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Optimization of Production Processes to Minimize Waste and Improve Efficiency in Automobile Servicing Plants Using Lean Six Sigma

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Abstract

This study focuses on optimizing production processes within an automobile servicing plant to minimize waste and enhance efficiency through the application of Lean Six Sigma (LSS) methodologies. Utilizing a case study approach, the research addresses real-time challenges related to productivity and waste reduction. Data collection involves assessing machine functionality metrics, material, and labor flow at various stages of the servicing process. The optimization strategy integrates lean tools including value stream mapping, process cycle efficiency analysis, Kaizen practices, 5S methodology, and Pareto charting. Findings indicate opportunities for improvement, including suboptimal process cycle efficiency, inadequate takt time, prolonged lead times, and excessive downtime. Following the implementation of LSS methodologies, significant enhancements are observed across all evaluated parameters. The study underscores the practical application of LSS principles in optimizing production processes within the automobile servicing industry, contributing valuable insights for enhancing operational efficiency and waste reduction. Further validation through lean-based software tools is recommended to reinforce the study's findings.

Keywords: Lean manufacturing, lead time, process cycle efficiency, takt time, value-added time

INTRODUCTION

Industrial organizations have increasingly turned to lean manufacturing principles in pursuit of operational excellence and customer satisfaction [1]. Rooted in the systematic elimination of waste while enhancing production performance, lean has emerged as a cornerstone methodology embraced across the manufacturing and supply chain domains [2]. Traditionally associated with manufacturing, lean methodologies are now finding applications in diverse industrial sectors, reflecting their adaptability and effectiveness.

In an era marked by escalating customer expectations and intensifying market competition, the imperative for companies to uphold the quality and reliability of their operations has never been more pronounced [3]. To meet these demands, organizations are compelled to continually refine their manufacturing systems by employing a repertoire of methods, approaches, and tools for continuous productivity and quality enhancement [4]. However, the selection and integration of these methodologies into organizational workflows necessitate a judicious assessment to ensure optimal outcomes [5].

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At the heart of lean manufacturing is the continuous drive for process enhancement, which closely mirrors the principles of total quality management [10]. While alternative methodologies such as re-engineering or automation also promise performance improvements, lean stands out for its holistic approach to operational optimization, emphasizing waste reduction and enhanced operational effectiveness.

Beyond the tangible metrics of quality and productivity, the implementation of lean manufacturing fosters intangible yet invaluable organizational changes, fostering a culture of continuous learning and leadership development. This strategic shift towards continuous improvement reflects a broader industry trend in which companies prioritize the enhancement of product/service quality as a means of retaining customers and securing market share.

The impact of lean manufacturing became particularly evident during periods of economic upheaval, as demonstrated by the 2008 global recession. Amidst plummeting consumer demand and industrial production, companies face unprecedented challenges, grappling with excessive inventories and dwindling sales [6]. The resilience of organizations adept at lean methodologies became apparent as they navigated through the crisis with agility, mitigating the adverse effects of the economic downturn.

Against this backdrop, this study explores the multifaceted dimensions of lean manufacturing within the context of industrial operations and examines its role in waste reduction, operational enhancement, and organizational resilience. Through a comprehensive review and analysis, we endeavored to illuminate the transformative potential of lean methodologies in driving sustained improvements in industrial performance and customer satisfaction [7].

METHODOLOGY

By employing a case study methodology, this research facilitates an in-depth investigation of the intricate functions of the automotive service station's value chain). Moreover, this methodology enables direct observations and data collection in a natural setting, ensuring the reliability and validity of the derived data) [8, 9].

This study addresses the real-time challenge of customer dissatisfaction with data collection focusing on machine functionality metrics (such as uptime, downtime, and cycle time) and material/labor flow at each process stage of the production line. The evaluation and improvement of the production process are driven by a range of lean tools, such as value stream mapping (VSM), process cycle efficiency (PCE), Kanban, Poka-Yoke, 5S, Pareto charts, and analysis. These tools serve as invaluable aids in diagnosing and resolving organizational problems) [10].

To visualize the process value chain, the Qi Macros application embedded in Microsoft Excel was used to design the VSM. This tool provides a comprehensive overview of the lean tools employed, facilitating a structured approach to process optimization within the automotive service station context. Through the systematic application of Lean Six Sigma (LSS) methodologies, this study aims to uncover insights into enhancing operational efficiency and customer satisfaction while minimizing waste in automobile service operations [11, 12].

Value Stream Mapping

It is a lean manufacturing tool designed to analyze and optimize the flow of materials and information necessary for delivering products to customers. Additionally, it helps significantly reduce waste during production.

Process Cycle Efficiency

It is defined as the ratio of the value-added time to the total process time, as shown in Equation (1).

Process cycle efficiency (PCE)

$$PCE = (VDT/TT) \times 100\%$$

Where,
PCE represents the process cycle efficiency (in hours).
VDT is value-added time (hr.)
TT is the total lead time = VDT + NVDT

Takt Time

This is defined as the time required to produce a sellable quantity of a product, aligning production with customer demand. This is represented by Equation (2).

$$T=Ta/Td$$

Where,
T is the takt time (the work time between two or more consecutive time intervals) (s)
Ta is the net time available for work
Td is the time demand (customer demand)

Note: Net available time refers to the amount of time allotted for work, excluding breaks and scheduled downtimes, such as maintenance, staff briefings, and training sessions.

Kaizen

This is a continuous improvement approach pioneered by early Japanese companies that incorporates tools such as Kanban (often referred to as just-in-time or JIT) and Poka-Yoke.

5S

The 5S philosophy, developed by Japanese companies, focuses on workplace standardization through five key principles, all starting with the letter "S." These principles aim to improve workplace efficiency by identifying, organizing, and maintaining work areas while ensuring sustained order [13]. The meanings of 5S are as follows:

1. *Sorting:* Identify and remove all unnecessary tools, parts, and instructions.
2. *Setting in order:* Arrange tools and machine parts so that the required items are easily visible and accessible.
3. *Sweeping:* Keep the workplace clean and free of hazardous materials or conditions that could lead to accidents.
4. *Standardizing:* Establish standard procedures for all tasks.
5. *Sustaining:* Develop methods to maintain and regularly review the standards.

Pareto Chart and Analysis

The Pareto Chart and Analysis are statistical methods used to identify the key actions or processes that contribute to most of the results. The analyzed data are presented in a bar chart, arranged in ascending or descending order, typically created using Excel software.

BACKGROUND OF CASE STUDY

This case study was conducted within an automobile service plant, a privately owned Limited Liability Company in Kerala. The organization encompasses five functional departments: Central Accounts, Production, Marketing, Logistics, and Procurement, with a total workforce of seventy (70) employees. Notably, the Production Department accounts for approximately 50% of the entire labor force, highlighting its pivotal role within the organization. It operates daily, receiving, processing, and delivering orders with an average volume of 67 cars per day. Figure 1 depicts the value chain of the production line, illustrating the interconnected subsystems within the organization, each contributing to the overall transformation process. The value chain serves as a systematic framework for analyzing the development of competitive advantage within the organization.

The stages comprising the value chain of the production line are outlined below.

1. *Concept visualization:* This initial stage involves conceptualizing vehicle repair and maintenance requirements, incorporating strategic and creative elements, and finalizing the concept design for approval.
2. *Diagnosis/analysis:* This stage entails diagnosing and analyzing the vehicle's issues to determine the necessary repair and maintenance tasks.
3. *Repair/service:* Here, the identified issues are addressed through repair and maintenance activities, including component replacement, adjustment, and service.
4. *Quality inspection:* Following repair and service, a thorough quality inspection is conducted to ensure the vehicle meets safety and performance standards.
5. *Testing:* The repaired vehicle undergoes thorough testing to confirm the success of the repair and ensure it operates at peak performance.
6. *Customer feedback:* Customer feedback is solicited and analyzed to gauge satisfaction levels and identify areas for improvement in service delivery.
7. *Follow-up maintenance:* Recommendations for follow-up maintenance and preventive measures are provided to the customer to enhance the longevity and performance of the vehicle.

Despite the significant role of the production department, the company exhibits limited compliance with lean manufacturing principles, presenting an opportunity for academia-industry collaboration. Through the implementation of lean methodologies, the company can streamline its operations, minimize waste, and enhance efficiency, ultimately delivering superior service quality and customer satisfaction in the competitive automotive service industry.

Business Case

To foster strong customer relationships, the management of an automobile service station aims to enhance the production process efficiency, reduce lead time, and optimize takt time. Moreover, they seek to minimize manufacturing waste, including downtime, non-conforming products, and labor inefficiencies. To achieve these goals, management has enlisted the expertise of LSS practitioners.

RESULTS

This section presents the results of the LSS assessment conducted both prior to and following the implementation of the LSS tools.

Present VSM of Automobile Service Station's Production Line

The current VSM of the automobile service station's production line reveals various activities across different operational stages. The data necessary for developing the existing VSM were extracted from Tables 1 and 2, including the number of operators (O), assistant operators (AO), and staff (S).

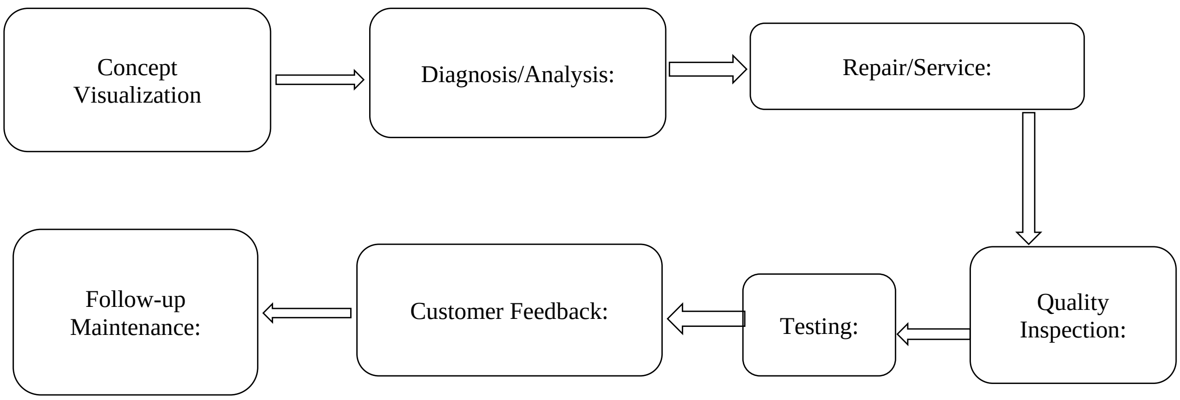

Figure 1. Value chain of AB production line.

Table 1. Present process cycle efficiency of the automobile service station.

S.N.	Processing stage	Average VDT (hour)	Average NVDT (hour)
1	Reception and inspection	1	2
2	Diagnostics	2	4
3	Service planning	24	48
4	Parts procreant	120	240
5	Repair and maintenance	48	120
6	Quality and control	12	24
7	Testing and verification	12	24
8	Cleaning	6	12
9	Customer feedback	2	6
10	Deployment	24	48
	Total	251 × 60 × 60 sec	528 × 60 × 60
		90360 sec	190080 sec

Table 2. Present takt time of production line.

S.N.	Description	Time(min)
1	Working shift/day	1 shift
2	Hours/shift	10 hours
3	Available time/shift	600 min
4	Setup time/shift	30 min
5	Lunchtime/shift	30 min
6	Planned shutdown time/shift	60 min
7	Networking time/shift	480 min
8	Net available time/shift	1728000 sec
9	Customer demand/day	67 cars/day
	Talk time	25791 sec/car
		7.76 hr./car

The estimation process involved introducing a timeline at the end of the map, recording both value-added and non-value-added times, with consideration given to the machine running operations. The current VSM of the production line of the automobile service station shows the flow of orders, raw materials, labor, information, value-added time, and non-value-added time.

It facilitates the calculation of the required processes, their respective cycle times, uptimes, customer orders, and batch sizes. Analyzing the current VSM allows for the identification of required labor at each stage, the amounts of value-added and non-value-added time, and potential improvements to boost PCE, reduce lead time, and optimize takt time.

Figure 2 depicts the current VSM of the automobile service station's production line, managed by three representatives. Customer orders initiate the production processes. Non-value-added time is notably present across various production units, quantified through uptime and downtime. The application of lean tools and Six Sigma methodologies is expected to decrease non-value-added time and streamline overall labor requirements.

Present PCE of Automobile Service Station

In the context of the automobile industry:

- Value-added time: 90360 seconds
- Non-value-added time: 190080 seconds
- Present lead time: value-added time + non-value-added time = 90360 + 190080 = 280440 s

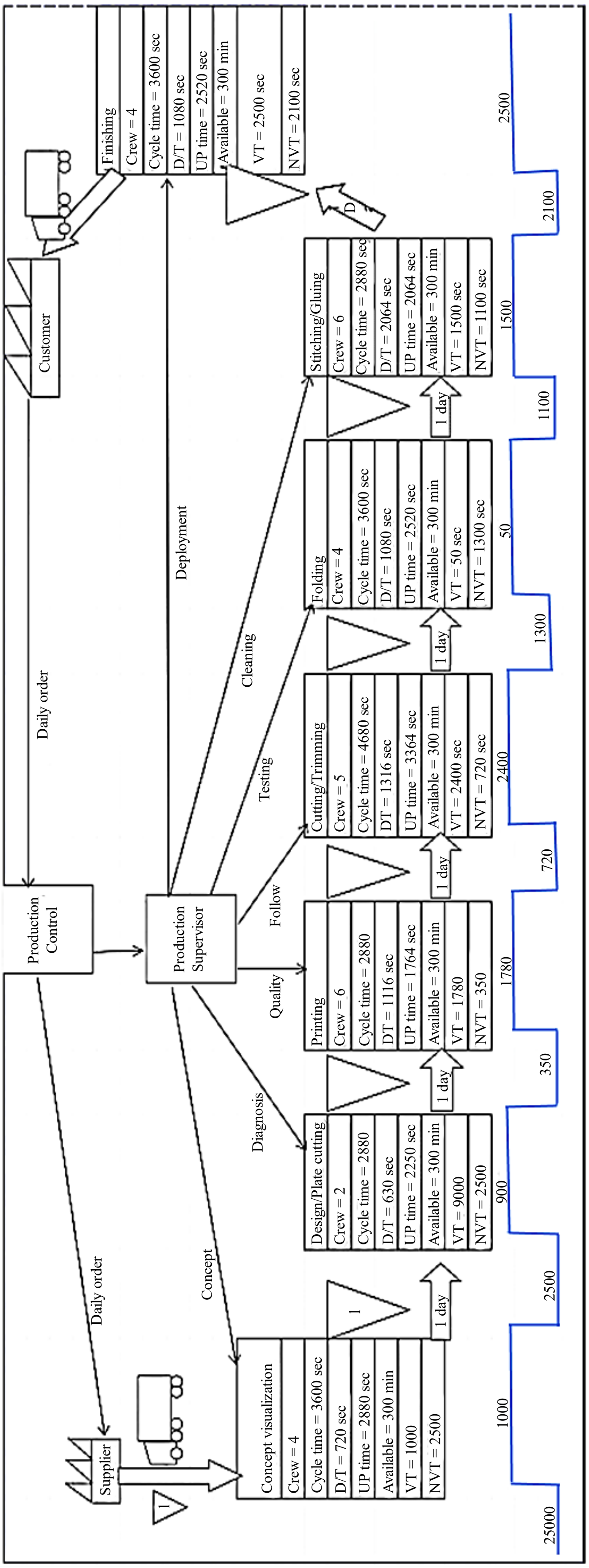

Figure 2. Present value stream mapping of AB production line.

Process cycle efficiency (PCE) is calculated as:

PCE= (VDT/TT) × 100 %

= (90360/280440) × 100 % = 32.22%

Present Takt Time of Production Line

The current takt time of the production line is calculated to be 25,791 s per car, which means that it takes 859 s to produce a sellable unit. This is shown in Table 2 and is expected to improve with the implementation of lean tools and Six Sigma.

Present Manufacturing Waste in the AB Production Line

Three key types of waste were identified in the AB production line: non-conforming products, wasted time (downtime), and unnecessary labor movement.

Estimation of Non-conforming Products

Estimating the number of non-conforming products in an automobile service center involves understanding various factors such as the volume of vehicles serviced, the types of services offered, and the effectiveness of quality control measures in place. Here is the simplified approach.

Estimation of Percentage Downtime in Production Line

To estimate the percentage of downtime in the production line of an automobile service station, a table can be created to track the downtime for each component or process involved in the production line. The structure of Table 3 is as follows:

- *Component/process:* List each component or process involved in the production line.
- *Total time (hours):* Enter the total time allocated for each component or process in hours. This can be based on the production schedule or expected duration.
- *Downtime (hours):* The actual downtime experienced for each component or process is recorded in hours. This information can be obtained from maintenance records, production logs, or real-time monitoring systems.

Percentage downtime = (downtime/total time) × 100
= (7000/13050) × 100
= 53%

From this, we can visualize the distribution of downtime across different components or processes in the AB production line and identify areas for improvement to reduce downtime and increase efficiency.

Table 3. Estimation of non-conforming products.

Process stage	Total arriving cars	Defects in parts	Improper repairs	Service delays	Failures to meet customer expectations
Reception and inspection	80	7	8	9	15
Diagnostics	75	5	6	8	12
Service planning	67				10
Parts procreant	65	5	5	5	10
Repair and maintenance	65	4	5	5	9
Quality and control	64	4	4	4	8
Testing and verification	62	2	3	4	8
Cleaning	62	2	3	6	7
Customer feedback	60	2	3	6	7

Pareto Analysis of Downtime in AB Production Line

Pareto Analysis is an effective tool for identifying and prioritizing the key factors that contribute most significantly to a problem. In the context of downtime in the AB production line of an automobile service plant, a Pareto Analysis can be performed to determine the components or processes that cause most of the downtime (Figure 3).

Estimation of Present Labor in Production Line

Estimating the present labor in the AB production line of an automobile service plant involves determining the number of workers required to operate the line efficiently.

Implementation of Lean Tools in AB Production Line

In the context of an automobile service plant, the present VSM reveals several areas for improvement within the AB production line.

The production supervisor highlighted delays and occasional shortages in raw materials, leading to increased non-value-added time. To address these challenges, the implementation of Kaizen methodologies, such as Kanban and Poka-Yoke, has been recommended to ensure a smoother flow of materials and minimize downtime.

Additionally, it has been observed that each stage of the production process suffers from non-value-added time owing to poor standardization and inadequate organization of tools and machine parts. To remedy this, the adoption of the 5S principles has been suggested. This involves the steps of Sort, Set in Order, Shine, Standardization, and Sustain. By systematically organizing workspaces, eliminating unnecessary tools and parts, and maintaining cleanliness, the aim is to reduce waste and optimize efficiency.

Furthermore, it has been noted that sorting and cleaning of the shop floors is not being adequately performed, potentially leading to safety hazards and further inefficiencies. Therefore, it is essential to enhance these practices to establish a safer and more organized work environment. In Figure 4, the VSM illustrates the current state of the AB production line along with the identified improvement points, emphasizing the importance of implementing Kaizen methodologies and 5S principles to streamline processes, minimize waste, and enhance overall productivity within the automobile service plan.

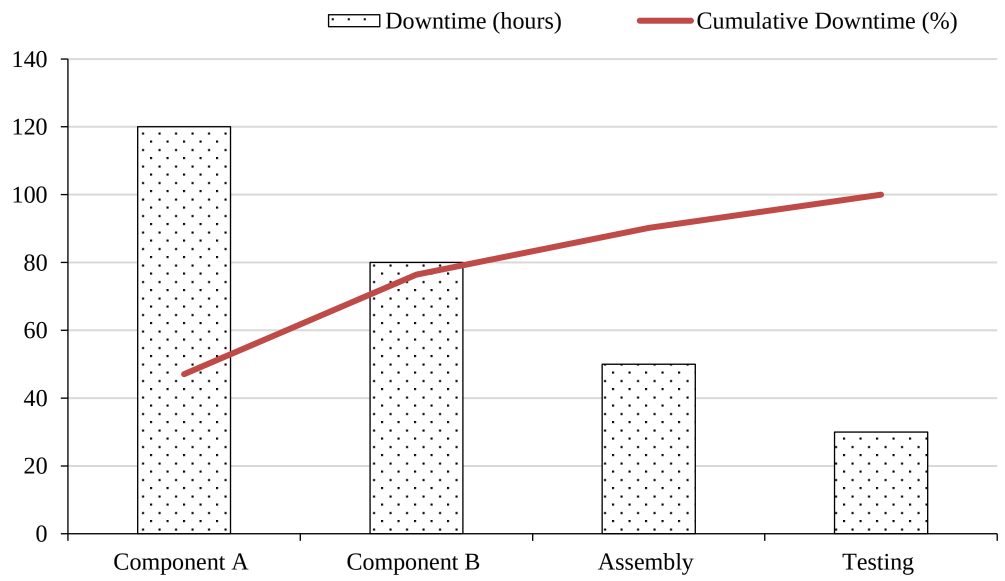

Figure 3. Pareto analysis.

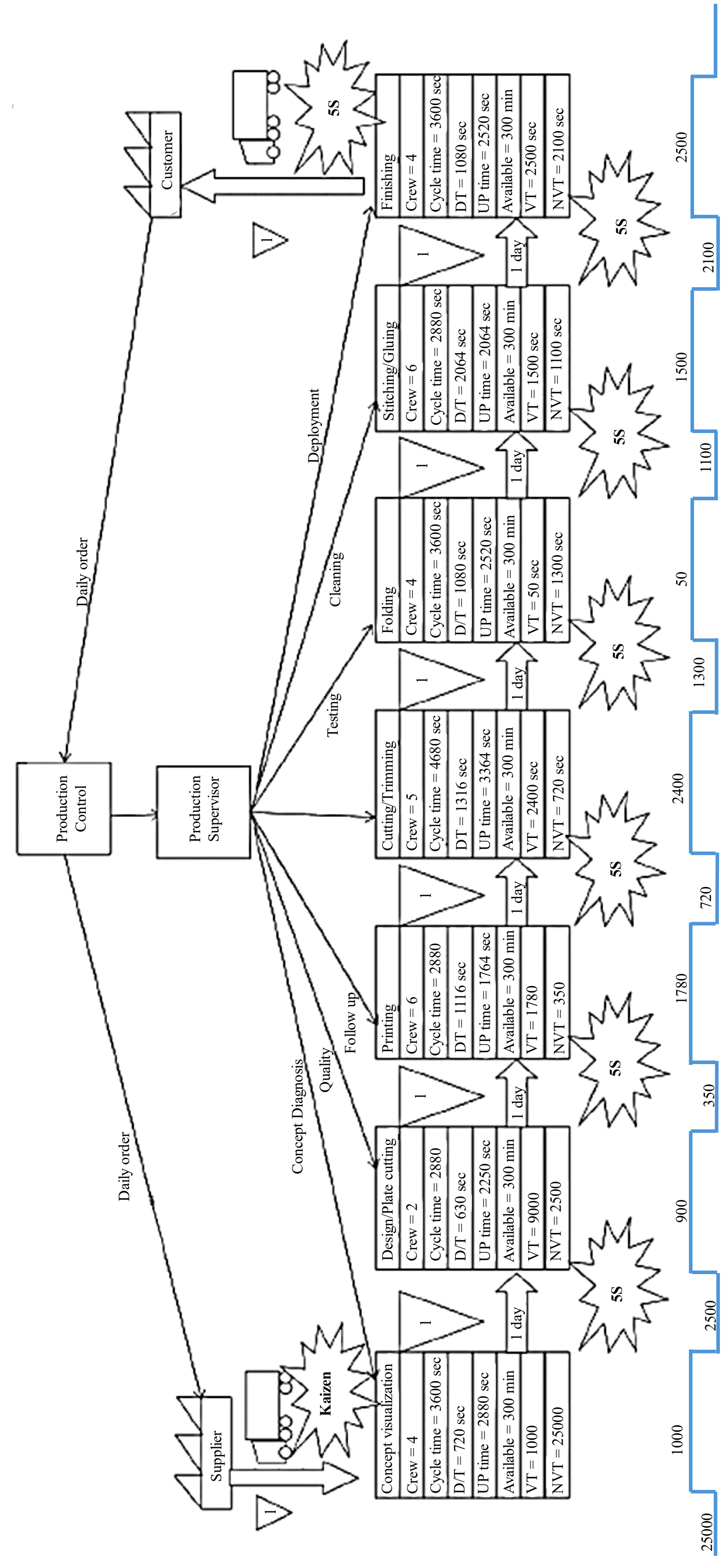

Figure 4. Present VSM of AB production line with improvement point.

Improved VSM of Production Line

In the improved VSM of the AB production line within an automobile service plant, several enhancements have been incorporated to address identified inefficiencies and optimize the workflow. The improvements made are described as follows.

- *Streamlined material flow:* Implementation of Kanban systems and Poka-Yoke techniques has facilitated a smoother flow of materials throughout the production line. Kanban helps to maintain optimal inventory levels by signaling when raw materials need replenishment, whereas POKA-YOKE mechanisms minimize errors and defects in the assembly process.
- *Standardized processes:* Each stage of the production process now adheres to standardized procedures, reducing variability, and enhancing predictability. Clear work instructions and visual cues ensured consistency and operational efficiency.
- *Optimized workspace organization:* Through the adoption of the 5S principles (Sort, Set in order, Shine, Standardized, and Sustained), workspaces have been meticulously organized to eliminate clutter, minimize waste, and improve accessibility to tools and machine parts. This guarantees a safer and more effective working environment.
- *Enhanced shop floor management:* Regular sorting and cleaning activities are now diligently conducted to maintain cleanliness and safety standards within the shop floor. Hazardous materials are correctly separated and disposed of, thereby minimizing the risk of accidents, and enhancing the overall workplace safety.
- *Continuous improvement culture:* A culture of continuous improvement has been fostered within the production team, encouraging proactive identification of inefficiencies and the implementation of innovative solutions. Ongoing reviews and feedback loops help ensure that the processes are continuously improved and optimized for peak efficiency. As shown in Table 4, non-value-added time decreased to approximately 72.54%. Figure 5 shows the updated VSM of the AB production line.

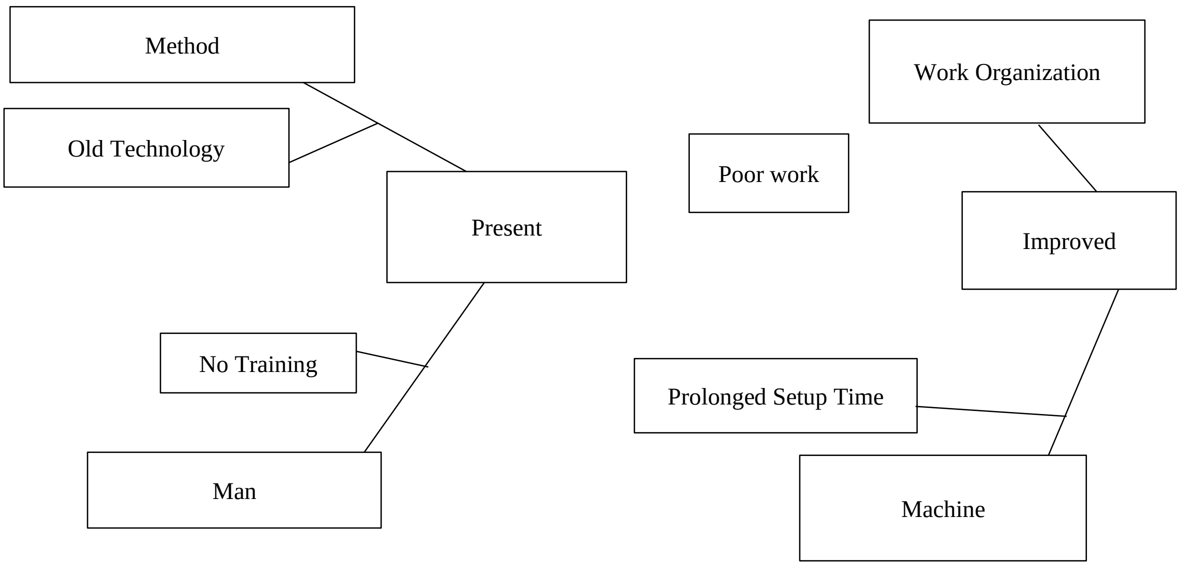

Figure 5. Fishbone diagram.

Table 4. Percentage Downtime.

Component/Process	Total time (sec)	Downtime (sec)	Percentage downtime (%)
Car A	630	350	55
Car B	340	210	61
Service planning	4500	3240	72
Testing	5600	3200	57
Total	13050	7000	53

Improved PCE of AB Production Line

After the proper implementation of lean tools and Six Sigma methodologies, the PCE of the AB production line is estimated to be approximately 72.54%. This improvement also led to a significant reduction in the average non-value-added downtime (NVDT), which decreased to 124,560 seconds.

Improved lead time = Value-added time + non-value-added time
= 124560+ 90360 sec
=2 14920 sec

Process cycle efficiency = (value-added time/lead time) × 100%
= (124560/214920) × 100
= 57.95%

Improved Takt Time of AB Production Line

Improving the takt time of the AB production line in an automobile service plant involves optimizing the pace of production to match customer demand more effectively. The steps to achieve this improvement are as follows.

1. Eliminate Non-Value-Added Activities
2. Optimize Setup and Changeover Times
3. Balance the Production Line
4. Reduce Downtime and Idle Time

Therefore, after reducing the setup time and lunchtime, the takt time is improved to 27940 sec/car from 25791 sec/car (Table 7).

Present Manufacturing Waste in the AB Production Line

Three main types of waste were identified in the AB production line: defective products, time wastage (downtime), and unnecessary labor movement.

Estimation of Non-conforming Products

In the context of an automobile service station, reducing the estimation of non-conforming products through the application of Six Sigma principles is paramount for ensuring high-quality service and customer satisfaction. By meticulously defining what constitutes a non-conforming product, such as defects in parts or errors in repairs, service stations can establish a baseline for current performance. Through rigorous measurement and analysis of data, the root causes of non-conformities can be identified, whether they stem from inconsistencies in repair processes, inadequate training of staff, or inefficiencies in supply chain management. Implementing targeted improvement measures, such as process standardization, employee training programs, and the integration of advanced technologies, enables service stations to eliminate defects and variations systematically. Continuous monitoring and control mechanisms are then put in place to sustain these improvements, fostering a culture of continuous improvement where efforts to enhance quality are embedded into every aspect of operations. By embracing Six Sigma methodologies, automobile service stations can significantly enhance their operational efficiency, minimize non-conforming products, and ultimately deliver exceptional services to their customers (Table 5).

Improved Estimation of Downtime in AB Production Line

By applying Six Sigma methodologies, the estimation of the downtime percentage in the AB production line at the automobile service station was significantly improved. By implementing Six Sigma’s rigorous problem-solving approach, critical factors contributing to downtime are meticulously analyzed, root causes are identified, and targeted solutions are implemented. Through statistical analysis and data-driven decision-making, inefficiencies within the production line were systematically addressed, leading to significant reductions in downtime. This reduction is not merely a short-term fix but rather a sustainable improvement achieved by fostering a culture of continuous improvement and empowering employees to actively participate in problem-solving initiatives.

Table 5. Present labor of AB production line.

S.N.	Production stage	No. of operator (O)	No. of assistant operator (AO)	No. of coworkers (CW)
1	Reception and inspection	4	4	3
2	Diagnostics	2	5	4
3	Service planning	3	2	1
4	Parts procreant	2	1	1
5	Repair and maintenance	4	5	3
6	Quality and control	1	3	1
7	Testing and verification	2	3	3
8	Cleaning	5	6	5
9	Customer feedback	2	3	2

Table 6. Percentage reduction in NVDT.

S.N.	Processing stage	Average VDT (hour)	Average NVDT (hour)	% reduction in NVDT
1	Reception and inspection	1	1	50
2	Diagnostics	2	2	50
3	Service planning	24	24	50
4	Parts procreant	120	180	75
5	Repair and maintenance	48	60	50
6	Quality and control	12	12	50
7	Testing and verification	12	18	75
8	Cleaning	6	9	75
9	Customer feedback	2	4	66.66667
10	Deployment	24	36	75
	Total	251 × 60 × 60 sec	346 × 60 × 60	72.54%
		90360 sec	124560	72.54%

Table 7. Work duration.

S.N.	Description	Time (min)
1	Working shift/day	1 shift
2	Hours/shift	10 hours
3	Available time/shift	600 min
4	Setup time/shift	10 min
5	Lunchtime/shift	10 min
6	Planned shutdown time/shift	60 min
7	Networking time/shift	520 min
8	Net available time/shift	57600 sec
9	Customer demand/day	67 cars/day
	Talk time	27940 sec/car
		7.16 hr./car

Table 8. Estimation of non-conforming products.

Process stage	Total cars	Defects in parts	Improper repairs	Service delays	Failures to meet customer expectations
Reception and inspection	80	2	3	4	3
Diagnostics	78	2	3	4	3
Service planning	69	2	3	4	3
Parts procreant	67	2	3	4	3
Repair and maintenance	67	2	3	4	3
Quality and control	67	2	3	4	3
Testing and verification	67	2	3	4	3
Cleaning	67	2	3	4	3
Customer feedback	67	2	2	2	2

As a result, automobile service stations experience enhanced operational efficiency, increased productivity, and improved customer satisfaction, ultimately reinforcing their position as leaders in the automotive service industry (Table 9).

Improved Estimation of Labor in AB Production Line

In the context of an automobile service station, implementing Six Sigma methodologies has led to a significant improvement in the estimation of labor requirements for the AB production line. By applying Six Sigma principles, such as reducing variation and minimizing defects, the accuracy and reliability of labor estimation processes have been greatly enhanced. Through rigorous data analysis and process optimization, potential sources of variability in labor requirements, such as production fluctuations and inefficiencies, have been identified and addressed systematically.

This has resulted in more precise forecasts of labor needs, leading to better resource allocation, improved workforce utilization, and ultimately, increased productivity within the production line. Furthermore, by continually monitoring and refining labor estimation processes as part of ongoing Six Sigma initiatives, the automobile service station can ensure sustained improvements in operational efficiency and effectiveness (Table 10).

Table 9. Average downtime.

Procedure	Cause of downtime	Downtime (hr.)	Average downtime	Remark
Reception and inspection	Implement digital forms	1	1	NA
Diagnostics	1. Standardize diagnostic procedures 2. Invest in advanced diagnostic equipment	1 1	2	
Service planning	Implement digital service management Standardized service procedures	12 12	24	
Parts procreant	Establish A reliable supplier relationship	60 60	120	
Repair and maintenance	Diagnostic tools and technology	48	48	
Quality and control	Automated inspection system Training	6 6	12	
Testing and verification	Standardized testing procedure	12	12	
cleaning	Time-saving cleaning equipment	6	6	
Customer feedback	Implement a real-time feedback system	2	2	
deployment	Utilize pre-deployment preparation	24	24	

Table 10. Details of workers.

S.N.	Production stage	No. of operator (O)	No. of assistant operator (AO)	No. of coworkers (CW)
1	Reception and inspection	3	4	3
2	Diagnostics	1	5	4
3	Service planning	2	2	1
4	Parts procreant	2	1	1
5	Repair and maintenance	3	5	3
6	Quality and control	1	3	1
7	Testing and verification	2	3	3
8	cleaning	3	6	5
9	Customer feedback	2	3	2

Gap Analysis Between Present and Improved States

In the context of applying Six Sigma principles in an automobile service plant, conducting a gap analysis between the present state and the improved state is crucial for identifying areas for improvement and measuring progress. This analysis helps pinpoint existing deficiencies or gaps in performance metrics and processes and highlights opportunities for enhancement. By comparing key performance indicators (KPIs), such as defect rates, cycle times, customer satisfaction scores, and process efficiencies, between the present and improved states, organizations can quantify the extent of improvement required to achieve Six Sigma levels of performance. Additionally, analyzing factors contributing to the identified gaps, such as process variability, waste, and errors, allows for targeted interventions and improvement initiatives. Through this systematic approach to gap analysis, automobile service plants can effectively prioritize improvement efforts, allocate resources efficiently, and drive continuous improvement toward achieving Six Sigma levels of quality and operational excellence.

Each cause can be further broken down to pinpoint the specific factors that contribute to performance gaps. By systematically analyzing and addressing these root causes, the automobile service plant can bridge the gap between the present and improved states, ultimately achieving higher levels of quality and operational excellence through the Six Sigma principles.

RESULTS DISCUSSION AND LESSONS LEARNT

This section discusses an in-depth analysis of the root causes of the issues, the improvement strategies implemented, and the lessons learnt.

Analysis of Process Cycle Efficiency

In the context of an automobile service station, the implementation of LSS has led to a significant improvement in the PCE from 32% to 57%. This improvement was essential, as excessive non-value-added time in non-machine operations, such as concept visualization, design/plate cutting, and finishing, extended production lead times and negatively affected PCE, causing it to fall below the minimum standard of 25%. The root causes of low PCE were identified as process methods and work organization issues. Operators lacked experience and used incorrect methods, while the control system was insufficient, leading to unfavorable attitudes among operators.

To address these challenges, a systematic approach to continuous improvement known as Kaizen was implemented across all processes. Kaizen initiatives aim to reduce unnecessary inventory, minimize production lead times, and decrease non-conforming products on the production floor. Periodic training and retraining sessions were held to improve operator skills and foster better teamwork. Additionally, work standardization was adopted to effectively organize production processes, achieve accurate line balancing, and minimize non-value-added activities, particularly in non-machine running processes.

The strategic framework for implementing Kaizen highlighted the significance of a strong management vision and effective teamwork. It included the planning and formation of teams focused on applying the 5S principles: Sort, Set in order, Sine, Standardized, and Sustained. This framework provides a structured approach to improving efficiency, quality, and overall performance within the automobile service station, aligning with the principles of LSS to drive continuous improvement and enhance customer satisfaction [14].

Analysis of Takt Time

In the context of an automobile service station, takt time, as defined by Adeosun et al. (2021) [15], defines it as the time needed to produce a sellable unit of the product based on the net available working time. Comparing the estimations of takt time before and after the implementation of Lean Six Sigma (LSS) from Tables 3 and 8, it’s evident that takt time improved from 7.16 hr./car to 7.76 hr./car after LSS implementation. This indicates an increase in the net available time to meet customer demands after implementation.

The low takt time can be traced to three key factors: setup time per shift, lunch breaks per shift, and planned downtime per shift, all of which particularly affect machine operations because of inefficient work organization. Operators spend excessive time on these factors, resulting in increased non-value-added time and reduced net available time to meet customer demands. Additionally, low operator productivity, especially in machine running processes, is influenced by extended planned shutdown times and other factors, likely stemming from motivational issues.

To tackle these challenges, LSS tools such as Total Productive Maintenance (TPM), 5S, and Single Minute Exchange of Die (SMED) have been introduced. TPM reduced the setup and planned downtime by streamlining production order changes and implementing preventive maintenance while also promoting operator involvement in machine maintenance. This approach aims to improve equipment reliability and reduce unnecessary downtime, thereby increasing the net available time for production.

The strategic framework for Total Productive Maintenance, as depicted in, emphasizes the importance of training operators and staff, decentralization of duties, and comprehensive implementation of TPM components at all production stages, especially in machine running processes. It advocates the establishment of monitoring and evaluation teams to ensure proper implementation and provide feedback, ensuring sustained improvements in equipment reliability and overall production efficiency within automobile service stations.

Analysis of Manufacturing Wastes

In the automobile industry, three key production wastes need to be addressed: defective products, downtime percentage, and excess labor, as shown in Tables 4, 5, and 6, respectively. Before the implementation of LSS, significant challenges existed, particularly in the printing section, which contributed to high quantities of non-conforming products, elevated percentage downtime, and excessive labor.

Comparing Tables 4 and 9, it is evident that the implementation of LSS results in substantial improvements across all categories of manufacturing waste. Before the LSS, the printing section was a major source of problems, leading to defects, downtime, and labor inefficiencies. Root causes include machine condition, operator skills, lack of standard procedures, and insufficient training.

To address these issues, LSS approaches such as TPM, Kaizen, work standardization, inventory management, 5S, and the DMAIC (Define, Measure, Analyze, Improve, Control) methodology of Six Sigma have been implemented. TPM, focusing on preventive, corrective, and maintenance measures, effectively reduced machine downtime and breakdowns. Kaizen and 5S initiatives helped improve product quality and streamline processes, while work standardization and inventory management optimized labor utilization and controlled staffing levels.

Overall, the implementation of the LSS methodologies successfully mitigated manufacturing waste in the automobile industry. By systematically addressing root causes and implementing continuous improvement initiatives, production efficiency, product quality, and resource utilization were enhanced, leading to significant improvements in the overall operational performance within the automobile manufacturing plant.

CONCLUSION

In conclusion, this study has demonstrated the significant contributions of LSS methodologies to the automobile service industry, particularly in addressing real-time challenges related to productivity and manufacturing waste, which directly impact customer satisfaction. By implementing LSS principles, a framework for continuous improvement has been established, offering theoretical and empirical implications for process industries seeking to enhance their operational efficiency and quality.

Improved Process Cycle Efficiency

The implementation of Kaizen and work standardization led to a remarkable improvement in PCE, increasing from 23% to 40%. This enhancement in productivity reflects the effectiveness of lean methodologies in optimizing workflow and resource utilization within the automobile service industry.

Reduction of Manufacturing Wastes

LSS initiatives have successfully addressed manufacturing waste, including non-conforming products, downtime, and overstaffing. The quantity of non-conforming products has been aligned with Six Sigma standards, whereas downtime and overstaffing have been significantly reduced through the application of TPM, work standardization, inventory management, and Six Sigma methodologies such as 5S, Define, Measure, Analyze, Improve, Control (DMAIC), and DMADV (Define, Measure, Analyze, Design, Verify). These improvements have led to cost savings and enhanced operational efficiency.

Adaptability to Other Process Metrics

The success of the LSS implementation in this study underscores its potential for addressing various process metrics beyond productivity and waste reduction. Quality, responsiveness, total turnaround time, and other performance indicators can also be effectively improved through the application of LSS principles in the automobile service industry.

Academic-Industry Collaboration

The involvement of experts with Black Belt certification, alongside university faculty resources and quality management students, has proven to be advantageous in executing LSS projects within the automobile service industry. This highlights the importance of academic-industry collaboration in driving innovation, knowledge transfer, and the practical application of lean methodologies.

In conclusion, the adoption of LSS methodologies offers tangible benefits for the automobile service industry, enabling organizations to enhance efficiency, quality, and customer satisfaction through systematic process improvements. Continued collaboration between academia and industry is encouraged to further leverage the potential of LSS in addressing contemporary challenges and driving sustainable growth in the automotive service sector.

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