuous improvement by data driven approach.

Keywords: Six sigma; Process improvement; Inventory shortage; Vehicle repairing activities; Workflow optimization; Standardized process.

1.0 Introduction

1.1 Linear p0rojects

Linear projects are defined by their extensive scope and involve constructing, expanding, or maintaining infrastructure that stretches over long distances such as roadways, railways and pipelines.

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However, linear projects present unique challenges for quality and performance management due to their size, complexity and the dynamic nature of the environments in which they operate. The recent studies show how quality and process optimization can be increased by applying six sigma methodology in construction projects as construction projects are considered as linear projects due to the repetitive nature of the activity and sequential workflow. Past studies focus on improving the quality and process optimization. In this paper the study area author chooses Garage Operation for the quality improvement and process optimization to achieve Six sigma in the operation of the Garage. 1. In Garage operation Sequential flow of activities takes place such as vehicle check-in, Diagnostics, Repair, Quality check and Delivery, each step cannot begin until the previous one is completed. 2. Each vehicle has a clear entry point and exit point; in that much time only a vehicle needs to be delivered to the customer. 3. For different vehicles operations are repeated which follows the same linear path making it repetitive linear project. 4. The output of one process becomes input for the next process, like diagnostics reports are essential for deciding whether parts need to be replaced or not. 5. Resource management is one of the important tasks in garage operation as it impacts vehicle delivery and also reduces the service time. This makes garage operation act as linear project which can be improved by applying six sigma in the operation to improve its quality and process optimization.

1.1.1 Key challenges in linear projects include

Linear projects often encompass a variety of geographic landscapes & each location presents a variety of challenges. Managing resources along a linear project corridor becomes difficult. Coordinating the on-time delivery of resources to different locations requires careful logistical planning and supply chain coordination. Acquiring land rights and permits required for linear projects can be a long and complex process that requires negotiations with different entities. Linear projects are exposed to weather-related interruption. Linear projects often involve multiple stakeholders & maintaining consistent quality standards throughout a large linear project presents serious challenges. Robust quality management processes and inspection procedures are required to ensure that construction activities meet design specifications.

1.1.2 Need for effective methodologies

This project focuses on applying Six Sigma principles to garage operations to identify inefficiencies and optimise processes. By analysing repetitive activities within garage operations and measuring their impact on overall productivity, this study aims to introduce Six Sigma improvements that enhance operational efficiency. The study also aims to demonstrate how Six Sigma can be leveraged to standardise operations, streamline workflows, and achieve higher service quality. By implementing Six Sigma improvements, this project seeks to provide practical solutions that enhance garage operations and contribute to long-term efficiency and sustainability in the automotive service industry.

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1.2 Six Sigma

Six Sigma is a data-driven methodology aimed at improving business processes by identifying and eliminating defects, reducing process variability, and enhancing overall efficiency. Developed by Motorola in the 1980s, Six Sigma has since been widely adopted across various industries, including manufacturing, healthcare, IT, finance, and service. The term "Six Sigma" refers to a statistical measure of process capability, where a process operating at a Six Sigma level produces only 3.4 defects per million opportunities (DPMO). This signifies near-perfection in business operations and results in higher customer satisfaction, reduced waste, and improved profitability. Overall, Six Sigma provides a systematic approach to process improvement and variation reduction, which is well suited to linear projects.

1.3 Objectives

- Review garage repair operations and inefficiencies.
- Measure the sigma level and process metrics.
- Identify and categorise defects in the process.
- Propose Six Sigma changes to reduce defects and increase efficiency.

1.4 Scope

This study covers a garage that does routine and complex vehicle repairs. Scope includes: Six Sigma can lead to measurable improvements in service, accuracy and inventory. Businesses will have shorter service times, fewer errors and more inventory available. These improvements will increase customer satisfaction and profitability. Review workflows, inventory management and service protocols. Identify the root causes of defects and inefficiencies. Use Six Sigma tools like DMAIC (Define, Measure, Analyse, Improve, Control), Pareto Analysis and Root Cause Analysis.

1.5 Need for the study

High Defect Rate in Linear Projects, Process Standardization and Efficiency Enhancement, Cost Optimization through Waste Reduction, Improving Quality, Data Driven Decision Making, Achieving Higher Sigma Levels and Reducing Defects.

2. 0 Methodology

2.1 Methods of six sigma

- DMAIC (Define, Measure, Analyse, Improve, Control) (Mast Jeroen de, 2012)
- Define: - Clearly define the problem, project scope, and objectives.
- Measure: - Gather data to understand the current process performance.
- Analyse: - Find the root causes of defects, delays, or inefficiencies.
- Improve: - Develop and implement solutions to eliminate inefficiencies.
- Control: - Maintain the improved process and prevent regression.

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2.2 Data collection process

- *Direct Observation:* Observing the time taken for each repair activity and identifying any unnecessary delays. Checking for recurring service delays due to staff inefficiency, lack of resources, or unavailability of spare parts.
- *Workforce Interviews:* Interviewing mechanics, supervisors, inventory managers and service advisors. (Garages employee).
- *Customer Feedback Logs:* Overall experience with the service provided. Waiting time before and during the service process.
- *Time Motion Studies:* Segmenting repair tasks into categories such as diagnostics, disassembly, repair, reassembly, and final inspection.
- *Defect Tracking Logs:* Every defect was categorized based on its nature to prioritize urgent repairs. Root cause analysis was conducted for major defects to determine whether they were due to manufacturing issues, improper servicing, or customer mishandling.
- *Benchmarking:* Measuring key performance indicators (KPIs) such as service completion time, defect rates, and customer satisfaction scores.

2.3 Segregation of non-conformities

- *Service delays:* Inefficient workflow due to lack of automation in tracking and scheduling. Absence of well-defined repair protocols leading to inconsistencies. Unorganized workspace causes delays in locating tools and parts.
- *Diagnostic delays:* Lack of structured diagnostic checklists resulting in misdiagnosis. Inconsistent skill levels among mechanics causing repair inefficiencies. Limited training on modern vehicle technologies affecting service accuracy.
- *Inventory shortages:* Inadequate forecasting of spare part requirements leading to frequent stock-outs. Reactive ordering instead of proactive inventory planning. Supplier delays cause extended vehicle servicing time.
- *Customer complaints:* Extended waiting times due to inefficiencies in scheduling and execution. Frequent callbacks due to incomplete or faulty repairs. Unavailability of critical spare parts leading to service delays.

2.4 Quantitative data collection

Table 1: Quantitative Data

Problem Area	Root Cause	No. of Unconformities	Total units Inspected	Delay due to Unconformities (Hrs.)
Service Delays	inefficient workflow	2	350	5
	lack of defined protocols	2	350	3
	unorganized workplace	2	350	1

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Diagnostic Errors	Inconsistent Skills	2	350	3
	Lack of Checklist	2	350	2
	Limited Training	3	350	1
Inventory Shortages	Long Wait Times	3	350	2
	Reactive Ordering	2	350	5
	Supplier Delays	4	350	15
Customer Complaints	Long Wait Times	3	350	6
	Frequent Callbacks	1	350	2
	Parts Unavailability	3	350	8
Total		29		55

2.5 Problem areas and the observation

- *Service delays:* Total 6 unconformities occurred out of 350 units which were inspected, which leads to delay in the operation of garage.
- *Diagnostic delays:* Total 7 unconformities occurred out of 350 units which were inspected, which leads to delay in operation of garage.
- *Inventory shortage:* Total 9 unconformities occurred out of 350 units which were inspected, which leads to delay in operation of garage.
- *Customer complaints:* Total 7 unconformities occurred out of 350 units which were inspected, which leads to delay in operation of garage.

By taking all the observation from different activities and by segregating it into 4 different problem areas a total of 29 unconformities occurred out of 350 total units inspected. Further based on data we collected sigma level is being calculated.

2.6 Sigma level calculations

Defects Per Million Opportunities:

$$\text{DPMO} = \frac{Total\ no.of\ Defects}{Total\ no.of\ Units\ Inspected} \times 1000000$$

$$= \frac{29}{350} \times 1000000$$

= 82,857 defects.

By comparing the DPMO value with the standard Six Sigma conversion table, we see that this corresponds to a Sigma Level of approximately 3.

Table 2: Standard Six Sigma Conversion Table

DPMO	Sigma Level
6,90,000.00	1
3,08,537.00	2
66,807.00	3
6,210.00	4
233.00	5
3.40	6

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Mean (μ) $=\frac{Total\ Defects}{Total\ Inspected}$

$=\frac{29}{350}$

=0.082

Mean (μ) is equal to 0.082.

Standard Deviation (σ) = $\sqrt{\mu}$

$=\sqrt{0.082}$

=0.286

Standard Deviation (σ) is equal to 0.286.

Process Capabilities Index (Cp): process's ability to operate within specification limits.

(Cp)= $\frac{USL - LSL}{6\sigma}$

$=\frac{1-0}{6\times 0.286}$

= 0.582

Process Capabilities Index (Cp) is equal to 0.582.

Process Capabilities performance index (Cpk): Process Capability Performance Index (Cpk) determines if the process is cantered within the acceptable limits.

Cpk = $Min(\frac{USL - \mu}{3\sigma}\ or\ \frac{\mu - LSL}{3\sigma})$

$= Min(\frac{1 - 0.082}{3 \times 0.286}\ or\ \frac{0.082 - 0}{3 \times 0.286})$

= Min (1.06, 0.095)

Cpk = 0.095

Process capability performance index (Cpk) is 0.095.

3.0 Statistical analysis

3.1 Pareto analysis

Pareto Analysis is based on the 80/20 rule, which suggests that 80% of problems arise from 20% of causes. By identifying and addressing these high-impact defects first, efficiency can be significantly improved. A Pareto Chart was created using defect data collected over a month. The findings were: Inventory shortages accounted for 42% of total service delays. Customer complaints (long wait times) contributed 30%. Service delays due to workflow inefficiencies contributed 17%. Diagnostic errors led to 11% of rework cases. By focusing on inventory shortages and customer complaints first, the garage could eliminate 72% of overall inefficiencies in a targeted manner. A frequent complaint involved delayed vehicle service due to unavailable spare parts.

3.2 Root Cause Analysis (RCA)

Root Cause Analysis (RCA) is a problem-solving method used to determine the underlying causes of defects or inefficiencies, rather than just addressing symptoms. An

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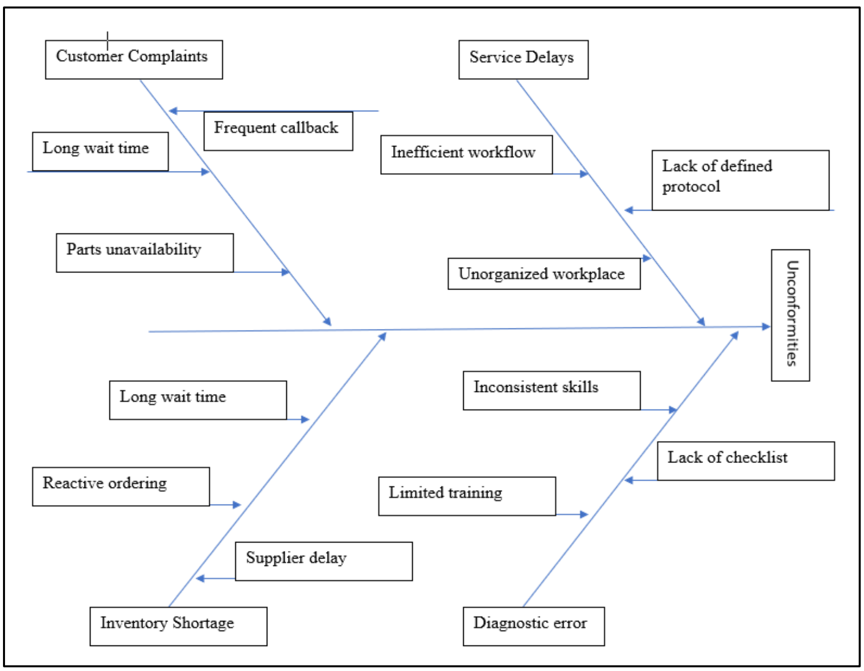
Ishikawa (Fishbone) Diagram was used to visually map the root causes of delays and inefficiencies. The major contributing factors identified were: Service delays were due to unorganized workspaces, Inventory shortages stemmed from poor supplier relationships, Diagnostic errors were linked to inconsistent training, long wait times were caused by inefficient scheduling and lack of real-time job tracking. A root cause analysis on frequent part shortages found that delays stemmed from reactive ordering rather than proactive inventory management. By shifting to predictive demand forecasting, inventory stock-outs decreased by 50%, ensuring continuous service operations.

4.0 Findings and Discussions

4.1 Findings

- *Process Performance and Defect Rate:* A total of 350 vehicle inspections were conducted, out of which 29 defects were recorded. The Defects Per Million Opportunities (DPMO) were calculated as 82,857, corresponding to a Sigma Level of approximately 3. A 3 Sigma process implies that defects occur in approximately 6.7% of all operations, which is higher than the industry standard of 4 Sigma or above. The current defect rate is too high, leading to inefficiencies in service execution. To achieve a higher sigma level, defects must be reduced by at least 50%, ensuring a more stable and capable process.

Figure 1: Fishbone Diagram



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- *Process Capability (Cp and Cpk) Findings:* The Process Capability Index (Cp) was calculated as 0.579, indicating high process variability. The Process Capability Performance Index (Cpk) was 0.096, showing that the process is not cantered within acceptable limits. Cp < 1 means that the process does not meet specifications consistently and is highly variable. Cpk < 1 suggests that the process is off-center, leading to frequent defects. Without reducing variation and improving process alignment, defects will continue to persist at an unacceptably high rate.
- *Common Defect Types and Root Causes:* From the Pareto Analysis, the major defect categories contributing to inefficiencies were identified: Inventory shortages are the leading cause of service inefficiencies, causing over 40% of delays. Diagnostic errors contribute to 24% of issues, indicating inconsistent troubleshooting practices. Customer complaints are closely linked to delays, highlighting the need for improved scheduling and process coordination

Table 3: Pareto Analysis Observation

Defect types	Occurrence (%)	Impacts
Inventory Shortages	40%	Delayed service times, increased downtime
Customer Complaints	24%	Reduced customer satisfaction, repeat service requests
Diagnostic Errors	24%	Misdiagnosed issues, unnecessary part replacements
Service Workflow Delays	12%	Extended turnaround times, bottlenecks in service execution

- *Root Cause Analysis (RCA) Insights:* A Fishbone (Ishikawa) Diagram was used to map out the primary root causes of inefficiencies. The following key factors were identified:

Table 4: Root Cause Analysis (RCA)

Category	Root Causes
Manpower	Lack of structured training, inconsistent skill levels
Materials	Frequent stockouts, delayed supplier deliveries
Methods	No standard operating procedures (SOPs), inconsistent service execution
Machines	Unmaintained tools, inefficient workspace layout
Measurement	Inconsistent quality checks, lack of performance tracking

Process inconsistencies are largely due to inadequate training and missing SOPs. Inventory mismanagement is a significant issue, leading to delays and incomplete repairs. Poor quality control and lack of standardized inspection methods contribute to recurring defects.

4.2 Discussions and suggestions

- *Service Delays*
  - *Improve workflow efficiency:* Implement standardized work procedures; Eliminate waste and unnecessary steps; Assign tasks based on worker expertise

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- *Define protocols for standardization:* Create standard operating procedures for each service; Conduct regular training sessions for workers; Use process flow diagrams and visual aids
- Organize the Workplace (5S Methodology): (Mazur Magdalena, 2024)

Sort: Remove unnecessary tools and items from the workspace, 2. Set in Order: Arrange tools and materials in a logical order for easy access, 3. Shine: Keep workstations clean to ensure smooth operations, 4. Standardize: Implement best practices for maintaining workplace efficiency, 5. Sustain: Conduct audits and provide regular training to reinforce these principles.

- *Diagnostic delays*
  - *Enhance worker skills:* Conduct technical training programs; Implement mentorship programs for new employees.
  - *Implement checklists for diagnosis:* Develop step-by-step diagnostic checklists; Introduce digital checklists for automated issue identification; Ensure technicians cross-check diagnoses.
  - *Provide continuous training:* Offer monthly training sessions on new diagnostic tools; Introduce certification programs for technicians to meet industry standards.
- *Inventory shortage*
  - *Reduce waiting time for parts:* Maintain buffer stock for frequently used parts; Implement automated inventory management system; Set minimum reorder points to avoid shortages.
  - Implement Just-in-Time (JIT) Ordering or Two Bin system:
  - *Just-in-time system:* Use demand forecasting techniques to predict parts requirements based on historical data. Coordinate with suppliers to ensure faster turnaround times for critical parts. Develop a vendor performance tracking system to monitor reliability. (Fullerton, 2001)
  - *Two Bin system:* It is an inventory system where stock is divided into two bins where, first bin is used for daily operations and the second bin is act as backup for the first bin which triggers replenishment when the first bin is empty. This will maintain the stock and ensure the continuous supply, reduce stockout and simplifies inventory management. (Tang Yuanjie, 2014)
  - *Improve supplier coordination:* Establish long-term contracts with suppliers; Develop a multi-supplier network; Use logistic tracking tools for real-time monitoring.
- *Customer complaints*
  - *Reduce wait times:* Implement real-time scheduling and queue management; Update customers on service progress via digital tools (e.g., text messages); Offer priority servicing for regular or urgent repairs.
  - *Minimize call-backs:* Train technicians to diagnose and resolve potential secondary issues; Improve first-time fix rate through inspection; Use quality control checklists before vehicle handover.

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- *Ensure parts availability:* Analyse customer demand trends; Implement automated inventory tracking to prevent stockouts.

5.0 Conclusion

The application of six sigma in garage operation is being studied which identifies key inefficiency including service delay, diagnostic delays, inventory shortage, customer complaints. Before applying six sigma methodology garages in operating at sigma level 3 which shows that improvement was needed to improve operation efficiency and reduce defects.

- Average number of defects per unit inspected is 0.082
- Degree of variation in the defect occurrence is calculated 0.286
- Process capabilities index is calculated 0.582
- Process capabilities Performance index is calculated 0.095

To address these issues the following are the recommendations. The use of 5S and Just-In-Time (JIT) alongside Six Sigma contributes to a comprehensive quality improvement system. 5S establishes workplace organization and discipline, reducing clutter and ensuring efficient workflows. Workflow management by implementing 5S principles at workplace and by adopting standardized procedures. Providing regular training to mechanics and developing structured checklist for accurate diagnostic. JIT eliminates waste by ensuring parts and processes occur precisely when needed, minimizing delays. Implementing Two-Bin system or Just-In-Time system to avoid inventory shortage and by strengthening supplier relationship. By adopting real time scheduling, reducing waiting time which will enhance customer experience. Both tools support Six Sigma’s focus on reducing variation and improving process consistency. This study shows the importance of data driven decision making to create smoother and more reliable operation.

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