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# Improving Supply Chain Management Using Lean Six Sigma: A Case Study

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***Abstract:*** Lean Six Sigma (LSS) is one of the most important approaches used to improve supply chain management (SCM), make it more efficient and effective, and sustain a culture of continuous improvement. The purpose of this study is to introduce a LSS framework, demonstrate its importance in improving SCM, and show how an integrated LSS-SCM approach model can improve supply chain efficiency, effectiveness, and customer satisfaction. In this context, this study focuses on developing LSS-SCM framework in a spare parts company in Egypt. This framework provides a step-by-step roadmap for improving SCM especially in manufacturing. The main results over three months were improving product quality from 85% to 89%, increasing sigma level from 2.5 to 2.7, reducing processing lead time from 645 to 370 hours/ton, improving overall equipment effectiveness (OEE) from 75% to 81%, increasing value added from 50% to 54%, and improving customer satisfaction from 87% to 89%.

***Keywords:*** *SCM, LSS, TQM, continuous improvement, effectiveness, efficiency.*

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## I. INTRODUCTION

Lean Six Sigma (LSS) is an approach that focuses on improving quality, reducing variation, eliminating waste, and improving customer satisfaction in an organization. Fig. (1) shows the difference between Lean and Six Sigma. Lean focuses on improving efficiency, while six sigma focuses on improving effectiveness. LSS is an approach that combines the tools and philosophies of both approaches. Table (1) shows the most common LSS tools., [1] , [2], [3], [4], [5]. Supply chain management (SCM) is essential for any organization to reduce costs and improve customer satisfaction. SCM is an integrated system for managing the flow of materials from suppliers through manufacturing and distribution chains to end customers. SCM aims to ensure that the customer gets the right product, at the right time, in the right place, at the lowest cost. [6], [7], [8], [9], [10]. LSS and SCM share common foundations in terms of focusing on improving customer satisfaction. LSS-SCM can help streamline a company's activities to eliminate waste, reduce defects, increase value added, improve customer satisfaction, and gain a competitive advantage in the market. As shown in Fig. (2) and Fig. (3), LSS allows SCM to become more efficient and effective in maintaining continuous improvement., [11], [12], [13], [14], [15].

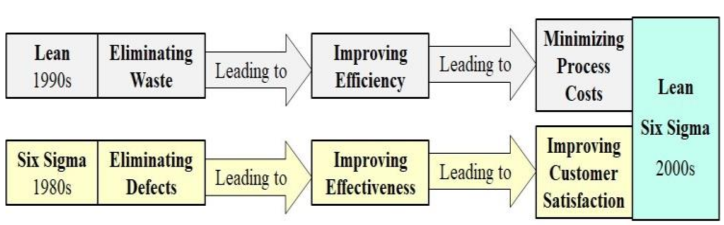


Fig. 1. Core objectives of LSS.

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TABLE 1
MOST COMMON LSS TOOLS

| # | Tool Symbol | Tool description |
|---|---|---|
| 1 | 5S / 6S | Visual control |
| 2 | 5Why | 5 Whys analysis |
| 3 | 7QC | 7 Quality control tools |
| 4 | 8Waste | Lean 8 waste analysis |
| 5 | ABC | Pareto classification analysis |
| 6 | ABC-XYZ | Advanced classification analysis |
| 7 | Actions | Improvement Actions |
| 8 | Andon | Visual control device |
| 9 | ANOVA | Analysis of variance |
| 10 | Brainstorming | Brainstorming group creativity technique |
| 11 | Benchmarking | Internal and external benchmarking & best practices |
| 12 | Bottleneck | Bottleneck analysis |
| 13 | C&E | Cause–effect diagram |
| 14 | CBA | Cost-benefit analysis |
| 15 | Charter | Project charter |
| 16 | Charts | Process control charts |
| 17 | COPQ | Cost of poor quality |
| 18 | Cpk | Process capability analysis |
| 19 | CSA | Customer satisfaction analysis |
| 20 | CTQ | Critical to quality |
| 21 | CTT | Critical to time |
| 22 | DMAIC | Define-Measure-Analyze-Improve-Control |
| 23 | DMADV | Define-Measure-Analyze-Design-Validate |
| 24 | DPMO | Defects per million opportunities |
| 25 | DOE | Design of experiments |
| 26 | Fishbone | Fishbone diagram |
| 27 | FMEA | Failure mode effect analysis |
| 28 | Gage R&R | Gage repeatability and reproducibility |
| 29 | Gantt | Gantt chart |
| 30 | Gemba | Go and see for yourself |
| 31 | Heijunka | Leveling of work flow |
| 32 | JIDOCA | Automatic detection |
| 33 | JIT | Just in time |
| 34 | Kaizen | Kaizen events |
| 35 | Kanban | Kanban board |
| 36 | KANO | KANO model |
| 37 | KPIs | Key performance indicators dashboard |
| 38 | Mapping | Process mapping (flow chart, SIPOC, Spaghetti diagram, etc.) |
| 39 | Network | Network diagram |
| 40 | OEE | Overall equipment effectiveness |
| 41 | Pareto | Pareto chart |
| 42 | PCE | process cycle efficiency |
| 43 | PDCA | Problem solving cycle (Plan-Do-Check-Act) |
| 44 | Poka-Yoke | Mistake proofing |
| 45 | QFD | Quality function deployment |
| 46 | RACI | Responsible, accountable, consulted, informed |

CONT....

| # | Tool Symbol | Tool description |
|---|---|---|
| 47 | RCA | Root cause analysis |
| 48 | SIPOC | Suppliers, Inputs, Process, Outputs, and Customers |
| 49 | SMART | SMART goals |
| 50 | SMED | Single-minute exchange of die |
| 51 | SW | Standard work |
| 52 | Taguchi | Taguchi method |
| 53 | Takt | Takt Time |
| 54 | TQM | Total quality management culture |
| 55 | TPM | Total productive maintenance |
| 56 | VAA | Value-added analysis |
| 57 | VOB | Voice of business |
| 58 | VOC | Voice of customer |
| 59 | VOP | Voice of process |
| 60 | δL | Sigma level |

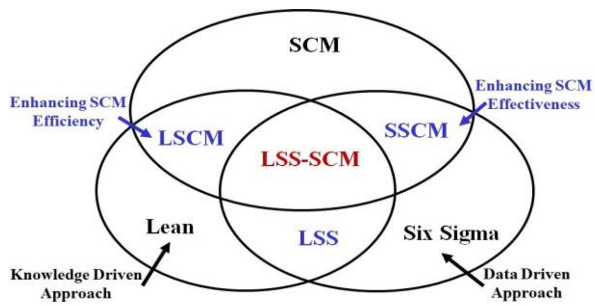


Fig. 2. Conceptualization of LSS, SCM and LSS-SCM

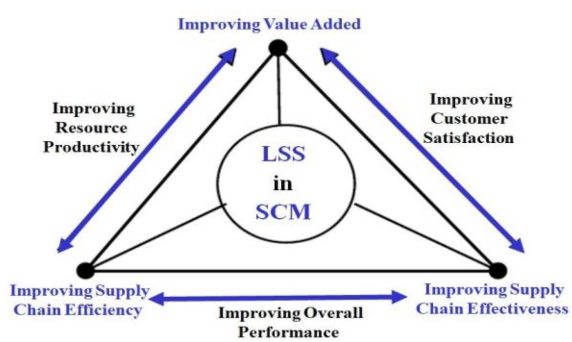


Fig. 3. LSS-SCM Objectives.

## II. LITERATURE REVIEW

There are a number of ways in which previous research has used LSS tools to improve SCM performance. Based on the literature review, it was found that the most important success factors of LSS-SCM are as shown in Table (2)., [1], [2], [13], [16], [17], [18], [19], [20], [21].

Many studies have focused on applications of LSS in different stages of SCM. Table (3) presents a comprehensive survey of LSS-SCM studies, categorized based on contribution, application, main objectives and main LSS tools. In conclusion, the main findings of the previous literature review indicate that, applying LSS framework in SCM 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, reducing production cost, reducing unit price, and increasing customer satisfaction.

TABLE 2
LSS-SCM CRITICAL SUCCESS FACTORS (CSFS)

| Perspective | Factors | [1] | [2] | [13] | [16] | [17] | [18] | [19] | [20] | [21] |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 Managerial factors | 1) Management support, commitment and involvement | x | x | x | x | x | x | x | x | |
| | 2) Leadership development and awareness | x | x | x | x | x | | | x | x |
| | 3) Clear strategic plan, business plan, vision and mission | | | | x | x | x | x | x | |
| | 4) Effective external and internal benchmarking of best practices | | x | | | | | | | |
| | 5) Clear goals, objectives, policies, and KPIs | | x | | | | | | | |
| | 6) Information quality and sharing | | | | | | x | x | x | |
| | 7) Focus on competitive priorities | | | | | | x | | x | |
| | 8) Effective teamwork management | | | | x | | | | | x |
| 2 Customer factors | 9) Customer engagement and satisfaction | | | | | x | | | x | |
| | 10) Effective customer relationship management (CRM) | | | | | x | | | | |
| 3 Supply chain factors | 11) Supply chain integration | | | | | x | x | x | | |
| | 12) Effective supplier relationship management (SRM) | | | | | x | | x | x | |
| | 13) Effective market demand forecasting, planning and control | | | x | | x | | x | | |
| | 14) Effective material requirement planning and control | | | | | x | | x | | |
| | 15) Effective inventory planning and control | | | | | x | x | x | | |
| | 16) Production system flexibility | | | | | | x | | | |
| 4 HRM factors | 17) Effective Organizational structure & responsibility matrix | x | x | | x | x | | | | |
| | 18) Employee training, education and awareness | x | x | x | x | x | | x | | x |
| | 19) Employee attitude, skills and expertise | | | | x | x | | | | x |
| | 20) Effectives reward, recognition and motivation system | | x | | x | x | | | | |
| 5 IT factors | 21) Effective information and communication technology | x | x | x | x | x | x | x | | x |
| | 22) IT Infrastructure | | | | | x | | | | x |
| | 23) Effective LSS-SCM software | | | | | x | | | x | |
| 6 Facility factors | 24) Effective facility layout, configuration and planning | | x | | | | | | | |
| | 25) Effective project selection, planning and control system | x | x | x | x | x | | x | | |
| | 26) Effective facility resources and infrastructure | | | x | | x | | | | |
| 7 Continuous improvement factors | 27) Understanding LSS-SCM methodology, techniques and tools | x | x | | | x | | x | | |
| | 28) Standardization of procedures and information | | | | | | | x | | |
| | 29) Linking LSS tools to business strategy | | | | | | | x | | x |
| | 30) Linking LSS tools to SCM elements | | | | | | | x | | |
| | 31) Employee engagement, empowerment and satisfaction | x | x | | x | | | | | |
| | 32) Project success stories, best practices and benchmarking | | | | x | | | x | | |
| | 33) Effective change management and Organizational culture | x | x | x | x | x | | | | x |
| 8 Financial factors | 34) Financial resource capabilities | | | x | x | x | | x | x | x |
| | 35) Economic benefits | | | | | | | | x | x |

TABLE 3
LSS STUDIES IN SCM ELEMENTS (FROM 2020 TO 2024)

| # | Ref. | Contribution | Application | Main objectives | Main LSS Tools |
|---|---|---|---|---|---|
| [22] | Adeodu, 2023 | Developed a LSS framework for warehouse processes | A case study in a third-party logistics service in Nigeria. | - Improving warehouse productivity<br>- Improving process cycle efficiency<br>- Reducing lead time | DMAIC, VSM, PCE, Cpk, 8Waste, Charts, 5S, RCA, C&E, KPIs |
| [23] | Reyes, 2023 | Proposed a model for lean supply chain planning in ind. 4.0 | A case study in a footwear company. | - Improving SC performance<br>- Reducing costs and waste | DMAIC, TPM, Kanban, Poka-yoke, 5S, Kaizen, JIT, Jidoka, Heijunka, Andon, VSM, |
| [24] | Sisman, 2023 | Presented a LSS framework in supply chain logistics | A case study in a plastics company in Turkey. | - Reducing logistics cost | DMAIC, Charter, Mapping, SIPOC, CTQ, 7QC, Brainstorming, FMEA, δL, RCA, |
| [25] | Sundram, 2023 | Discussed a LSS framework for supply chain logistics | A case study in a supply chain logistics company. | - Improving logistics Cost<br>- Improving HR procedures<br>- Improving employee performance | DMAIC, Charter, CTQ, brainstorming, Tree diagrams, Mapping, , Cpk, RCA, C&E |
| [2] | Gomaa, 2024 | Developed a LSS framework for manufacturing | A case study in a spare parts company in Egypt | - Improving process OEE<br>- Improving sigma level<br>- Improving process capability | DMAIC, Mapping, VSM, 8Waste, Pareto, δL, Charts, 5S, OEE, DOE, TAG, RCA, C&E |
| [26] | Trubetskaya, 2023 | Proposed a LSS framework for manufacturing | A case study in a compound animal feed manufacturing | - Reducing inventory stock<br>- Reducing lead time | DMAIC, Mapping, VSM, Pareto, SW, PCC |

CONT.....

| # | Ref. | Contribution | Application | Main objectives | Main LSS Tools |
|---|---|---|---|---|---|
| [27] | Mittal, 2023 | Discussed a six-sigma framework for manufacturing | A case study in a rubber weather strips company | - Reducing rejection rate<br>- Reducing production cost | DMAIC, CTQ, Mapping, Pareto, C&E, 5S, CBA. |
| [28] | Sharma, 2022 | Proposed a LSS framework for manufacturing | A case study in an automobile manufacturing | - Reducing defect %<br>- Increasing production rate<br>- Reducing idle time | DMAIC, Mapping, Charter, VSM, 8Waste, Pareto, C&E, δL |
| [29] | O'Mahon y, 2021 | Discussed LSS tools in SCM of an operating room in a hospital | A case study in health services | - Reducing Stock Holding Value<br>- Reducing out-of-date stock | DMAIC, Charter, SMART, Mapping, SIPOC, RACI, CTQ, VOC, 5S |
| [30] | Praharsi, 2021 | Presented a LSS framework in SCM | A case study in maritime industry | - Achieving supply chain resilience | DMAIC, 7Waste, CTQ, C&E, FMEA, δL |
| [31] | Tay, 2021 | Discussed LSS tools for digital transformations and SCM | Three logistics case studies in Asia | - Achieving enterprise-wide improvements<br>- Enhancing value across the supply chains. | DMAIC, Mapping, VOC, VSM, C&E, Poka-Yoke, KPIs Dashboard. |
| [32] | Tay, 2021 | Discussed LSS tools for logistics supplier selection | A case study in logistics services for a health-care company | - Improving the supplier selection process | DMAIC, Mapping, VOC, C&E, 5S, SW, KPIs Dashboard. |
| [33] | Kumar, 2021 | Developed a LSS framework for manufacturing | A case study in an engine cylinder company | - Reducing defect %<br>- Increasing sigma level. | DMAIC, Charter, Mapping, ABC, Pareto, Charts, C&E |
| [34] | Hardy, 2021 | Presented a LSS framework for manufacturing | A case study in laminated panel production | - Reducing machine downtime<br>- Improving process OEE | DMAIC, Charter, Mapping, CTQ, Takt, VSM, OEE, Charts, C&E, PDCA, FMEA. |
| [35] | Murmura , 2021 | Developed a LSS framework for manufacturing | A case study in iron industry | - Reducing lead time<br>- Reducing defect %<br>- Increasing sigma level. | DMAIC, Charter, Gantt, Mapping, VSM, δL, Charts, 5Why, C&E |
| [36] | Patyal, 2021 | Proposed a six-sigma framework for manufacturing | A case study in a chemical company | - Reducing customer complaints | DMAIC, Charter, Mapping, Cpk, 5Why, C&E |
| [37] | Almutairi , 2020 | Developed a LSCM framework for health-care organizations | A case study in a hospital SCM in Saudi | - Improving non-added activities | TQM, VOC, Mapping, VSM, TPM, ANOVA |
| [38] | Andersso n, 2020 | Proposed a six-sigma framework for supply chain risk management | Case selection in seven Swedish companies | - Improving the awareness and management of supply-chain risk | DMAIC, TQM |
| [39] | Madhani, 2020 | Presented a LSS framework in SCM | Theoretical analysis | - Enhancing supply chain efficiency and effectiveness | DMAIC, 8Waste, VSM |
| [40] | Liu, 2020 | Presented a VSM framework for manufacturing | A case study in footwear manufacturing | - Reducing defect %<br>- Reducing lead time<br>- Reducing WIP | DMAIC, VSM, Takt, DOE, Taguchi |
| [41] | Nandaku mar, 2020 | Developed a LSS framework for manufacturing | A case study in food industry | - Improving process OEE | DMAIC, Mapping, VSM, OEE, ANOVA, 5S, C&E |
| [42] | Tiwari, 2020 | Proposed a sustainable lean production framework | A case study in cookware manufacturing | - Improving sustainability<br>- Minimizing safety incidents | DMAIC, Charter, KPIs, VSM, Pareto, 8Waste, C&E |

## III. CASE STUDY

This study was conducted in one of the spare parts manufacturing companies in Egypt. It focuses on the machining processes of steel alloy casting items as the main and critical items in this case. The LSS-DMAIC (define, measure, analyze, improve, and control) framework is proposed and implemented as follows.

### *A. Define Phase*

The purpose of this phase is to clarify the scope of work and identify the main objectives and problems. Af- ter building the study SCM teamwork, an analysis of the current situation was prepared through a brainstorming session. According to the company's history of the pro- cess performance, a list of problems and objectives was identified, as shown in Table (4). KPIs detailed calcu- lations for the different SCM areas are shown in Table (5). Current SCM-KPIs dashboard is shown in Fig. (4). Based on literature review and brainstorming, the main LSS tools for different SCM areas are shown in Table (6) and Table (7). The production process flow chart of the major spare parts is shown in Fig. (5). As it is clear from the analysis of the current situation, the production process was the most influential area in improving SCM, and therefore it was focused on in this research, and we will address improving the rest of the SCM elements in in future research.

### *B. Measure Phase*

This phase aims to document and understand the current state of the system and identify important metrics related to product quality and process performance. A survey was conducted to collect average quality ratio and process lead time (hours/ton) for a period of 25 working days, as shown in Table (8). It was observed that the average quality (first time) was 80.59% (sigma level was 2.36) and the average process lead time was 10.76 hours/ton. Table (9) shows a list of the main defects of the machining process and their level of risk (rework time, rework cost, … etc.) during this period.

### *C. Analyze Phase:*

The purpose of this phase is to analyze problems and identify the root causes. Fig. (6) shows quality control chart. Fig. (7) shows process lead time control chart. Fig. (8) shows the Pareto chart of the defect types. ABC-HML classification is a common and effective method of classifying defects according to their frequency and importance. Table (10) shows ABC-HML classification for each defect. As shown in this table, the most common defect was bad surface finish. Therefore, a brainstorming session was conducted to identify the root causes of bad surface finish as shown in Fig. (9). 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. The process capability was analyzed as shown in Fig. (11), the results showed a low value of Cpk = 0.30 and indicated that the process was not capable. Fig. (12) shows process control charts (Xbar-R chart). A value stream mapping (VSM) was constructed to document the information flow, material flow and lead time flow. As shown in Fig. (13), the process efficiency was about 37.2%. Through a detailed study of the process, non-value-added activities and process waste analysis were identified as shown in Fig. (14).

### *D. Improve Phase:*

This phase begins with listing the recommendations and solutions obtained during the analysis phase. The project team works together to develop, test, and implement an improvement plan that brings continuous improvements to the process. Table (11) shows a summary of the monthly improvement plan. The 7S (5S + Safety + Sustainability) principle has been followed to organize and improve work efficiency and reduce safety risks.

### *E. Control Phase:*

At this stage, the teamwork developed a control plan to monitor and maintain the improvement plan. This plan explained how processes would be standardized as well as how procedures would be documented. Furthermore, actions taken to improve the process and best practices should also be well documented. The final activity in this phase was to close the project and prepare the final project closure report. As shown in Figures (15), (16), and (17), the implementation of the proposed recommendations improved in product quality, process variance, and process capability. Fig. (18) shows value stream planning after optimization, value added efficiency increased from 37.2% to 54.1%. Finally, as shown in Table (12) and Fig. (19), main results over three months improvements were improving product quality from 85% to 89%, increasing sigma level from 2.5 to 2.7, reducing processing time from 645 to 370 hours/ton, improving overall equipment effectiveness (OEE) from 75% to 81%, increasing value added from 50% to 54%, and finally, improving customer satisfaction from 87% to 89%.

TABLE 4
MAIN PROBLEMS, OBJECTIVES, KPIS AND TARGETS FOR THE DIFFERENT SCM AREAS.

| # | SCM Area | Main Problems | Main objectives | Main KPIs | Targets |
|---|---|---|---|---|---|
| 1 | Sales & market | Low customer satisfaction | Improving customer satisfaction | Customer satisfaction | ≥92% |
| | | Low effectiveness | Improving effectiveness Ratio | Effectiveness % | ≥85% |
| 2 | Final inventory | High product stock-outs | Minimizing product stock-outs | Product stock outs % | ≤ 5% |
| 4 | Product quality | Low product quality | Improving product quality | Quality % | ≥90% |
| | | Low sigma level | Improving sigma level | Sigma level | ≥2.8 |
| 5 | operations | Low production rate | Improving production rate | Production rate | ≥1.1 ton/hour |
| | | Low overall equipment effectiveness (OEE) | Improving OEE | OEE | ≥80% |
| | | Low time utilization | Improving time utilization | Time utilization | ≥60% |
| 6 | Critical resources | Low labor productivity | Improving labor productivity | Labor productivity | ≥0.5 ton/ man-hour |
| | | Low machine productivity | Improving machine productivity | Machine productivity | ≥2.0 ton / machine-hour |
| 7 | Material inventory | High material stock-outs | Minimizing material stock-outs | Material stock outs % | ≤ 5% |
| 8 | Financial | Low profit % | Improving profit | Profit % | ≥20% |
| | | Low value added % | Improving value added | Value added % | ≥55% |

TABLE 5
KPIS DETAILED CALCULATIONS FOR THE DIFFERENT SCM AREAS.

| # | SCM Area | Main KPIs | Equation | Unit | Actual |
|---|---|---|---|---|---|
| 1 | Sales & Market | Customer satisfaction | (Sales quantity – Claims quantity) / Sales quantity | % | 87.5 |
| | | Effectiveness % | Net Quantity / Target Quantity | % | 81.1 |
| 2 | Final Inventory | Product stock outs % | Product stock out quantity / Sales Quantity | % | 18.8 |
| 4 | Product Quality | Quality % | Net Quantity / Total Quantity | % | 85.7 |
| | | Sigma level | Sigma level table | # | 2.57 |
| 5 | Operations | Production rate | Net Quantity / Running Time | ton/hour | 0.9 |
| | | OEE | Availability ∗Performance ∗Quality | % | 75.1 |
| | | Time utilization | Standard Time / Actual Time | % | 41.7 |
| 6 | Critical Resources | Labor productivity | Net Quantity / (# of Workers ∗Running Time) | ton/ man-hour | 0.227 |
| | | Machine productivity | Net Quantity / Total Machining Time | ton/mach.-hour | 1.6 |
| 7 | Material Inventory | Material stock outs % | Material stock out quantity / Used Material Quantity | % | 17.4 |
| 8 | Financial | Profit % | (Unit Price - Unit Cost) / Unit Cost | % | 18.8 |
| | | Value added % | (Unit Price - Material cost per unit) / Unit Price | % | 50.9 |


Fig. 4. Current KPIs for the different SCM areas

TABLE 6
LSS TOOLS FOR THE DIFFERENT SCM AREAS.

| # | SCM Area | Main objectives | Main LSS Tools |
|---|---|---|---|
| 1 | Sales & Market | Improving customer satisfaction | VOC, CSA, 5S, SW, 5WA, C&E |
| | | Improving effectiveness Ratio | |
| 2 | Final Product Inventory | Minimizing product stock-outs | 5S, PC, ABC-XYZ, SW, Kanban, 5WA, C&E |
| 4 | Product Quality | Improving product quality | VOC, CTQ, L, 5S, VSM, TPM, OEE, PC, Pareto, ABC-XYZ, SW, 5WA, C&E |
| | | Improving sigma level | |
| 5 | Operations | Improving production rate | VOC, CTQ, L, 5S, VSM, TPM, OEE, PC, Pareto, ABC-XYZ, SW, 5WA, C&E |
| | | Improving OEE | |
| | | Improving time utilization | |
| 6 | Critical Resources | Improving labor productivity | VOC, CTQ, L, 5S, VSM, TPM, OEE, PC, Pareto, ABC-XYZ, SW, 5WA, C&E |
| | | Improving machine productivity | |
| 7 | Raw Material Inventory | Minimizing material stock-outs | 5S, PC, ABC-XYZ, SW, Kanban, 5WA, C&E |
| 8 | Financial | Improving profit % | 5S, PC, SW, 5WA, C&E |
| | | Improving value added % | |

TABLE 7
SCM LEAN WASTES (DWONTIME) AND LSS TOOLS

| # | Waste Type | Waste Description | Root Cause | Main LSS Tools |
|---|---|---|---|---|
| 1 | Defects | Produce defective products or need to be rectified. | Lack of motivation | Pareto, ABC-XYZ, 5WA, C&E |
| 2 | Waiting | To wait unnecessarily, waiting for materials and waiting for handling | Poor coordination | VSM, TPM, OEE, 5WA, C&E |
| 3 | Over-Production | Produce more than the customer demanded | Poor production planning | PP, SW, 5WA, C&E |
| 4 | Not Utilizing Talent | Lose time, ideas, skills by ignoring employee ideas | Resistance to change | PP, SW, 5WA, C&E |
| 5 | Transportation of materials | Unnecessary transportation of materials | Poor housekeeping | 5S, VSM, SW, 5WA, C&E |
| 6 | Inventory Excess | Over stock of raw materials, WIP and final products | Poor material planning | Pareto, ABC-XYZ, 5WA, C&E |
| 7 | Motion of people | Perform unnecessary movements for work | Poor housekeeping | 5S, VSM, SW, 5WA, C&E |
| 8 | Excess Processing | More work or higher quality than required | Lack of standardization | 5S, VSM, SW, 5WA, C&E |

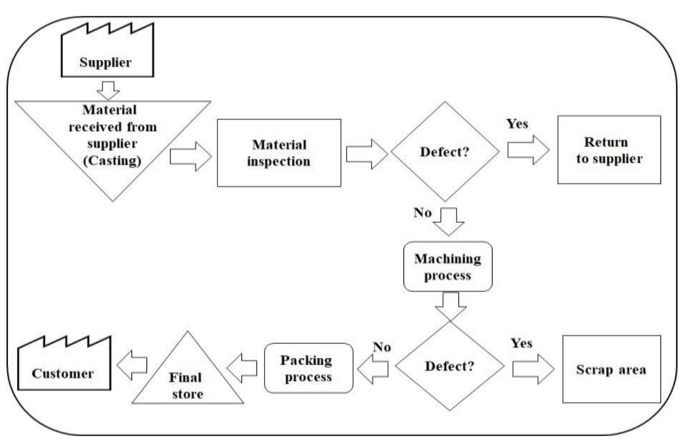


Fig. 5. Production process flow chart for the major spare parts.

TABLE 8

AVERAGE QUALITY % AND PROCESS LEAD TIME (BEFORE IMPROVEMENT)

| Working Day # | Average Quality % (First Time) | Average Lead Time (hours/ton) |
|---|---|---|
| 1 | 81.1 | 10.84 |
| 2 | 80.0 | 10.78 |
| 3 | 80.8 | 10.76 |
| 4 | 79.3 | 10.84 |
| 5 | 80.7 | 10.75 |
| 6 | 79.9 | 10.69 |
| 7 | 80.6 | 10.63 |
| 8 | 81.9 | 10.86 |
| 9 | 81.0 | 10.84 |
| 10 | 81.5 | 10.77 |
| 11 | 80.8 | 10.73 |
| 12 | 80.5 | 10.63 |
| 13 | 81.5 | 10.85 |
| 14 | 82.2 | 10.64 |
| 15 | 80.5 | 10.72 |
| 16 | 80.3 | 10.84 |
| 17 | 80.5 | 10.87 |
| 18 | 81.3 | 10.78 |
| 19 | 79.9 | 10.84 |
| 20 | 81.2 | 10.65 |
| 21 | 78.0 | 10.83 |
| 22 | 79.2 | 10.67 |
| 23 | 81.6 | 10.79 |
| 24 | 80.6 | 10.66 |
| 25 | 79.8 | 10.71 |
| Average | 80.59 | 10.76 |
| Range | 4.2 | 0.24 |
| Standard Deviation | 0.9293 | 0.0809 |
| Coefficient of Variance % | 1.15% | 0.75% |
| Range % | 5.21% | 2.23% |

TABLE 9

MAIN DEFECT LIST FOR THE MACHINING PROCESS (BEFORE IMPROVEMENT).

| # | 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.

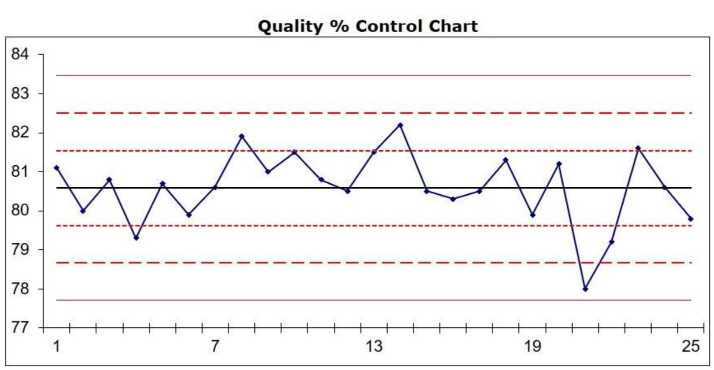


Fig. 6. Quality Control Chart (Before improvement).

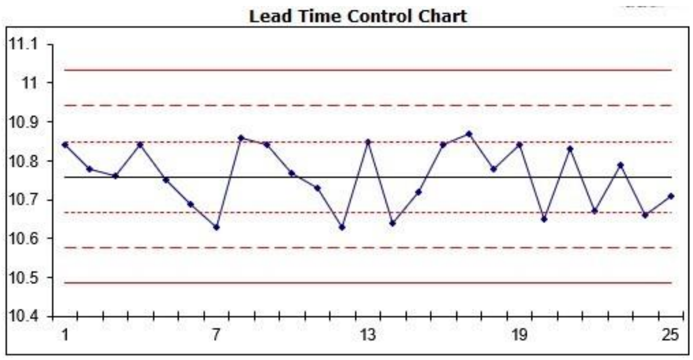


Fig. 7. Lead Time Control Chart (Before improvement).

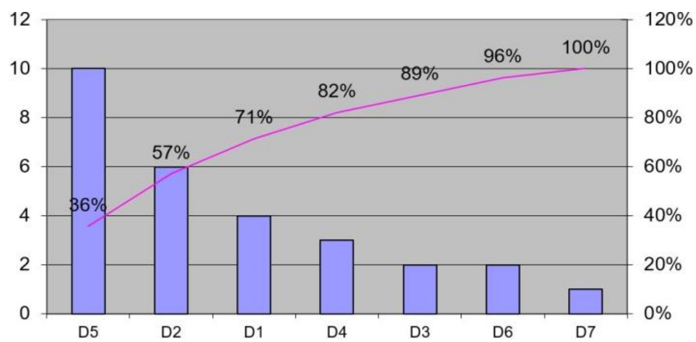


Fig. 8. Pareto chart of defect types (before improvement).

TABLE 10
. ABC-HML CLASSIFICATION FOR PROCESS DEFECTS.

| | | | | |
|---|---|---|---|---|
| **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** |

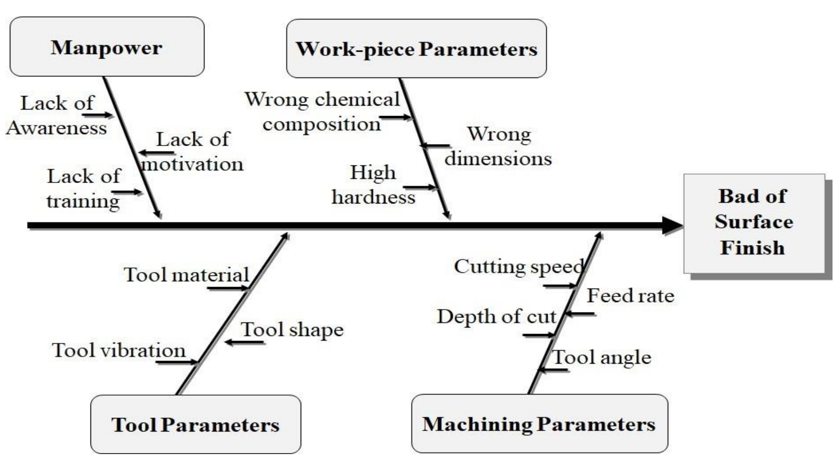


Fig. 9. C&E diagram for bad of surface finish.

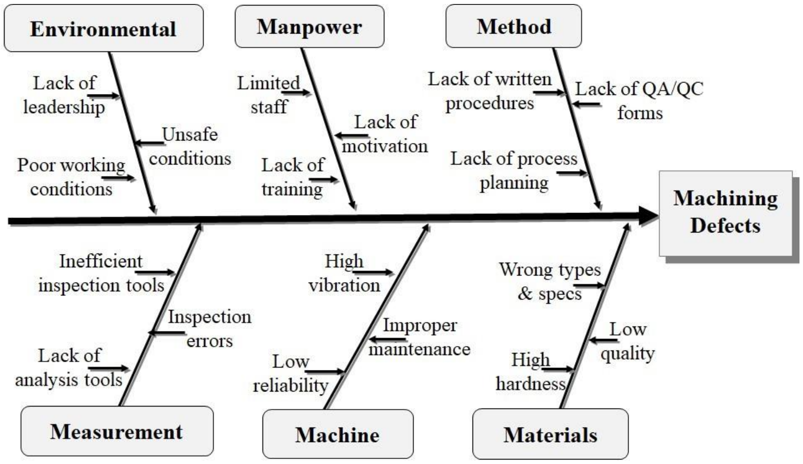


Fig. 10. Fishbone Diagram for Machining Defects.

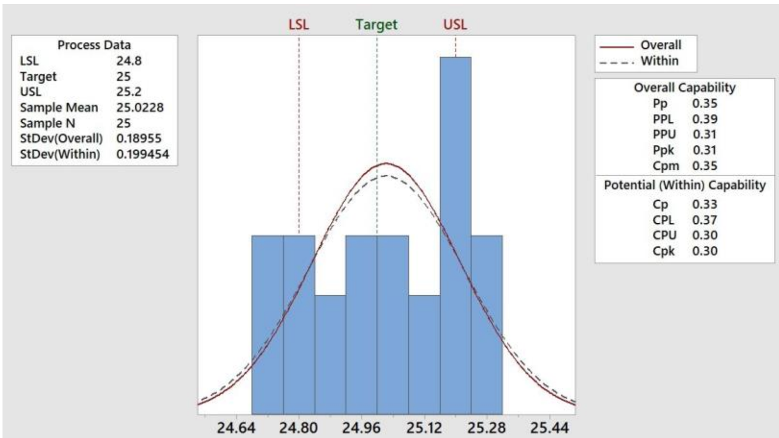


Fig. 11. Process capability analysis (before improvement).

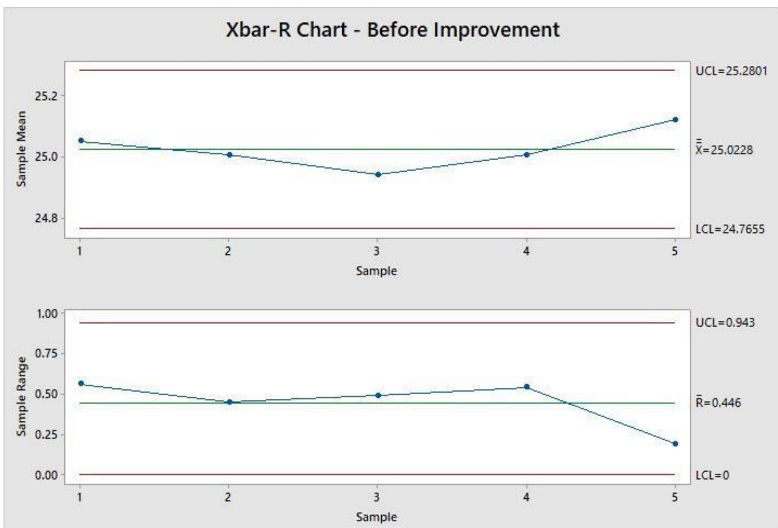


Fig. 12. Process control charts (before improvement).

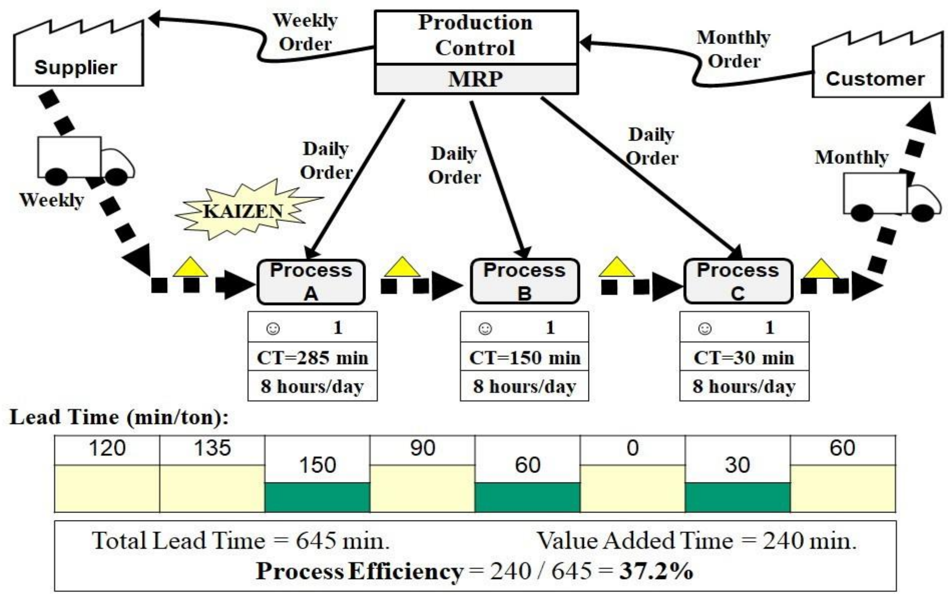


Fig. 13. Value stream mapping (before improvement).

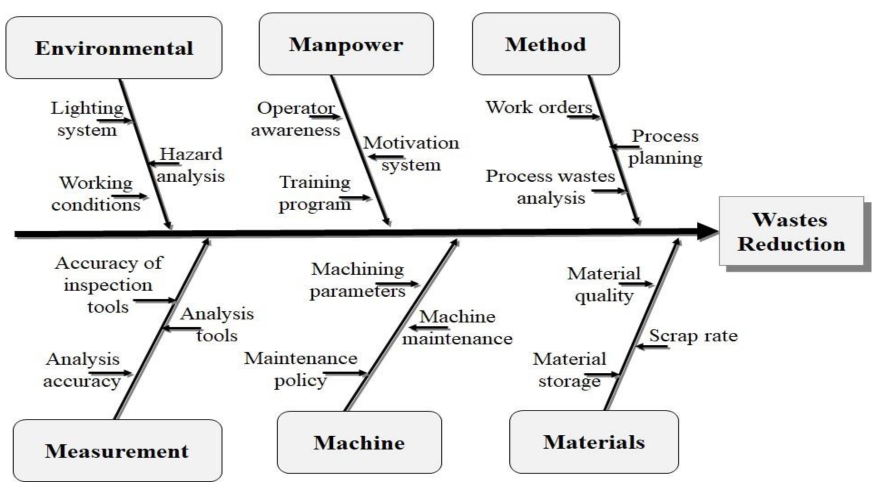


Fig. 14. C&E diagram for non-value-added reduction.


Fig. 15. Quality control chart (after improvement).

TABLE 12
A SUMMARY OF MONTHLY IMPROVEMENT PLAN (DURING THREE MONTHS)

| Activity Type | Main Activities | Duration | Frequency of check | Responsibility |
|---|---|---|---|---|
| Material | - Visual control (7 S)<br>- Material classification<br>- Material Defect Analysis | 4 weeks | Daily | Material Leader |
| Method | - QA / QC check list<br>- Standard procedure & doc.<br>- Standard time analysis | 4 weeks | Weekly | Quality Leader |
| Machine | - Check machining parameters<br>- Process time analysis<br>- Value added time analysis | 4 weeks | Daily | Process Leader |
| Manpower | - KAIZEN training program<br>- Advanced training program<br>- Update motivation program | 4 weeks | Weekly | Process Leader |
| Measurement | - Accuracy of inspection tools<br>- Sampling size and analysis<br>- Auditing system | 4 weeks | Weekly | Quality Leader |
| Environmental | - Visual control (7 S)<br>- Improve working conditions<br>- Job hazard analysis (JHA) | 4 weeks | Weekly | Safety Leader |

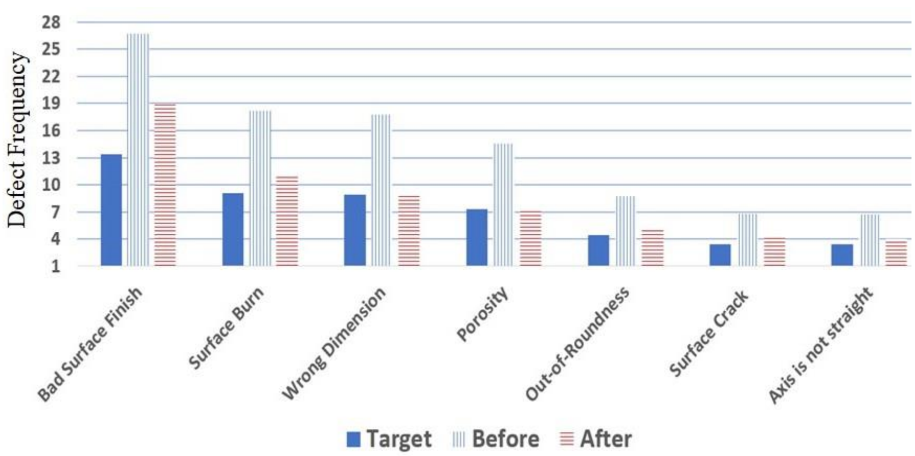


Fig. 16. Defect frequency (before and after improvement).

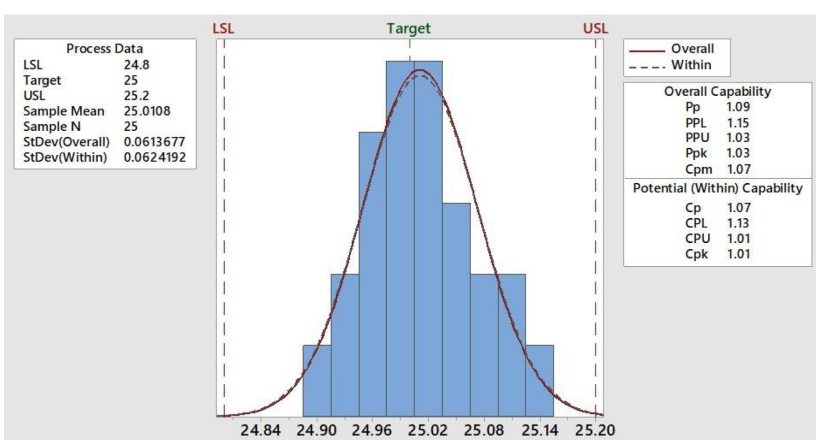


Fig. 17. Process capability analysis (After Improvement).

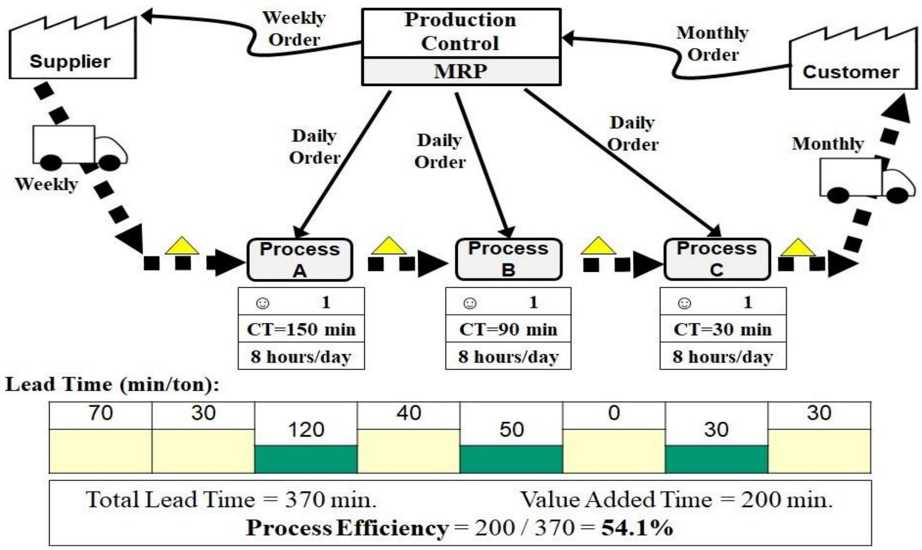


Fig. 18. Value stream mapping (After improvement).

TABLE 13
A SUMMARY OF PROCESS PERFORMANCE INDICATORS (BEFORE AND AFTER IMPROVEMENT)

| Indicators | Unit | Target | Before | After |
|---|---|---|---|---|
| Product quality (first time) | % | ≥ 90 | 80.6 | 85.1 |
| Product quality (after rework) | % | ≥ 95 | 85.7 | 89.0 |
| Sigma level (first time) | # | ≥ 2.8 | 2.36 | 2.54 |
| Sigma level (after rework) | # | ≥ 3.14 | 2.57 | 2.73 |
| Process lead time | min./ton | ≤ 360 | 645 | 370 |
| Process Efficiency | % | ≥ 60 | 37.2 | 54.1 |
| OEE | % | ≥ 80 | 75 | 81 |
| Value added | % | ≥ 55 | 50 | 54 |
| Customer satisfaction | % | ≥ 92 | 87 | 89 |

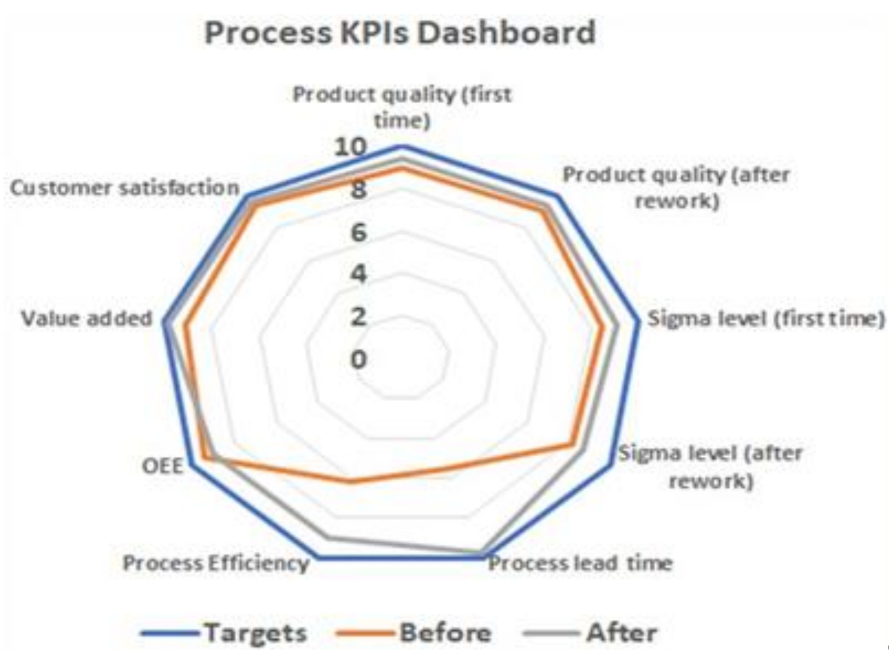


Fig. 19. A summary of process performance indicators (before and after improvement)

## IV. CONCLUSION

Lean six sigma (LSS) allows supply chain manage- ment (SCM) to become more effective and efficient, and has become a competitive tool. In this context, this study focuses on the implementation of the LSS-SCM frame- work in a spare parts company in Egypt. A general LSS- SCM framework has been developed. This framework provides a roadmap and step-by-step implementation of LSS-SCM especially in manufacturing domain. Accord- ing to the analysis of the current situation, the production process was the most influential area in improving SCM, and therefore it was focused on in this study, and we will address improving the rest of the SCM elements in future research. The main results were improving product quality, increasing sigma level, reducing processing lead time, improving overall equipment effectiveness (OEE), increasing added value, and improving customer satisfaction.

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