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Operational Excellence for Improving Manufacturing Performance Using Lean Six Sigma

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Abstract: Operational excellence is the process of aligning people, resources, processes and capabilities to achieve sustainable growth and continuous improvement. Reducing costs and improving customer satisfaction is a top priority for every organization. Lean Six Sigma (LSS) is a continuous improvement strategy that increasing process performance resulting in reducing costs and enhancing customer satisfaction. The purpose of this study is to investigate the status of LSS implementation in manufacturing domain. An integrated LSS-DMAIC framework is developed for improving process performance. In this context, the proposed framework was applied in a car spare parts manufacturer in Egypt. The main factors causing process defects and wastes were identified, and the solutions applied led to an increase in quality rate and value-added-time. During three months, product quality rate (first time) increased from 26.7% to 80.0%, and quality rate (after rework) increased from 80.0% to 100%, resulting in sigma level (first time) increasing from 2.12 to 2.34, and sigma level (after rework) from 2.34 to 6.0. Furthermore, processing lead time was reduced from 1,847 to 915 sec./unit, which led to improved value-added process efficiency from 47% to 79%.

Keywords: *LSS, DMAIC, LSS-SCM, process improvement, TQM, manufacturing.*

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INTRODUCTION

Implementing an operational excellence program streamlines organizations to achieve maximum efficiency and effectiveness, allowing them to reduce costs, improve product quality, and improve customer satisfaction. To achieve these goals, many organizations have turned to the powerful methodology of Lean Six Sigma (LSS). LSS provides a comprehensive toolkit (DMAIC - Define, Measure, Analyze, Improve and Control) and many tools for continuous improvement. Details of the main LSS tools for shutdown maintenance are provided in the following subsections, from (Gomaa, 2024) (Gomaa, 2023b); (Gomaa, 2023a); (Gomaa, 2022); (Almaz & Akar, 2023); (Crowdle & McDermott, 2023); (Nelson & McDermott, 2023); (Antony & Garza-Reyes, 2021); (Ishak & Gustia, 2020):

- **Customer satisfaction** is the core of any shutdown project and therefore must be enhanced through voice of the customer (VOC) analysis, which is a critical analysis procedure that provides accurate information regarding customer requirements. Critical to quality (CTQ) is a popular method used in continuous improvement and quality management. Central to CTQ is understanding the characteristics or requirements of a product or service needed to meet or exceed a customer's needs.

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- **Process mapping** is a technique used to visually map workflows and processes. It involves creating a process map, also referred to as a flowchart, process flowchart, or workflow diagram. The purpose of a process mapping is to communicate how a process works in a concise and straightforward manner. It allows any team member to be able to easily understand how to complete a particular process without a long verbal explanation.

- **SIPOC diagram**, which stands for Suppliers, Inputs, Processes, Outputs and Customers, is a mapping and visual analysis tool used in business process improvement. A SIPOC diagram is a high-level process map that helps organizations understand and document key elements of the process.

- **Standard work (SW)** is one of the fundamental disciplines of lean manufacturing. Also called standardized work. SW is key to maintaining stability, solving problems effectively and scientifically.

- **Standard documentation** system to ensure that your project information and documentation is clear, complete, reliable, and valuable, it is important to follow some best practices for an effective documentation system.

- **Visual control (5S)** is a Japanese organizational system that consists of five words beginning with the letter "S". These terms are Seiri (Sorting), Seiton (Setting in Order), Seiso (Shining), Seiketsu (Standardize), and Shitsuke (Sustain). The purpose of this approach is to establish an efficient and productive workspace by categorizing and storing utilized items, maintaining cleanliness and organization, and consistently upholding the established order.

- **Eight Waste** is the heart of lean waste identification and disposal, known in Japanese as Muda. There are eight types of waste (DOWNTIME) that an organization must remove from a value stream:
  - Defects – Repair or rework and excessive scrap
  - Waiting – Excessive idle time between steps
  - Overproduction – Producing items not demanded by the customer
  - Not utilizing talent - Skills – Unused employee creativity
  - Transportation – Inefficient transport over long distances
  - Inventory – Excess raw materials, work in process or finished goods
  - Motion – Unnecessary worker motion when completing a task
  - Excess processing - Overprocessing – Provide higher quality parts than necessary

- **Value-added (VA)** versus non-value-added (NVA) are fundamental concepts in process improvement methodologies. VA activities are those that, in the eyes of the customer, improve the product or service, making it more or more desirable. On the other hand, NVA activities are processes or steps that take time, resources, or space but do not increase the value of the product. Identifying and reducing NVA activities while enhancing VA activities is critical to increasing efficiency, reducing waste and improving overall customer satisfaction.

- **Value stream mapping (VSM)** is a simple basic exercise that involves drawing a value stream diagram, which includes all the actions; value added (VA) and non-value added (NVA) needed to move a product or service from raw materials to the customer, including the flow of materials, information, and lead time.

- **Pareto Principle**(also known as the 80/20 rule, the law of the vital few and the principle of factor sparsity) states that for many outcomes, approximately 80% of the consequences come from 20% of the causes ("the vital few").

- **Poka-Yoke**, commonly referred to as mistake-proofing or error-proofing, is a technique used to avoid mistakes or errors in commercial or industrial operations. Poka-Yoke attempts to improve the quality of goods and services, reduce rework and waste, enhance productivity and efficiency, improve safety, and allow greater flexibility in operations by identifying and eliminating potential sources of errors or errors.

- **Fault tree analysis (FTA)** is a type of failure analysis in which undesirable condition of the system is examined. This analysis method is primarily used in reliability engineering to understand how systems fail, and to determine the best ways to reduce risks.

- **Failure mode effect analysis (FMEA)** is a systematic and proactive risk management technique to identify and mitigate potential system, process or product failures. This technique is widely used across industries to analyze potential failure modes, their causes, and their effects on overall operation. FMEA allows companies to prioritize and address the most significant risks by assessing each failure mode's severity, probability of occurrence, and detectability. FMEA can also help companies improve product quality, reliability, and safety by implementing targeted actions to prevent or reduce the impact of failures.

- **Total productive maintenance (TPM)** is a methodology designed to improve overall equipment effectiveness. The focus of TPM is on processes and people as integral parts of TQM. TPM includes all employees, from department leaders, operations staff, and maintenance staff. At the core of TPM is the 5S method, which aims to keep a clean and well-organized work environment.

- **SMED (Single-Minute Exchange of Die)** is a system for dramatically reducing the time it takes to complete equipment changeovers. The basic idea of SMED is to reduce the setup time on equipment. The essence of the SMED system is to convert as many changeover steps as possible to "external" (performed while the equipment is running), and to simplify and streamline the remaining steps.

LITERATURE REVIEW

Based on the literature review, it was found that the most important critical success factors for LSS are as follows, (Samanta & Virmani, 2023); (Ali & Hossen, 2020); (Amir Karbassi Yazdi & Gómez, 2021); (Houti & Abbadi, 2019); (Selvaraju & Bhatti, 2019):

- Management commitment, support and involvement
- Leadership development and awareness
- Effective external and internal benchmarking, objectives, and KPIs
- Employee training, education, engagement, empowerment, and satisfaction
- Effective information and communication technology infrastructure
- Understanding LSS methodology, tools and techniques
- Focus on customer, relationship and satisfaction
- Effective LSS project planning and control system
- Effective change management process
- Effective Organizational structure & responsibility matrix

Several studies have focused on the applications of LSS in manufacturing domain. Table (1) presents a comprehensive survey of LSS studies, and they are classified based on contribution, application, main objectives and main LSS tools. In conclusion, the results found that, applying LSS approach can improving quality, reducing process variation, eliminating waste, improving production rate, improving process productivity, reducing cycle time, reducing non-value-added time, reducing lead time, and reducing production cost. Which lead for reducing unit price and increasing customer satisfaction. Furthermore, the results can be used for a systematic literature review by researchers and manufacturing leaders before embarking on a continuous improvement journey. Finally, an integrated LSS-DMAIC framework is developed for improving manufacturing efficiency and effectiveness.

Table 1 *LSS STUDIES IN MANUFACTURING DOMAIN, FOR EXAMPLE*

#	Contribution	Application	Main objectives	Main LSS Tools
Singh, 2024	Presented an environmental LSS framework for manufacturing	A case study in a medical equipment manufacturing	- Improving capacity utilization - Reducing defect % - Improving indoor air quality	DMAIC, Charter, Mapping, Pareto, VSM, RCA, C&E, 6S, SW
Srinivasan, 2024	Discussed a LSS framework for manufacturing	A case study in steel industry	- Reducing NVA time - Improving Process efficiency	DMAIC, Mapping, Charter, VSM, Pareto, RCA, C&E
Gomaa, 2024	Developed a LSS framework for manufacturing	A case study in a spare parts company	- Improving process OEE - Improving sigma level - Improving process capability	DMAIC, Mapping, VSM, 8Waste, Pareto, δL, Charts, 5S, OEE, DOE, TAG, RCA, C&E
Tsarouhas, 2023	Discussed a six-sigma framework for manufacturing	A case study in a packaging olives production	- Minimizing defects - Reducing variance - Reducing production cost	DMAIC, charter, Mapping, CTQ, Pareto, DOE, Capability, Charts, RCA, C&E
Altug, 2023	Discussed a six-sigma framework for manufacturing	A case study in a spare parts company	- Improving performance - Reducing lead time - Reducing production cost	DMAIC, Mapping, δL, R&R%, ANOVA, FMEA, RCA, C&E
Andron, 2023	Developed a Kaizen framework for increasing energy efficiency	A case study in a refrigerating company	- Increasing energy performance	DMAIC, Layout, Mapping, 5S, Kaizen, 8Waste
Conde, 2023	Discussed a LSS framework for manufacturing	A case study in a manufacturing car parts	- Reducing process defects	DMAIC, Charter, Mapping, CTQ, Charts, Pareto, Capability, C&E
Enache, 2023	Developed a LSS framework for manufacturing	A case study in a metal door manufacturing	- Reducing scrap rate	DMAIC, Charter, Mapping, CTQ, R&R%, Charts, Pareto, C&E
Habib, 2023	Discussed a lean framework for manufacturing	A case study in a labeling and packaging	- Reducing lead time - Improving effectiveness - Reducing Customer complaint	DMAIC, Charter, Mapping, VSM, 5S, charts, RCA, C&E
Jimenez, 2023	Developed a LSS framework for manufacturing	A case study in a Textile Sector	- Improving quality & productivity - Reducing lead time	DMAIC, Charter, Mapping, VSM, 5S, charts, Capability, C&E
Mittal, 2023	Discussed a six-sigma framework for manufacturing	A case study in a rubber weather strips company	- Reducing rejection rate - Reducing production cost	DMAIC, CTQ, Mapping, Pareto, C&E, 5S, CBA
Oliveira, 2023	Discussed a lean framework for Manufacturing	A case study in an automotive parts assembly line	- Reducing setup time	Mapping, 8Waste, SMED, Gemba, SW, charts, Pareto, C&E
Sasikumar. 2023	Developed a LSS framework for manufacturing	A case study in a bias tire manufacturing	- Reducing waste - Improving OEE	DMAIC, Mapping, OEE, charts, Pareto, RCA, C&E
Satolo, 2023	Developed a LSS framework for manufacturing	A case study in milking processes	- Reducing defect % - Reducing cost	DMAIC, Mapping, VSM, RCA, C&E, PDCA
Toki, 2023	Proposed a LSS - Quick Changeover - framework	A case study in ready-made garments	- Improving Process efficiency - Reducing production cost	Mapping, SMED, RCA, C&E
Trubetskaya, 2023	Developed a LSS framework for manufacturing	A case study in a compound animal feed manufacturing	- Reducing inventory stock - Reducing lead time	DMAIC, Mapping, VSM, Pareto, SW, PCC
Utama, 2023	Developed a sustainable LSS framework for manufacturing	A case study in producing carrageenan	- Improving Manufacturing Sustainability Index (MSI)	DMAIC, Mapping, CTQ, VSM, FMEA, RCA, C&E

PROPOSED LSS FRAMEWORK

LSS-DMAIC framework is developed to improve manufacturing efficiency and effectiveness. Applying LSS principles involves a systematic approach to identify and eliminate inefficiencies, reduce waste, and improve overall performance. The proposed DMAIC approach can be summarized as follows:

Define Phase:

Studying process, product and problems in detail:

- Defining the project goals, objectives and scope of work
  - Clearly define the goals and objectives of the LSS project
  - Identify the specific processes that need improvement.
  - Define the scope of the project, including key deliverables and success criteria.
- Building a cross-functional team:
  - Form a team with members from different departments involved in product and processes.
  - Ensure that the team has a mix of skills, including process knowledge, data analysis, and problem-solving.
- Define product description and required processes.
- Defining current situation (SWOT analysis)
- Defining process problems and targets
- Creating a project charter & a project plan
- Understanding and identifying the customer requirements:
  - Identify and understand the requirements and expectations of customers.
  - Using tools like VOC analysis to capture customer feedback and incorporate it into improvement goals
  - Identify CTQ for the final product or service.
- Mapping the current state process:
  - Create a detailed process map (process flow chart, SIPOC, . . . etc.) that outlines the current state of the processes.
  - Identify key inputs, processes, outputs, and stakeholders involved in each step of processes.
- Identifying Key Metrics:
  - Determine key performance indicators (KPIs) that align with the objectives.

Measure Phase:

Designing and collecting the required information:

- Designing standard templates & collecting the required information:
- Measuring current performance evaluation, KPIs related to product and process, such as lead times, cycle times, resource productivity, inventory levels, and defect rates.
- Measuring sigma level & process capability
- Preparing current value stream mapping
- Measuring process wastes & defects

Analyze Phase:

Applying analysis tools and identifying root causes:

- Using appropriate statistical analysis tools and techniques to analyze the collected information and identify areas for improvement.
- Analyzing process defects
- Analyzing of process variance
- Analyzing critical to quality (CTQ)
- Analyzing process wastes & bottleneck
- Analyzing process parameters
- Conducting root cause analysis (RCA) and fishbone diagrams.
- Determining improvement recommendations

Improve Phase:

Implementing solutions according to priorities:

- Identifying and prioritizing opportunities for improvement:
- Conduct a thorough analysis to identify bottlenecks, waste, and inefficiencies in the processes.
- Prioritize improvement opportunities based on their impact on customer satisfaction and overall process performance.
- Preparing the improvement plan
- Training the teamwork groups
- Implementing kaizen & lean principles: Applying lean principles to eliminate waste and improve flow within the process. This may include:
  - Reducing excess inventory through JIT practices.
  - Implementing visual management to enhance transparency and communication.
  - Streamlining processes to minimize unnecessary steps and delays.
- Applying six sigma techniques: Using Six Sigma techniques to address variations and defects in the processes. This may involve:
  - Conducting root cause analysis to identify and address the underlying causes of defects.
  - Implementing statistical process control to monitor and control process variability.
  - Utilizing DMAIC methodology for continuous improvement.
- Implementing changes and monitoring progress:
  - Pilot test the proposed changes on a small scale.
  - Gather feedback and make adjustments as needed.
  - Implement the identified improvements.

Control Phase:

Monitoring the process and achieving daily improvements:

- Developing and implementing a control plan
- Designing and document standard practices
- Following process control charts
- Following quality assurance / quality control (QA/QC) checklists
- Following Kaizen improvement and auditing check lists for 5S, lean 8 wastes, total productive maintenance, etc.
- Establishing KPIs and control mechanisms to monitor the process efficiency and effectiveness.
- Establishing Before / after analysis, continuously track and report progress to ensure sustained improvements.
- Creating a culture of continuous improvement:
  - Foster a culture of continuous improvement within the organization.
  - Encourage feedback from employees involved in the product and processes, and empower them to identify and address issues proactively.
- Documenting and standardizing processes:
  - Document the improved processes and create standard operating procedures.
  - Ensure that the standardized processes are communicated and followed consistently across the organization.
- Providing training and support:
  - Train employees on the new processes and methodologies.
  - Provide ongoing support and resources to maintain a focus on continuous improvement.
- Preparing project close-out report
- Communicating results & learned lessons:
  - Share the results and successes of the LSS project with stakeholders.
  - Share the results and successes of the LSS project with stakeholders.

By following these steps, organizations can effectively apply LSS principles to improve manufacturing operations. Table (2) shows the proposed LSS-DMAIC framework for the manufacturing domain. Fig. (1) shows the proposed lean 8 waste audit checklist, Fig. (2) shows the proposed 5S audit checklist, and Fig. (3) shows the proposed TPM audit checklist.

Table 2 *PROPOSED LSS-DMAIC FRAMEWORK FOR MANUFACTURING PROCESSES.*

Phase	Objectives	Key Activities	Used Tools
Define	Studying process, product and problems in detail.	1) Defining the goals, objectives and scope of work	Brainstorming
		2) Building teamwork & developing project charter	Brainstorming
		3) Defining product description and required processes	Brainstorming
		4) Defining current situation (strength & weakness)	SWOT matrix
		5) Defining process problems and targets	Brainstorming
		6) Create a project charter & a project plan	Project charter
		7) Defining customer requirements & CTQ factors	CTQ and VOC
		8) Defining process mapping (flow chart, SIPOC)	SIPOC diagram
		9) Identifying key metrics	KPIs metrics
Measure	Designing and collecting the required information.	10) Designing standard templates & collect information	Brainstorming
		11) Measuring current performance evaluation	KPIs dashboard
		12) Measuring sigma level & process capability	Sigma level, Cpk
		13) Preparing current value stream mapping	VSM
		14) Measuring process wastes & defects	8 Lean wastes
Analyze	Applying analysis tools and identifying root causes.	15) Using appropriate statistical analysis tools	7QC tools
		16) Analyzing process defects	Pareto chart
		17) Analyzing process variance	ANOVA
		18) Analyzing critical to quality (CTQ)	SPC & 7QC
		19) Analyzing process wastes & bottleneck	RCA
		20) Analyzing process parameters	DOE
		21) Conducting RCA and fishbone diagrams	C&E diagram
		22) Determining improvement recommendations	Brainstorming
Improve	Implementing solutions according to priorities.	23) Identifying and prioritizing opportunities for improvement	Brainstorming
		24) Preparing the improvement plan	Brainstorming
		25) Training the teamwork groups	Advanced training program
		26) Implementing kaizen & lean principles	Kaizen, 5S, SW, … etc.
		27) Implementing six sigma principles	7QC tools
		28) Implementing changes and monitoring progress	Brainstorming
Control	Monitoring the process and achieving daily improvements.	29) Developing and implementing a control plan	Brainstorming
		30) Designing and document standard practices	QA/QC
		31) Following process control charts	Control charts
		32) Following QA/QC checklists	QA/QC
		33) Following Kaizen improvement	Kaizen, 5S, SW, … etc.
		34) Following KPIs, Sigma level, process capability, …	KPIs dashboard
		35) Before / after analysis	KPIs analysis
		36) Creating a culture of continuous improvement	Kaizen events
		37) Documenting and standardizing processes:	Auditing
		38) Providing training and support	Brainstorming
		39) Preparing project close-out report	Brainstorming
		40) Communicating results & learned lessons	Brainstorming

Factor	Item	Check
Defects	• There is a list of product defects and root causes • There is a list of machine failures and root causes • Production staff know all kinds of process defects • Maintenance staff know all kinds of equipment failures • There is always a pre-evaluation of suppliers before choosing them	
Waiting	• Staff know the expected execution time for each activity • There are waiting times between production activities • There are waiting times between maintenance activities • There are waiting times for materials and work in process • There are waiting times for handling materials and products	
Over-Production	• There is a production plan for each product and process • There is a standard time for each product and process • Unexpected delays/unnecessary downtime is recorded • There is over production for any product and process • There is over maintenance for any equipment	
Not Utilizing Talent	• There is a job description for each production staff • There is a job description for each maintenance staff • The methods used by each staff meet their practical knowledge • There are unused talents and skills among production staff • There are unused talents and skills among maintenance staff	
Transportation	• There are specific routes to transport the products • Raw materials and work in process transportation • Work stations are always clean and tidy to facilitate movement • There is a record of all types of materials that can be transported • There are very many transportation times for any product or material	
Inventory Excess	• There is material plan and inventory control system • Expiry dates of used materials are systematically checked • Unplanned consumption of materials is recorded • There is overstocked of raw materials and work in process • There is overstocked of spare parts	
Motion of people	• The equipment layout is organized in a logical sequence • The process includes procedures for correct transportation of materials • Staff have procedures for the correct handling of materials • There is unnecessary movement of production staff • There is unnecessary movement of maintenance staff	
Excess Processing	• There is an operation planning sheet for each process • There are optimal operation parameters for each process • The operation sequence and times are recorded • There are excessive or too frequent production activities • There are excessive or too frequent maintenance activities	

Figure 1 *Proposed lean 8 wastes auditing check list.*

Factor	Item	Check
Sort	• In the workplace, no unnecessary items are left or stored • Broken, unusable or occasionally used items are stored in the storage area • Equipment and machines are regularly used • There are standards for removing unnecessary items, and they are followed • There are standards in place for removing unnecessary items, and they are followed	
Set in order	• Tools and equipment are properly located, well organized, and easily accessible • There is a well-organized system for locating products and materials • Labels are used to label locations, boxes, shelves, store items, … etc. • There are signs of inventory management, such as FIFO, Kanban Cards, … etc. • Safety equipment and supplies are in good condition and easily identifiable	
Shine	• There is no dirt or dust on the floors, walls, ceilings, pipes, … etc. • Participants maintain a clean environment for shelves, cabinets, racks, … etc. • Cleaning tasks have been identified and are being followed up • Individuals maintain the cleanliness of machinery, equipment, and other tools • Cleanliness is maintained in the storage of materials, components, products, … etc.	
Standardize	• Create informational displays and banners with color coding, and other markings • 5S assessments, schedules and routines have been developed and are currently in use • Everyone is aware of their obligations, as well as when and how they must fulfill them • Procedures for maintaining the first 3S in good working order are shown • Evaluations and measures are used to conduct audits regularly	
Sustain	• 5S tends to be a lifestyle rather than a practice • Tools and parts are always properly stored • Procedures for all of the above are evaluated and updated regularly • Inventory controls should be strongly implemented • Part of the 5S process includes rewarding and recognizing employees.	

Figure 2 *Proposed 5S auditing check list.*

Factor	Item	Check
Cleaning	• Availability of cleaning schedule • Availability of cleaning checklist sheet • Availability of cleaning tools • Availability of visual controls for cleaning activities • Availability of cleaning standard • Availability of autonomous maintenance (cleaning) training	
Inspection	• Availability of inspection schedule • Availability of inspection checklist sheet • Availability of inspection tools • Availability of visual controls for inspection activities • Availability of inspection standard • Availability of autonomous maintenance (inspection) training	
Lubrication	• Availability of lubrication schedule • Availability of lubrication checklist sheet • Availability of lubrication tools • Availability of visual controls for lubrication activities • Availability of inspection standard • Availability of autonomous maintenance (inspection) training	
Tightening	• Availability of tightening schedule • Availability of tightening checklist sheet • Availability of tightening tools • Availability of visual controls for tightening activities • Availability of tightening standard • Availability of autonomous maintenance (inspection) training	

Figure 3 *Proposed TPM auditing check list.*

CASE STUDY

The proposed framework was applied in an auto parts manufacturing company in Egypt. This company specializes in producing high quality ductile and gray cast iron products. It is one of the main suppliers of spare parts for car maintenance and repair centers in Egypt. The aim of this study is to reduce product defects, eliminate the different types wastes and reduce the non-value-added time in the production processes. Fig. (4) shows the chosen product and SIPOC diagram for the machining process. Fig. (5) shows the process flow chart of the used product.

RESULTS AND DISCUSSION

This section discusses the results obtained before and after applying LSS approach in the machining process. Fig. (6) shows sigma level analysis report, the main factors causing machining defects were pointed out, and the solutions applied reduced the percentage of defects from a chronically high level to an acceptable level. The quality rate (first-time) increased from 26.7% to 80.0%, and the quality rate (after-rework) increased from 80.0% to 100%. The sigma level (first-time) increased from 2.12 to 2.34, and the sigma level (after-rework) increased from 2.34 to 6.0. Fig. (7) shows the process control charts (first-time), and as is clear, the variance has been reduced to an acceptable range. Also, Fig. (8) shows the process capability (First-Time), which has been improved by an acceptable percentage.

ABC-HML classification is a common and effective method of classifying defects according to their frequency and importance. This methodology allows the leaders to identify and prioritize the defects that generate the most value for the business, as well as those that require more detailed management. Table (3) shows a list of the main defects of the machining process and their level of risk (rework time, rework cost, . . . etc.). Fig. (9) shows the Pareto chart of the defect types, as shown in this figure, the most common defect in this process is the bad surface finish. Table (4) shows ABC-HML classification for each defect.

The resulting cause and effect diagram shown in Fig. (10) was used to identify the key factors caused by elements such as materials, methods, machinery, manpower, measurements and environment that may influence machining defects.

Value stream mapping (VSM) is a specific process management tool, which simultaneously provides an overview of processes and any possible improvements. VSM identifies and eliminates waste when designing information flows for processes and materials across the value chain. Fig. (11) shows value stream mapping (before improvement) and Fig. (12) shows value-added time analysis (before improvement). Fig. (12) shows value stream mapping (after improvement) and Fig. (14) shows value-added time analysis (after improvement). As shown these figures processing time reduced from 1,847 sec./unit to 915 sec./unit. Moreover, the process efficiency increased from 47% to 79%.

Finally, as shown in Table (6) and Fig. (15), during three months, product quality rate (first time) increased from 26.7% to 80.0%, and quality rate (after rework) increased from 80.0% to 100%, resulting in sigma level (first time) increasing from 2.12 to 2.34, and sigma level (after rework) from 2.34 to 6.0. Furthermore, processing lead time was reduced from 1,847 to 915 sec./unit, which led to improved value-added process efficiency from 47% to 79%.

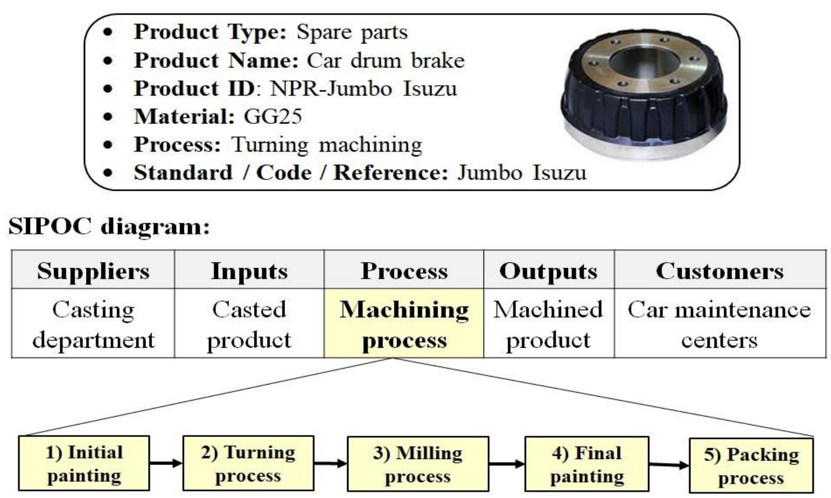

Figure 4 *Process description and SIPOC diagram.*

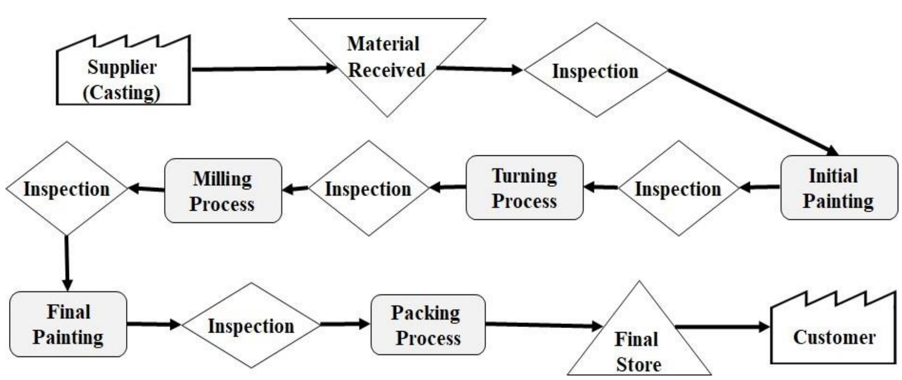

Figure 5 *Process flow chart.*

Sigma Level Analysis Report:

- **Product Name:** Car drum brake
- **Product ID**: NPR-Jumbo Isuzu
- **Material:** GG25
- **Process:** Machining Process

Number of Machines: 3 (M1, M2, M3)
Critical To Quality:
- **Inner Diameter:** ϕ 156 ± 0.04 mm
- **Surface Roughness:** Ra 3.2 μm

Before LSS	After LSS
• **Defect (First-Time)** = Rework + Rejected = 11 / 15 = 73.3%	• **Defect (First-Time)** = Rework + Rejected = 3 / 15 = 20.0%
• Rework = 8/15 = 53.3 %	• Rework = 3/15 = 20.0 %
• Rejected = 3/15 = 20.0%	• Rejected = 0/15 = 0.0 %
• **Quality (First-Time)** = 26.7%	• **Quality (First-Time)** = 80.0 %
• **Quality (After Rework)** = 80.0 %	• **Quality (After Rework)** = 100 %
• **Defect (First-Time)** = 733,000 DPPM	• **Defect (First-Time)** = 200,000 DPPM
• **Sigma Level (First-Time)** = 2.12 (D)	• **Sigma Level (First-Time)** = 2.34 (D)
• **Defect (Rejected)** = 200,000 DPPM	• **Defect (Rejected)** = 67,000 DPPM
• **Sigma Level (After-Rework)** = 2.34 (D)	• **Sigma Level (After-Rework)** = 6.0 (A+)

Figure 6 *Sigma level analysis report (Before / After).*

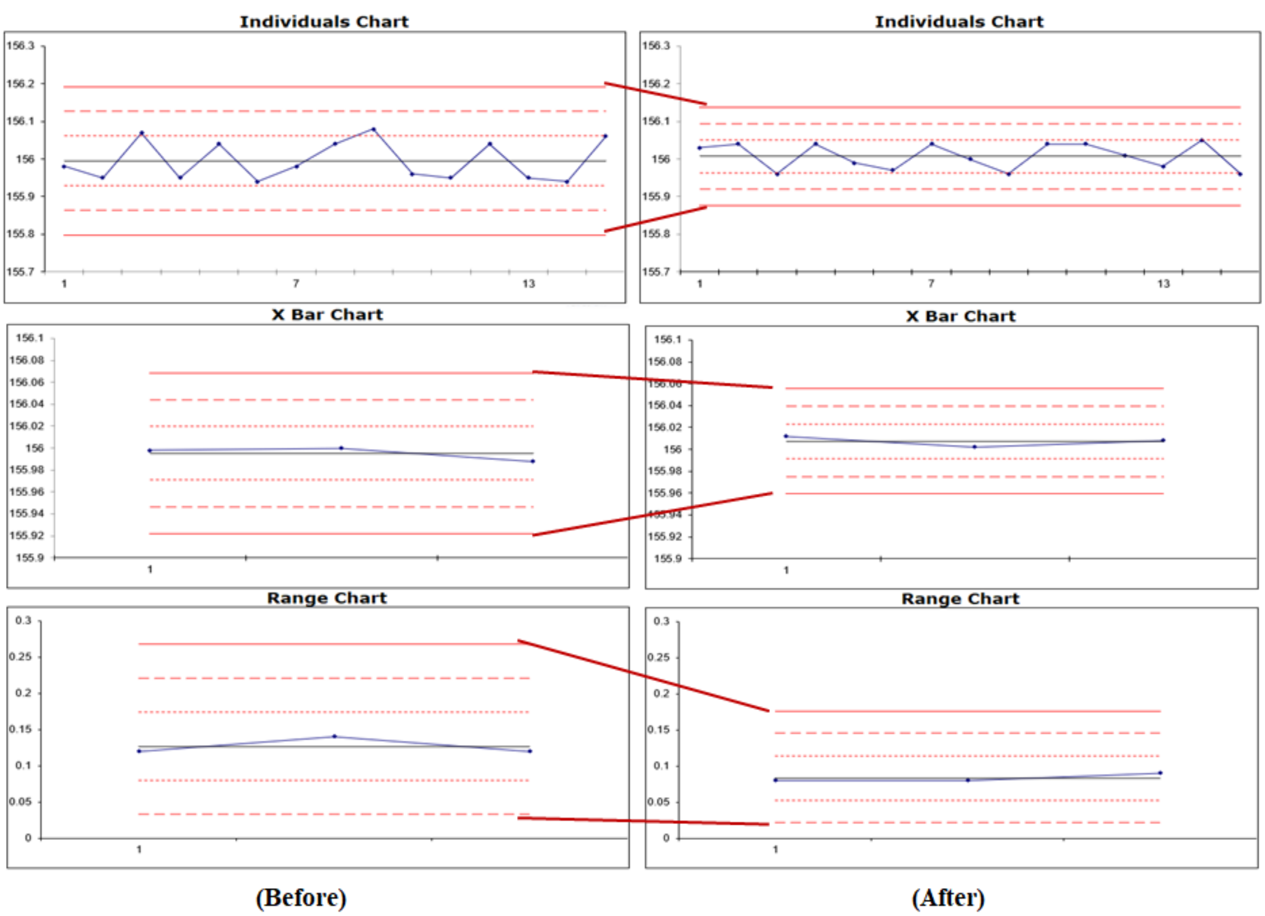

Figure 7 *Process control charts first-time (Before / After).*

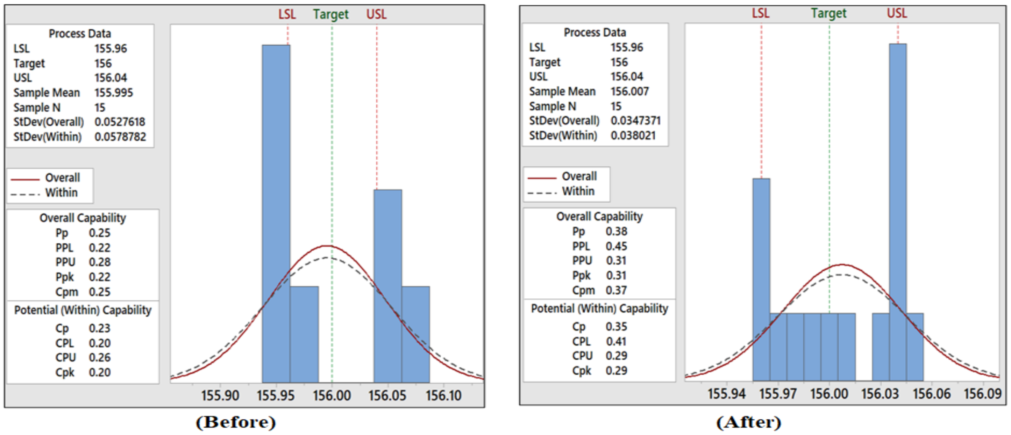

Figure 8 *Process capability first-time (Before / After).*

Table 3 *MAIN DEFECT LIST FOR THE MACHINING PROCESS.*

Defect Types		Total Defect #	Defect Risk
D1	Wrong Dimension	4	M
D2	Surface Burn	6	L
D3	Axis is not straight	2	L
D4	Porosity	3	M
D5	Bad Surface Finish	10	H
D6	Out-of-Roundness	2	M
D7	Surface Crack	1	H

Defect Risk (Rework time, Rework cost, … etc.): H:High, M:Medium, L:Low.

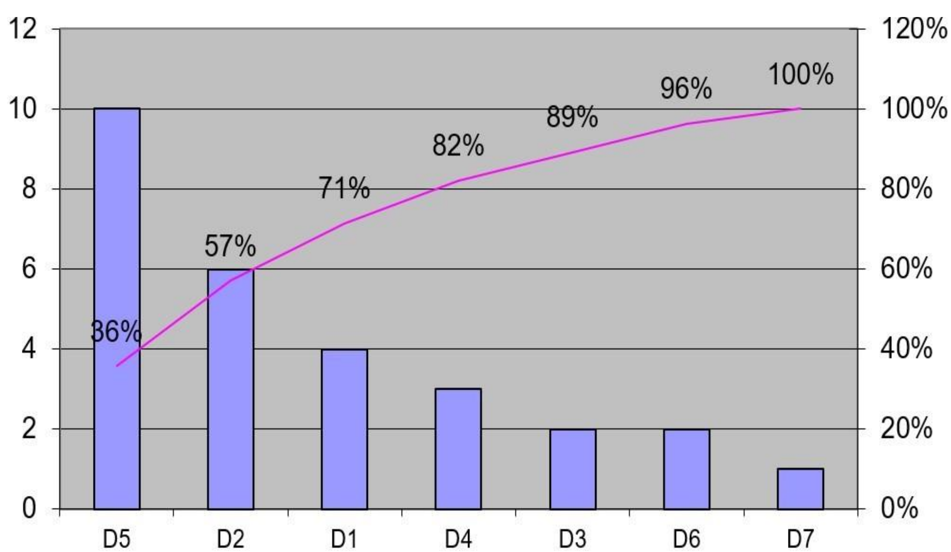

Figure 9 *Pareto chart of defect types (Before improvement).*

Table 4 *ABC-HML CLASSIFICATION*

Product Defect %	**A**	**D2**	**D1**	**D5**
	B		**D4**	
	C	**D3**	**D6**	**D7**
		L	**M**	**H**
		Defect Risk (Rework time, Rework cost, … etc.)		

Criticality	**VH**	**H**	**M**	**L**	**VL**
Defect ID	**D5**	**D1**	**D2, D4, D7**	**D6**	**D3**
Control Level	**Close**	**Max.**	**Medium**	**Low**	**Very Low**

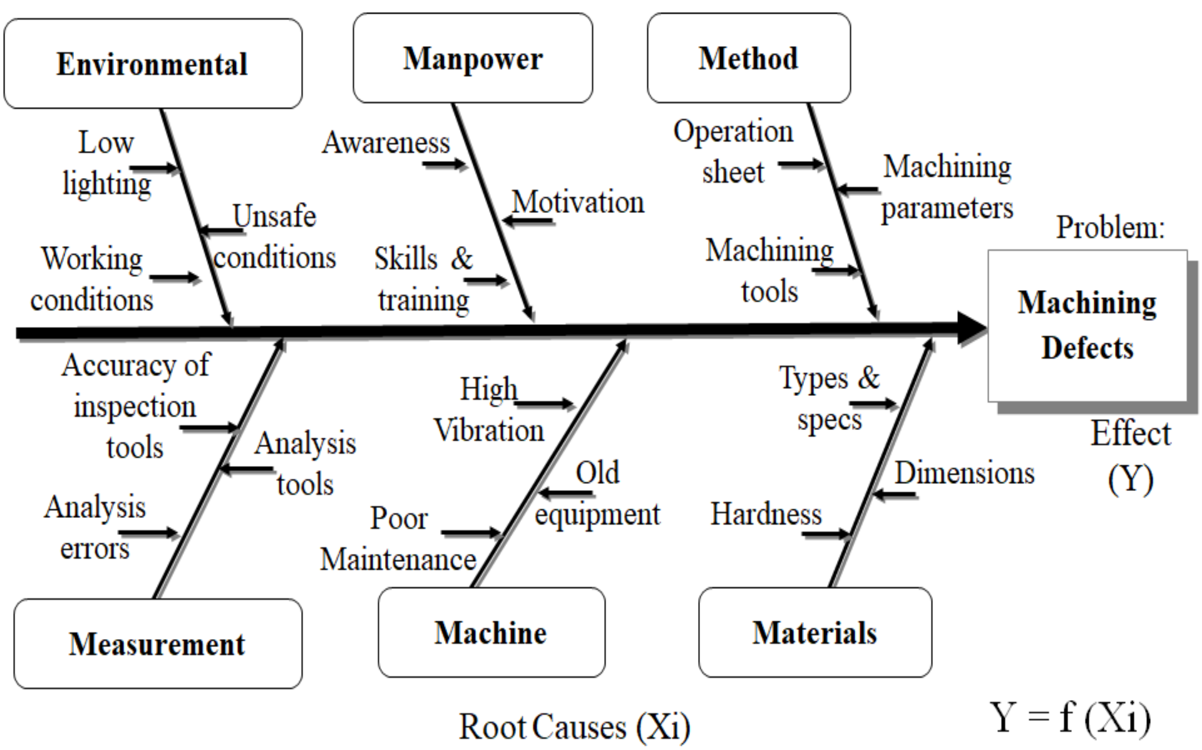

Figure 10 *Fishbone diagram for machining defects.*

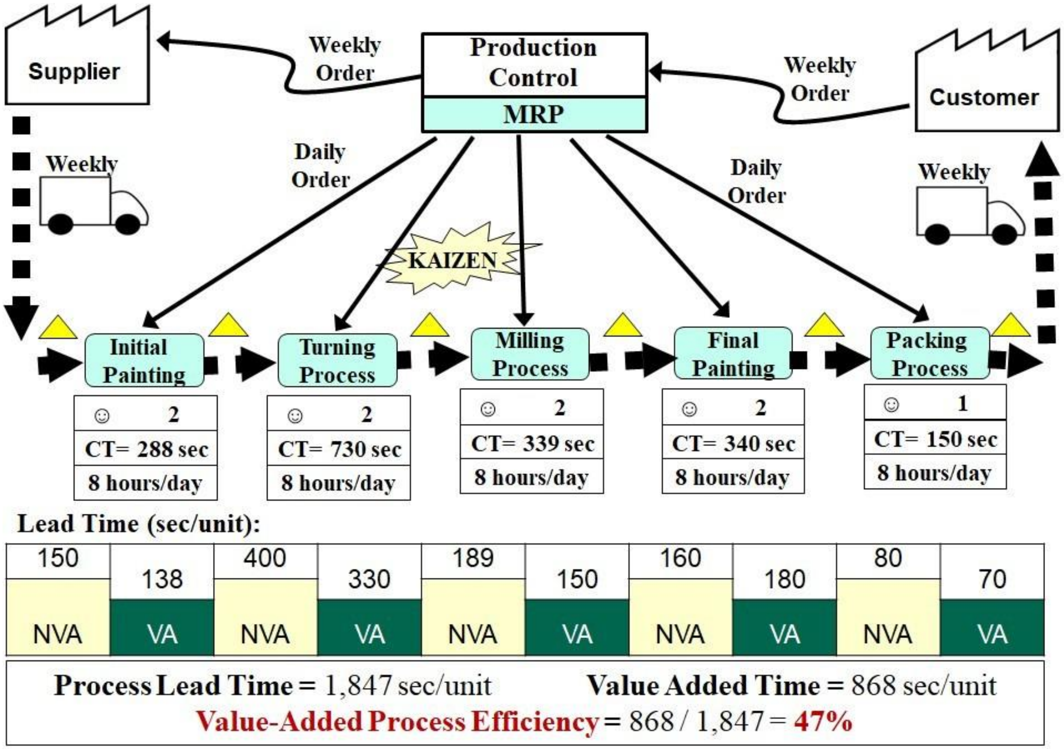

Figure 11 *Value stream mapping (before improvement).*

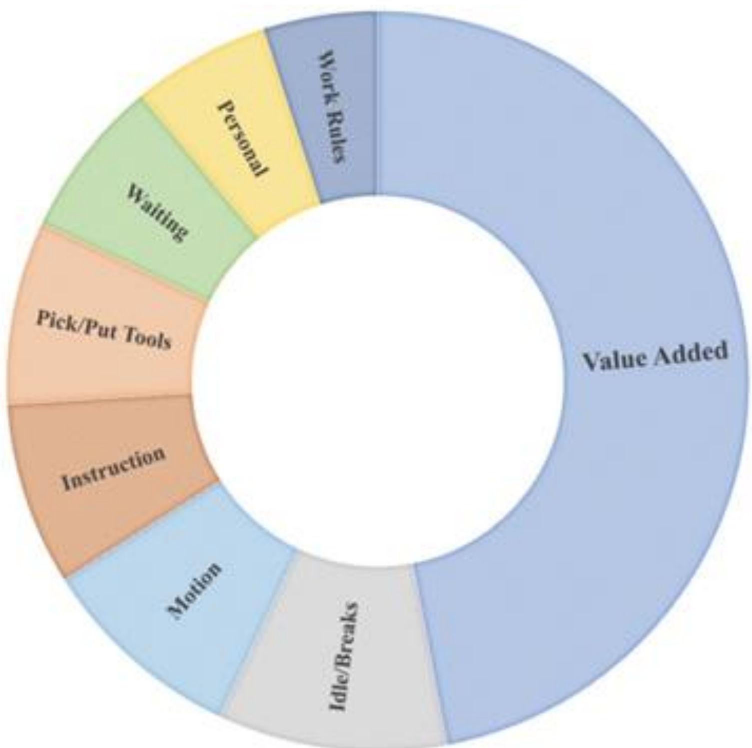

Figure 12 *Value-added time analysis (before improvement).*

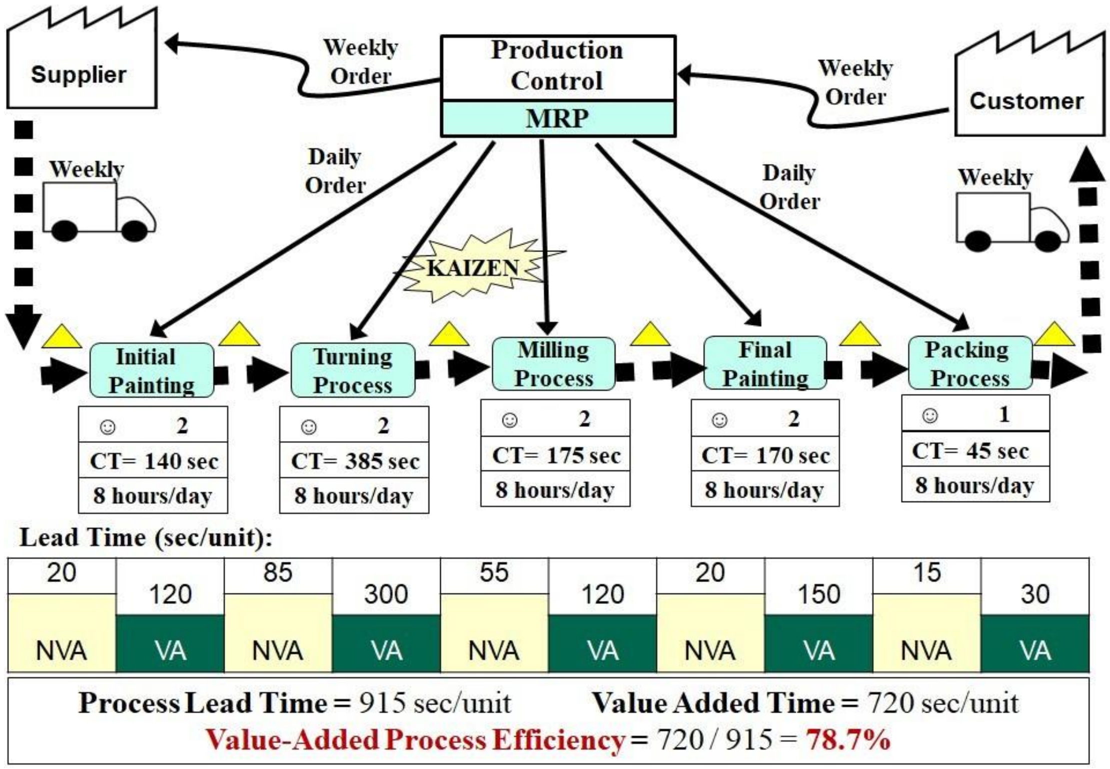

Figure 13 *Value Stream Mapping (After 3 months improvement).*

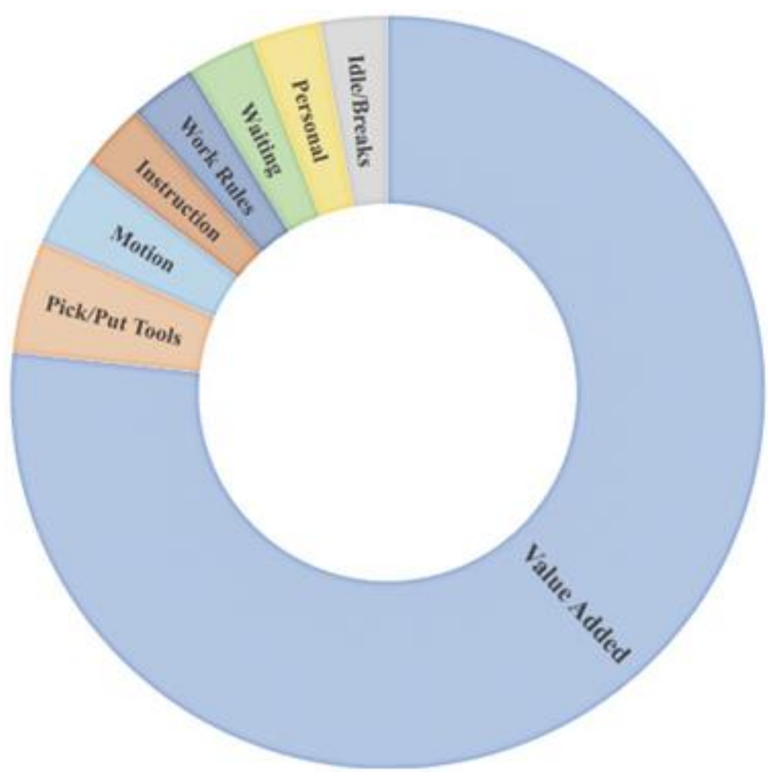

Figure 14 *Value-Added Time Analysis (After 3 months improvement).*

Table 5 *A SUMMARY OF PROCESS PERFORMANCE INDICATORS (BEFORE AND AFTER IMPROVEMENT).*

KPIs	Unit	Target	Before	After
1) Product quality (first time)	%	90	26.7	80
2) Product quality (after rework)	%	100	80	100
3) Sigma level (first time)	#	2.8	2.12	2.34
4) Sigma level (after rework)	#	6	2.34	6
5) Process lead time	sec. / unit	780	1847	915
6) Value-added process efficiency	%	90	47	79

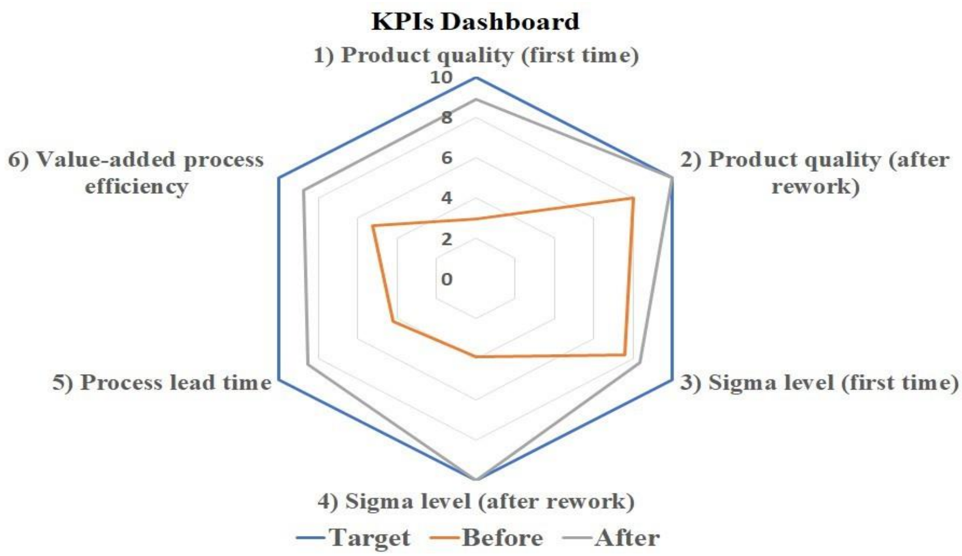

Figure 15 *A summary of process performance indicators (Before and after improvement).*

CONCLUSION

Lean Six Sigma (LSS) has proven to be an effective methodology and strategy for the manufacturing sector's success to improve process productivity and quality. This study explored the state of the art, current trends, and perspectives of LSS in the context of the manufacturing sector. Also, this study proposed a DMAIC framework to improve manufacturing efficiency and effectiveness. In this context, the proposed framework was applied in a car spare parts manufacturer in Egypt. The chosen product was a car drum brake (NPR-Jumbo Isuzu). During three months, product quality rate (first time) increased from 26.7% to 80.0%, and quality rate (after rework) increased from 80.0% to 100%, resulting in sigma level (first time) increasing from 2.12 to 2.34, and sigma level (after rework) from 2.34 to 6.0. Furthermore, processing lead time was reduced from 1,847 to 915 sec./unit, which led to improved value-added process efficiency from 47% to 79%.

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