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Improving Shutdown Maintenance Management Performance Using Lean Six Sigma Approach: A Case Study

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Abstract: Shutdown maintenance is a critical process in various industries due to process downtime losses. Lean Six Sigma (LSS) in shutdown maintenance is a systematic approach for continuous improvement to achieve shutdown objectives and reduce downtime. Through a systematic review of relevant literature, case studies, and published materials, this study investigates the potential of LSS principles to improve project management performance. An integrated LSS DMAIC framework was developed to improve the shutdown maintenance efficiency. Furthermore, a case study conducted for maintenance shutdown project in one of the petrochemical companies in Egypt. Results indicate that the proposed methodology is successful in improving shutdown project KPIs. For example, planned maintenance improved from 86% to 93%, operational reliability improved from 72% to 79%, and shutdown project efficiency improved from 62.3% to 69.7 %.

Keywords: *: Shutdown, project management, LSS, DMAIC, TQM, continuous improvement*

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I. INTRODUCTION

Shutdown maintenance, often referred to as planned maintenance or turnaround maintenance, is a proactive approach to maintaining and improving the reliability of industrial assets. It involves the scheduled shutdown of a facility or a specific piece of equipment to carry out necessary maintenance, repairs, inspections, and upgrades. This periodic downtime is a planned event, unlike unexpected breakdowns, and is an integral part of industrial asset management. [1]; [2].

Lean six sigma (LSS) approach aims for improving process efficiency and effectiveness. Efficiency shows how productively resources are used to achieve the project objectives. Effectiveness is a measure of the relevance of these objectives to the customer satisfaction. Efficiency is about doing things right and effectiveness is about doing the right thing. As shown in Fig. (1), LSS approach combines lean manufacturing and six sigma techniques. LSS uses DMAIC (Define, Measure, Analyze, Improve, Control) for problem solving in a structured and systematic approach manner, see Fig. (2). LSS uses many tools in order to get the best of the two methodologies, increasing speed while also increasing accuracy. Fig. (3) shows the main LSS tools, and adopting these tools can help project managers significantly improve quality, reduce time and cost, align project objectives with customer requirements, and enhance the culture of continuous improvement. LSS in shutdown management is a systematic approach to emphasize value-added, minimize waste, reduce defects, and control quality, time, costs, and risk., [3]; [4]; [5]; [6]).

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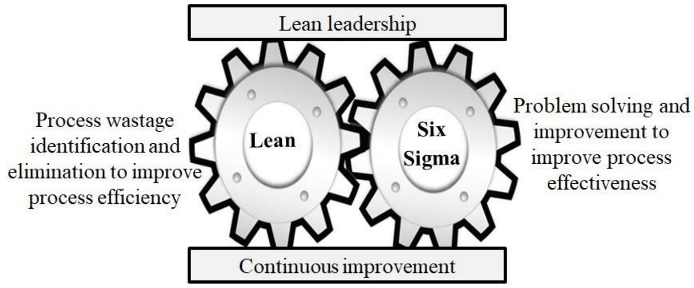

Fig. 1. LSS concept.

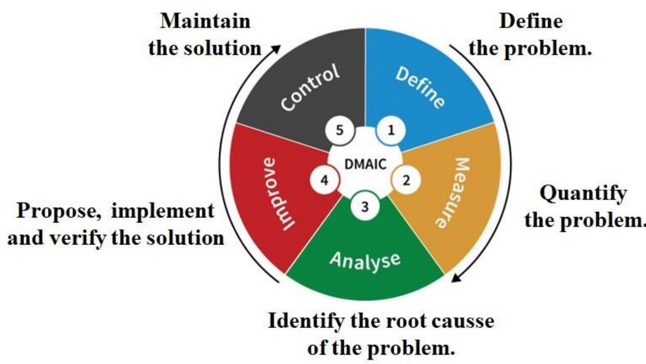

Fig. 2. LSS DMAIC cycle.

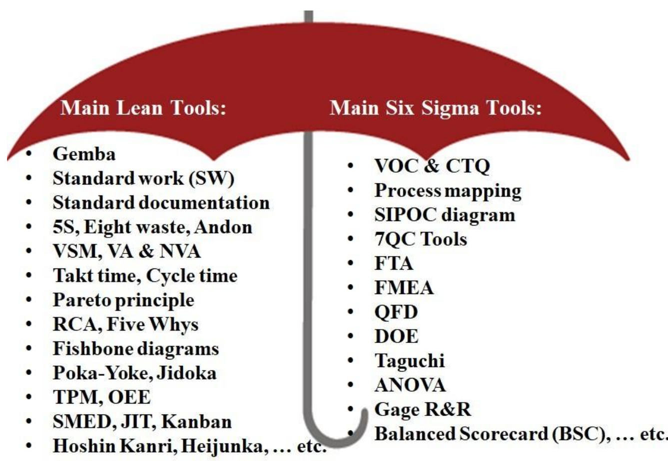

Fig. 3. Main LSS tools.

Having reviewed the literature, it is clear that a large number of research studies have demonstrated the efficiency of LSS in routine maintenance systems. However, this study is one of the few attempts to apply LSS in a shutdown maintenance system on critical equipment. The objective of this study is to develop an integrated LSS DMAIC framework to improve the performance of shutdown management. The paper is structured as follows: Section 2 presents a literature review. The research framework and methodology are described in Section 3. The case study is outlined in Section 4. Results and discussion in Section 5, Section 6 highlights the conclusion and future work.

II. LITERATURE REVIEW

Several studies have focused on the applications of maintenance process and LSS in manufacturing domain. Table (1) presents a comprehensive survey of maintenance and LSS studies, and they are classified based on contribution, application, main objectives and main LSStools. As a result of previous studies, it is clear that a large number of research studies have proven the efficiency of LSS in routine maintenance systems. However, this studyis one of the few attempts to apply LSS in a shutdown management on critical equipment. The proposed LSS framework may help improve shutdown management efficiency and thus contribute to their quest for continuous improvement.

TABLE 1
TPM AND LSS STUDIES IN MAINTENANCE PROCESS (2017-2024).

#	Contribution	Application	Main objectives	Main LSS Tools
[7]	Proposed TPM framework for inspections and repairs	A case study in machinery fleet	- Improving OEE	TPM, 5S, OEE
[2]	Proposed DMAIC framework for maintenance	A case study in dairy industry	- Reducing maintenance downtime	DMAIC, Project charter, VOC, Process mapping, SIPOC, TPM, 5S.
[8]	Proposed TPM framework for inspections and repairs	A case study in Pharmaceutical Manufacturing	- Reducing maintenance downtime	TPM, 5S, t-test
[9]	Proposed TPM framework	A case study in Cement Plant	- Improving OEE	TPM, 5S, OEE
[1]	Proposed LSS DMAIC framework for maintenance	A case study in a petrochemical company	- Improving OEE - Improving Reliability	DMAIC, VOC, SIPOC, VSM, KPIs, FMEA, RCA, TPM, 5S.
[10]	Developed lean maintenance framework	A case study in wiring harness production	- Reducing unplanned downtime. - Reducing MTTR	TPM, RCM, VSM, RCA, 5S.
[11]	Proposed LSS for maintenance	A case study in a pharmaceutical ingredient plant	- Improving OEE - Reducing corrective maintenance	DMADV, TPM, RCM, FMEA, OEE, VSM, RCA, 5S, Pareto, KPIs.
[12]	Developed LSS for maintenance process	A case study in oil service company	- Improving maintenance process efficiency - Increasing availability	DMAIC, TPM, SIPOC, Statistical tests.
[13]	Reported LSS for sustainable maintenance	A case study in floor coverings company.	- Improving machine availability - Reducing failure time	DMAIC, CTQ, TPM, 5S, SIPOC, Charts, Statistical tests.
[14]	Developed a framework for lean maintenance	A case study in aviation industry	- Improving maintenance process efficiency	JIT, TPM, Poka-Yoke, Simulation, flow chart
[15]	Proposed TPM framework	A case study in crude oil processing	- Improving OEE - Reducing corrective maintenance	TPM, 5S, OEE
[16]	Proposed a framework for lean maintenance	A case study in aircraft maintenance	- Reducing aircraft downtime	VOC, VSM, TPM, 5S, Poka-Yoke, PDCA.
[17]	Developed a framework for lean maintenance	A case study in a coal handling plant	- Improving overall plant availability	TPM, VSM, Pareto Chart, 5S.
[18]	Reported a framework for lean maintenance	A case study in a textile company	- Increasing equipment availability	Takt time, VSM, OEE, 5S, SMED, flow chart.
[19]	Developed a framework for lean maintenance	Three case study in oil and gas fields	- Improving planned maintenance (PM) % - Improving production	TPM, VSM, 5S, KPIs, Process flow chart.
[20]	Proposed a framework for lean maintenance	A case study in die maintenance process	- Reducing maintenance downtime	VSM, Process flow map, 5S.
[21]	Developed a TPM framework	A case study in CNC Lathes	- Reducing downtime - Improving OEE	TPM, 5S, 5Why.
[22]	Proposed a six sigma framework	A case study in production machines	- Improving equipment availability	Process map, FMEA, SIPOC, SW.

III. RESEARCH FRAMEWORK AND METHODOLOGY

The primary objective of this section is to propose a LSS framework for shutdown management to improve the maintenance process efficiency. Based on in-depth analysis of the literature review, LSS DMAIC framework was developed using various analysis and improvement tools. DMAIC methodology used in LSS is a disciplined and structured process used in solving project problems and achieving continuous improvement. If there is a problem in the process that prevents the project from producing high-quality products and services efficiently and consistently within the specified time and at low cost, LSS-DMAIC tools help identify the root cause of the defects. Table (2) shows the proposed LSS-DMAIC framework for project management. Details of the DMAIC frame- work are provided in the following subsections.

A. Define Phase

The purpose of this phase is to clarify the project scope of work and identify the objectives and problems. This phase can be summarized in the following main steps:

- Step #1: Defining scope of work and main objectives.
- Step #2: Building process improvement teamwork.
- Step #3: Defining system selection and required information.
- Step #4: Identifying Problem Statement
- Step #5: Defining the customer requirements
- Step #6: Defining project network
- Step #7: Formulate the project plans
- Step #8: Defining process mapping.
- Step #9: Defining project supply chain.

B. Measure phase

This phase aims to document and understand the cur- rent state of the system and identify important metrics related to maintenance quality and performance. This phase can be summarized in the following main steps:

- Step #10: Designing standard templates & collecting the required information.
- Step #11: Assessing the current state of design, plans, delivery, . . . etc.
- Step #12: Measuring the current performance evaluation.
- Step #13: Measuring the current Sigma Level.
- Step #14: Preparing the maintenance value stream mapping (Before improvement).
- Step #15: Identifying the top failures for the critical equipment

C. Analyze Phase

The purpose of this stage is to analyze the problems and shortcomings of the system and determine the root cause of the problems. This phase can be summarized in the following main steps:

- Step #16: Constructing risk assessment & maintenance strategies.
- Step #17: Analyzing project risk & proactive strategies.
- Step #18: Analyzing problems root causes (RCA).
- Step #19: Constructing fishbone diagram.
- Step #20: Constructing Failure Mode Effect Anal- ysis (FMEA).

D. Improve phase

This phase begins by listing the recommendations and solutions obtained during the analysis phase. This phase can be summarized in the following main steps:

- Step #21: Constructing project risk register.
- Step #22: Preparing the proposed improvement recommendations.
- Step #23: Preparing project standardization system
- Step #24: Preparing the project improvement plan
- Step #25: Training the teamwork groups.
- Step #26: Implementing kaizen & lean principles
- Step #27: Implementing changes and monitoring progress.
- Step #28: Updating the project Value Stream Map- ping (After improvement).

E. Control Phase

In this phase, the project team develops a control plan to monitor and maintain the improvement plan. This phase can be summarized in the following main steps:

- Step #29: Controlling before/after KPIs analysis.
- Step #30: Creating a culture of continuous improvement.
- Step #31: Documenting and standardizing the pest practice.
- Step #32: Providing advanced training and support.
- Step #33: Preparing project close-out report (annual report).
- Step #34: Communicating results & learned lessons.

TABLE 2
PROPOSED LSS-DMAIC FRAMEWORK FOR PROJECT MANAGEMENT

Phase	Objectives	Key Activities	Used Tools
Define	Studying project, process, resources and problems in detail.	1) Defining scope of work and main objectives	• Brainstorming
		2) Building process improvement teamwork	• Brainstorming
		3) Defining system selection and required information	• Brainstorming
		4) Identifying problem statement	• Brainstorming
		5) Defining the customer requirements	• Voice of customer
		6) Defining shutdown project network	• Network
		7) Formulate the shutdown project plans	• Gantt Chart
		8) Defining process mapping	• Process flow chart
		9) Defining shutdown project supply chain	• SIPOC diagram
Measure	Designing and collecting the required information.	10) Designing standard templates & collecting information	• Brainstorming
		11) Assessing the current state of design, plans, delivery, … etc.	• Brainstorming
		12) Measuring the current performance evaluation	• KPIs Dashboard
		13) Measuring the current sigma level	• Sigma level
		14) Preparing the project value stream mapping	• VSM
		15) Identifying the top problems, failures and risks	• Brainstorming • Rule 80/20
Analyze	Applying analysis tools and identifying root causes	16) Constructing risk assessment & proactive strategies	• Risk assessment
		17) Analyzing project risk & proactive strategies	• Risk matrix
		18) Analyzing problems root causes	• Pareto chart • RCFA
		19) Constructing fishbone diagrams	• Fishbone diagram
		20) Constructing Failure mode effect analysis	• FMEA
Improve	Implementing solutions according to priorities	21) Constructing project risk register	• Brainstorming
		22) Preparing the proposed improvement recommendations	• Brainstorming
		23) Preparing project standardization system	• SW
		24) Preparing the project improvement plan	• Brainstorming
		25) Training the teamwork groups	• Training program
		26) Implementing kaizen & lean principles	• Kaizen, 5S, SW, • 8 lean wastes
		27) Implementing changes and monitoring progress	• Brainstorming
		28) Updating the project value stream mapping	• VSM
Control	Monitoring the process and achieving daily improvements	29) Controlling before/after KPIs analysis	• KPIs, OEE
		30) Creating a culture of continuous improvement	• Kaizen events
		31) Documenting and standardizing the pest practice	• Auditing
		32) Providing advanced training and support	• Brainstorming
		33) Preparing project close-out report	• Close-out report
		34) Communicating results & learned lessons	• Brainstorming

IV. CASE STUDY

The proposed framework is validated with a case study conducted for maintenance shutdown project in one of the petrochemical companies in Egypt. A case study of a feedwater pumping station in a steam system is used to illustrate the proposed framework. Furthermore, this section discusses the results obtained before and after applying the LSS approach in the shutdown project. The project charter is the first step in an LSS-PM project. It is a roadmap consisting of details of the problem statement, scope, objectives, timeline, and teamwork. Detailsof the DMAIC framework are provided in the followingsubsections.

A. Define Phase

The purpose of this stage is to clarify the scope of work and identify the main objectives and problems. The scope of work of this study was to improve the shutdown project of the feedwater pumping station in the steam system. The main objectives were to improving shutdown project efficiency and effectiveness. Fig. (4) shows process flow diagram (PFD) for the selected project. Fig (5) and Fig. (6) shows the maintenance process mapping for the selected case. Based on historical information, the main problem with this pump is the pump bearing failure.

B. Measure Phase

This phase aims to document and understand the current status of the shutdown process and identify important metrics related to maintenance shutdown quality and project process performance. As shown in Fig. (7), based on equipment history, the equipment maintenance KPIs are planned maintenance (PM%), mean time between failure (MTBF), and mean time to repair (MTTR). Fig. (8) shows maintenance value stream mapping (before improvement). As shown in this figure, the efficiency of the maintenance process is about 62.3% and therefore the non-value-added is about 37.7%.

To identify and reduce non-value-added elements, two main tools were applied, namely lean eight wastes and visual control (5S). The heart of lean is the identification and elimination of waste, known in Japanese as muda. As shown in Table (3), there are eight types of waste (DOWNTIME) that an organization must removefrom a value stream:

- Defects – Repair or rework and excessive scrap
- Waiting – Excessive idle time between steps
- Overproduction – Producing items not demandedby the customer
- Not utilizing talent - Skills – Unused employeecreativity
- 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

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 establishedorder. This system usually is the result of a discussion about standardization, which helps workers understand how the job should be done. Table (4) shows implementation of 5S in maintenance process.

C. Analysis Phase

The purpose of this stage is to analyze problems and identify root causes. Fig. (9) shows Why-Why Analysis for pump bearing failure. Fig. (10) shows Fishbone diagram for pump station failure based on equipment items. Fig. (11) shows Fishbone diagram for pump station failure based on maintenance process inputs.

D. Improve Phase

This stage focuses on listing the recommendations and solutions obtained during the analysis stage. Based on several brainstorming sessions, Table (5) shown FMEA for the centrifugal pump. Table (6) shows the main recommendations to update the PM Program.

E. Control Phase

At this stage, the brainstorming team 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. Further- more, actions taken for continuous process improvement 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. Fig. (12) shows maintenance value stream mapping (after improvement).As shown in this figure, the efficiency of the maintenance process is about 69.7% and therefore the non-added value is about 30.1%.

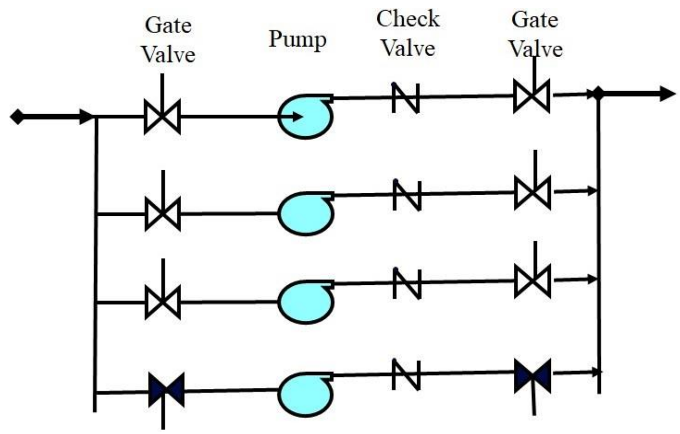

Fig. 4. Process flow diagram (PFD) – (4 pumps: 3 running + 1 standby).

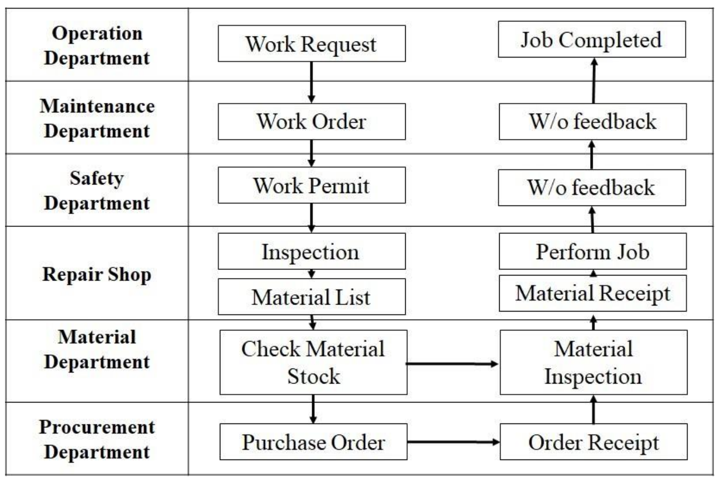

Fig. 5. Process flow chart for maintenance process.

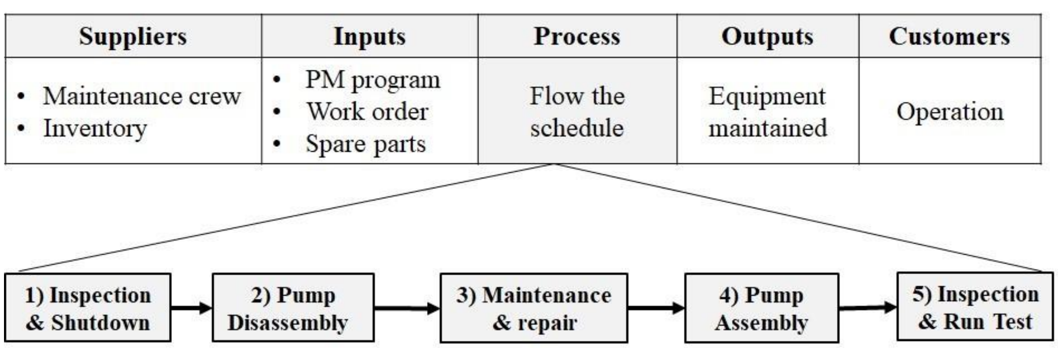

Fig. 6. SIPOC diagram for maintenance process.

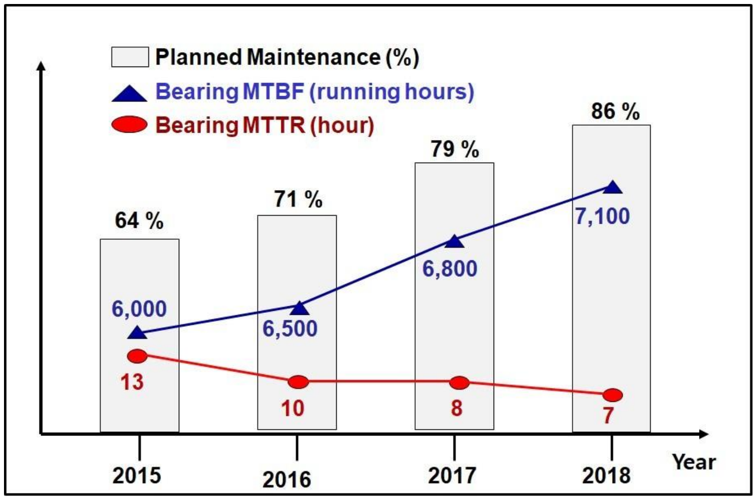

Fig. 7. History equipment maintenance KPIs

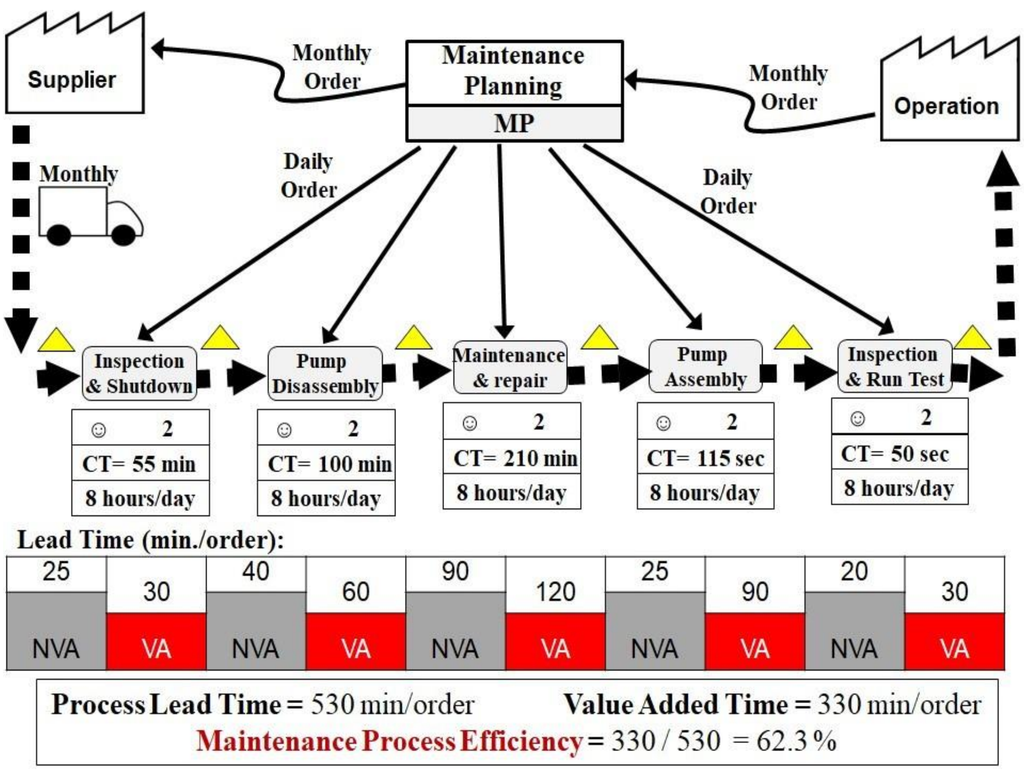

Fig. 8. Maintenance value stream mapping (before improvement).

TABLE 3
LEAN WASTES (DWONTIME) ANALYSIS FOR PROJECT PROCESSES.
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#	Waste Type	Waste Examples	Root Cause	Main LSS tools
1	Defects	Equipment failures	Lack of motivation	Pareto chart Cause–effect diagram
2	Waiting	Waiting times between maintenance activities Waiting times for materials Waiting times for handling	Poor coordination	Value stream mapping (VSM) Total productive maintenance (TPM)
3	Over-Production	Over works	Poor planning	Process planning Standard work
4	Not Utilizing Talent	Unused talent and skills of people	Resistance to change	Advanced training Motivation program
5	Transportation of materials	Materials and tools transportation	Poor housekeeping	5S (Visual control) Value stream mapping (VSM)
6	Inventory Excess	Overstocked of materials	Poor material planning	Material classification Material planning
7	Motion of people	Unnecessary motion of people	Poor housekeeping	5S (Visual control) Standard work
8	Excess Processing	Excessive or too frequent maintenance activities	Lack of standardization	Standard work Advanced training

TABLE 4
IMPLEMENTATION OF 5S IN PROJECT PROCESSES.

5S Steps	Examples	Solution
Sort	There is a lot of unnecessary or outdated information.	Remove all unnecessary or outdated information.
	Rejected parts are kept inside the site.	Rejected parts are removed and space is freed.
Set in Order	Previous stains on the floor hinder the movement of materials using the cart.	The patches are filled with cement, which helps the material flow smoothly.
	Materials and tools are placed randomly in the shelves and no labels are placed on them.	Materials and tools are stored in their designated places with labels.
	No labels	Create labels for all components.
Shine	Work place not very tidy and clean.	Clean and tidy work place. Floor garbage removal.
Standardize	There are no standard documents (work order, work permit, quality inspection list, etc.)	Create standard work order Create standard safety permit Create standard quality inspection Create standard work procedures
Sustain		Project objectives and KPIs are presented in Arabic and English. Keep all changes

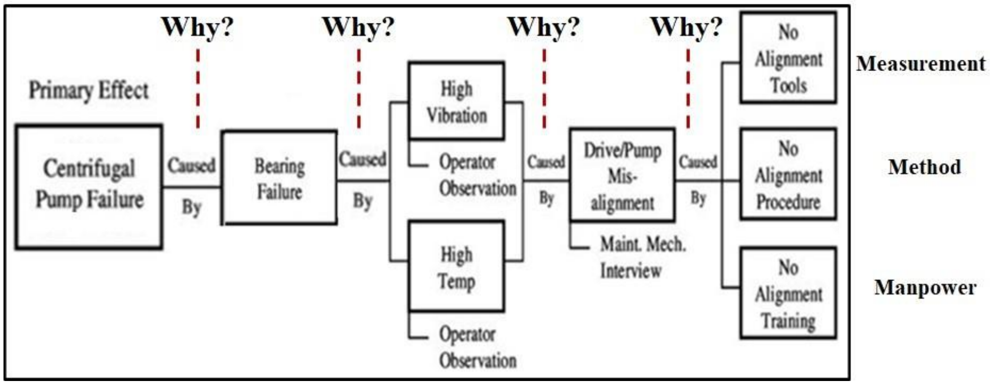

Fig. 9. Why-Why analysis.

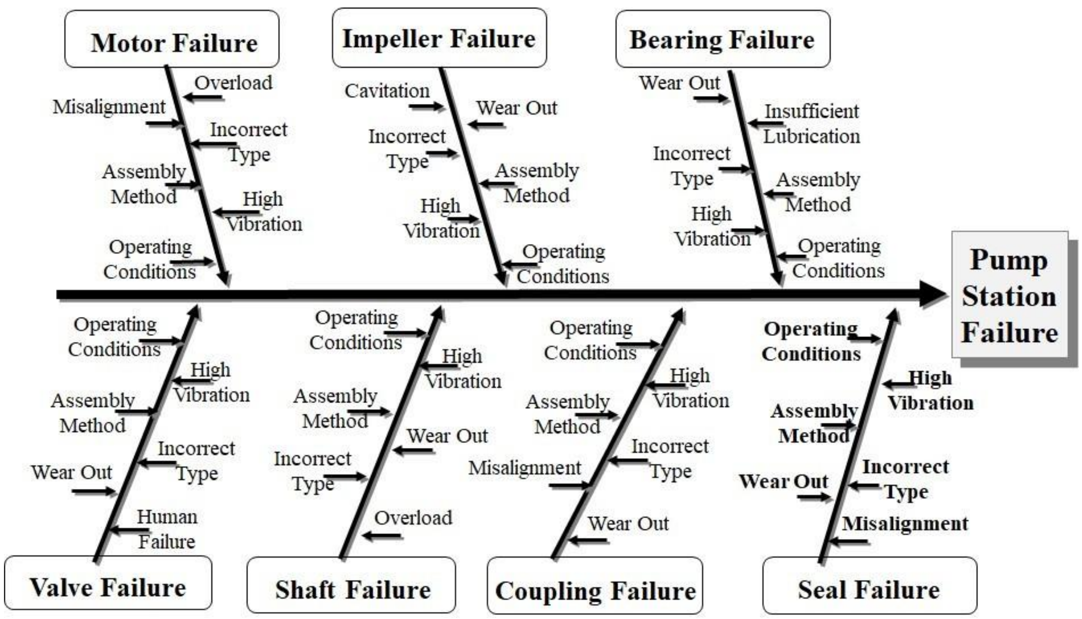

Fig. 10. Fishbone diagram based on equipment items.

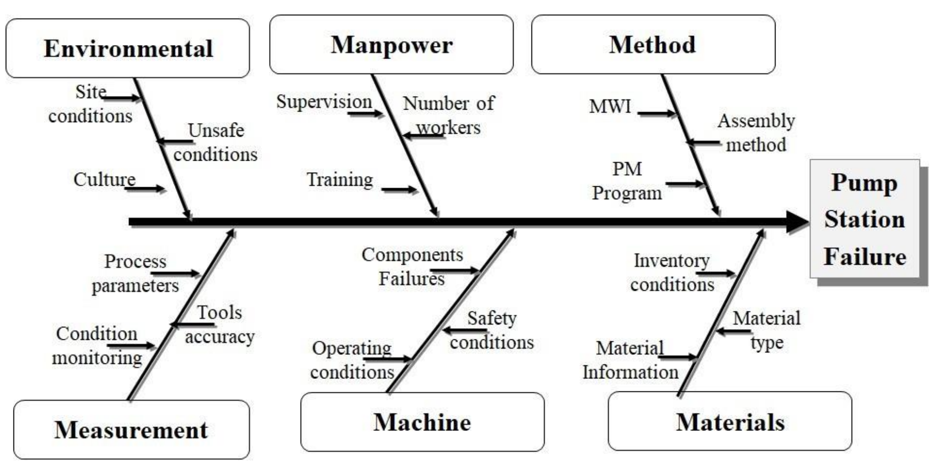

Fig. 11. Fishbone diagram based on maintenance process inputs.

TABLE 5
FMEA FOR THE CENTRIFUGAL PUMPS

Identify			Analysis			Control	
	Description	Failure Mode	Failure Cause	Failure Effect	Risk Level	Maintenance Task	Frequency
Functions	Fluid Flow	No flow	- Overloaded motor	Motor failure	H	- Check misalignment - Check motor	Quarter
		Insufficient flow	- Cavitation on impeller - Insufficient NPSH	Low pump efficiency	M	- Check impeller - Check NPSH	Quarter
	Fluid Head	Insufficient head	- Cavitation on impeller - Insufficient NPSH	Low pump efficiency	M	- Check impeller - Check NPSH	Quarter
Main Items	Mechanical Seal	Fluid leakage	- Seal fails - Poor maintenance	Leakage Low pump efficiency	M	- Check seal - Material selection	Quarter
	Pump Bearing	Excessive vibration	- Bearing fails - High bearing temp. - Poor maintenance	Bearing failure	M	- Check misalignment - Check bearing temp. - Check bearing vib.	Quarter
	Impeller	Insufficient head	- Cavitation - Insufficient NPSH - Poor maintenance	Low pump efficiency	M	- Check impeller - Check NPSH	Quarter
	Coupling	Excessive vibration	- Coupling damage	Misalignme nt	M	- Check misalignment	Quarter

TABLE 6
MAIN RECOMMENDATIONS TO UPDATE THE PM PROGRAMS

PM Level	Pump	Coupling	Motor	Valves	Pipeline
Every 1,000 RH	Check	Check	Check	Check	Check
Every 2,000 RH	Check	Check	Check	Check	Check
Every 4,000 RH	Replace Seal	Check	Check	Check	Check
Every 8,000 RH	Replace Seal & Bearing	Repair / Replace	Check	Check	Check
Every 16,000 RH	Replace Seal & Bearing	Repair / Replace	Replace Bearing	Check	Check
Every 32,000 RH	Replace Seal & Bearing	Repair / Replace	Replace Bearing	Repair / Replace	Check

V. RESULTS AND DISCUSSION

This section discusses the results obtained before and after applying the proposed framework. Table (7) and Fig. (13) show a summary of maintenance performance indicators (after 2 years continuous improvement). Results indicate that the proposed methodology is successful in improving maintenance shutdown efficiency and effectiveness. For example, planned maintenance improved from 86% to 93%, operational reliability improved from 72% to 79%, and shutdown project efficiency improvedfrom 62.3% to 69.7 %.

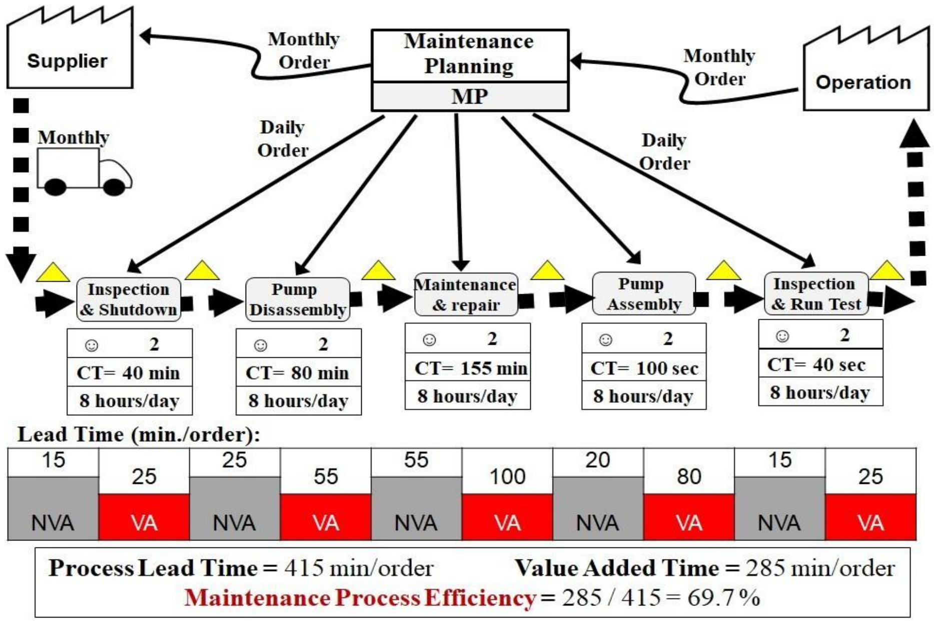

Fig. 12. Maintenance value stream mapping (after improvement).

TABLE 7
A SUMMARY OF MAINTENANCE PERFORMANCE INDICATORS

Indicators	Unit	Target	Before Improvement	After Improvement
1) Planned Maintenance	%	≥ 95%	86%	93%
2) Bearing MTBF	hours	≥ 8,200	7,100	7,800
3) Bearing MTTR	hours	≤ 5.0	7.0	6.0
4) Operational Reliability	%	≥ 95%	72%	89%
5) Maintenance Process Efficiency %	%	≥ 75%	62.3 %	69.7 %

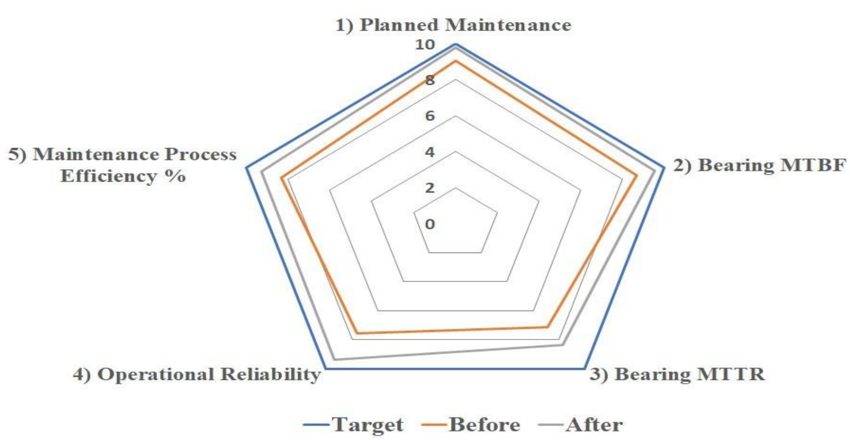

Fig. 13. Shutdown project KPIs dashboard.

VI. CONCLUSION

Lean six sigma (LSS) approach aims for improving customer satisfaction while reducing waste and defects. The study strongly argues for the use of LSS concepts to increase the effectiveness and efficiency of project management. Adopting LSS tools can help project managers significantly improve quality, reduce time and cost, align project objectives with customer requirements, and enhance the culture of continuous improvement. this study investigates the potential of LSS principles to improve project management efficiency and effectiveness. LSS critical failure factors (CFFs) in project management are discussed. The results found that applying LSS in project management can help project managers significantly improve quality, reduce time and cost, align project objectives with customer requirements, and enhance the culture of continuous improvement. An integrated LSS-PM framework was developed to improve the efficiency and effectiveness of project management. Furthermore, a case study conducted for maintenance shutdown project in one of the petrochemical companies in Egypt. Results indicate that the proposed methodology is successful in improving maintenance shutdown efficiency and effectiveness. For example, planned maintenance improved from 86% to 93%, operational reliability improved from 72% to 79%, and shutdown project efficiency improvedfrom 62.3% to 69.7 %.

As future research, it is proposed to expand the study to include the company's critical production equipment, where the criticality system and risk assessment and thus other control points in the production line can be analyzed, to further evaluate the effectiveness of the LSS method and the results. The extension of the data recording and analysis period can also be used to draw conclusions regarding the production of defective products.

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