Maintenance Process Improvement Model by Integrating LSS and TPM for Service Organisations

Barrak Alsubaie and Qingping Yang

Abstract This paper presents an integrated model to provide guidance and support for those organisations who aim to reach world-class standards in maintenance processes through continual improvement. A strategic model has been developed through conceptual integration of three popular process improvement strategies, which are six sigma, total productive maintenance (TPM) and lean. Lean Six Sigma can operate in parallel with the TPM strategy and will make it easier to understand by shop floor operators. The application of the model has been demonstrated using a case study in maintenance of a fleet of military vehicles. The proposed model is very generic in nature and can be applied to any service organisations with maintenance functions to achieve high process performance and overall equipment effectiveness.

Keywords Lean Six Sigma • TPM Strategy • Integrating Lean Six Sigma and TPM • Maintenance Process Improvement

List of Abbreviations

A	Availability
CTQ	Critical to quality characteristics
DMAIC	Define, measure, analyse, improve and control
DPMO	Defect per million opportunities
LSS	Lean Six Sigma
MTBF	Mean time between failures
OEE	Overall equipment effectiveness
PE	Performance rate
PM	Preventive maintenance
Q	Quality rate
SIOPC	Supplier-input-process-output-customer
SMED	Single minute exchange of dies

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TPM	Total productive maintenance
VOC	voice of customer

1 Introduction

Maintenance management refers to the process of scheduling and allocating resources to the maintenance activities (repair, replacement and preventive maintenance) [1]. The leading objective of the maintenance function in any organization is to maximize asset performance and optimize the use of maintenance resources. The implementation of current maintenance management systems has not reached the expected level of success (e.g. maintenance schedules are not implemented on time, and priorities are difficult to identify) [2]. The underlying reason is the lack of maintenance management skills and practical experience, which leads to poor impacts and negative effects on performance [2]. Unnecessary repair or inspection will increase maintenance budget commitments and may decrease quality performance, as described by [3] concerning the wastes in the maintenance area. These issues indicate that maintenance processes have nonvalue-adding steps that need continual improvement.

The challenge of “designing” the ideal model to drive maintenance activities according to [4] has become a research topic and a major question for attaining effectiveness and efficiency in maintenance management and achieving enterprise objectives. This study has been carried out based on a maintenance division which is responsible for maintenance of a fleet of military vehicles. The maintenance division has been facing ever-increasing military expenses to maintain military readiness with aging vehicle fleet systems. Hence, the division is keenly interested in finding a suitable model with practical guidelines for the maintenance providers to improve the service processes. Whilst various authors have proposed what they consider as the best practices or models for maintenance management, this study emphasizes the integration of the state-of-the-art approaches in process improvement for the effective and efficient management of the vehicle fleet maintenance, as presented in this paper.

2 Model Strategies

2.1 Integration of Six Sigma and Lean

Lean Six Sigma combines lean methods and Six Sigma, using specific DMAIC processes to provide companies with better speed and lower variability to increase customer satisfaction [5]. The first phase in DMAIC process is to define project objectives and customer needs. The second phase is to measure the current process performance as well as quantifying the problems. The third phase is to analyse the process and find the causes of problems, particularly the root causes. The fourth phase is to improve the process, i.e. correcting the causes of defects and reducing process variability. The final phase is to control the process and maintain the improved performance. These five phases can assist Lean Six Sigma teams to systematically and gradually develop process rationalisation, starting with defining the problem and then introducing solutions targeted to the fundamental causes, so constructing the optimal implementation method and ensuring the sustainability of solutions [6]. This approach has gained increasing recognition in process improvement practices.

2.2 TPM

Total Productive Maintenance (TPM) may be defined as an innovative approach to maintenance that improves equipment effectiveness, eliminates breakdowns, and supports autonomous maintenance by operators through day-to-day activities including the total workforce [7]. TPM is a maintenance management program with the objective of reducing equipment downtime and improving overall equipment effectiveness [8]. Nevertheless, TPM is not a maintenance specific policy; it is a culture, a philosophy and a new attitude for maintenance. The effective adoption and implementation of strategic TPM initiatives in the manufacturing organizations is a strategic approach to improve the performance of maintenance activities [9]. TPM brings maintenance into focus as a crucial and very important part of the business. TPM seeks to engage all levels and functions in an organization to maximize the overall effectiveness of production equipment.

2.3 Integration of TPM and Lean Six Sigma

This study has proposed an integrated approach of TPM with LSS to reach world class maintenance performance, with the core model shown in Fig. 1. Lean Six Sigma forms the basic foundation for the TPM strategy and makes it easier to understand by shop floor operators who are the most important enablers of successful TPM implementation. Within the five phases of DMAIC, various problems and sub-processes of the maintenance department are defined, the process performance is measured, the most important causes of the defects or non-conformities are identified and analyzed, improvement or corrective actions are then taken with the improvements sustained by standardisation and continuing process control. Moreover, the iterative process of DMAIC is used as the main operational approach for the implementation of this model in order to achieve continual improvement of maintenance activities and ultimately to reach world class performance in terms of both sigma level and overall equipment effectiveness. The implementation of this model or approach will be supported with a rich collection of tools from Six Sigma, lean, TPM, quality control and problem solving practices.

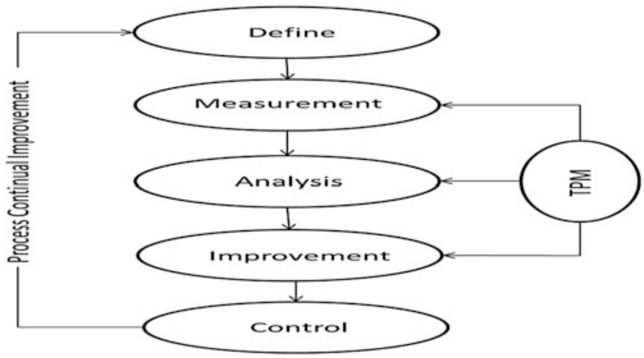

Fig. 1 Methodology to develop integrated model

Table 1 Key activities and tools of implementing the TPM oriented LSS maintenance model

Stage	Activities	Tools
1. Define	• Build process improvement team • Identify problems & weaknesses of the process • Select CTQ characteristics	• SIOPC • Brainstorming • VOC • Pareto analysis
2. Measure	• Select measuring system • Gather information about key maintenance processes • Calculate the current OEE	• Process map • TPM • OEE
3. Analyse	• Identify root causes of problems • Implement basic levels of TPM • Identify improvement opportunities	• Cause and effect diagram • TPM
4. Improve	• Propose solutions and implement changes for maintenance improvement • Evaluate the process performance • Calculate the new OEE	• Seven Wastes • SMED • Poka—yoke • 5S • TPM
5. Control	• Standardize the best practices • Integrate the changes to the organisation knowledge base • Continual improvement	• SPC • Performance management • Education and training

In any process improvement project, utilization of a well-defined improvement procedure is critically important. The procedure and key activities of the TPM oriented Lean Six Sigma can be summarized in Table 1, under the DMAIC phases, together with typical tools.

3 Case study

In order to test the proposed TPM oriented LSS model for the vehicle maintenance, a case study was performed for the engine maintenance process, since engine for a vehicle is as vital as the heart of a human being and its maintenance is essential. As demands for service quality and cost reduction in vehicle maintenance have both increased in recent years, the effectiveness of a maintenance system for engines has become an important issue. Engines are subject to deteriorations in relation to both usage and ageing, which leads to reduced product quality and increased maintenance costs. The maintenance division executes preventive maintenance (PM) on engines to prevent or slow down such deteriorations.

3.1 Define

Step_D1: The project started with Define phase that gives a clear problem definition using the supplier-input-process-output-customer (SIPOC) tool. This tool describes the step-by-step process for the engine maintenance as shown in Fig. 2. The first process is the engine service or maintenance. The input to this process includes the engine to be serviced, parts and preventive maintenance program and procedure, whilst the supplier is the maintenance crew. The output of this process is engine serviced, the customer is the field service unit. The second process is repair and replacement of engine. The inputs to this process are operation notification and work order, the supplier is the field service unit. The output of this process is engine repaired or replaced and the customer is the field service unit.

Step_D2: The engine preventive maintenance (PM) being analysed is verified to be significant by the field study. Engine PM cost represents a high percentage of vehicle PM cost. The team members participate in brainstorming sessions to identify critical to quality characteristics (CTQ) based on the voices of customer input. Also, the component(s) failure that results in high machine downtime or cost (due to machine breakdown) is classified as critical components. Critical engines failures have been reported for the engines in the field study which causes

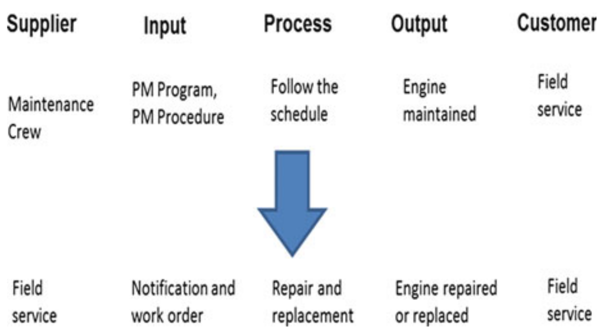

Fig. 2 Two example SIPOC processes

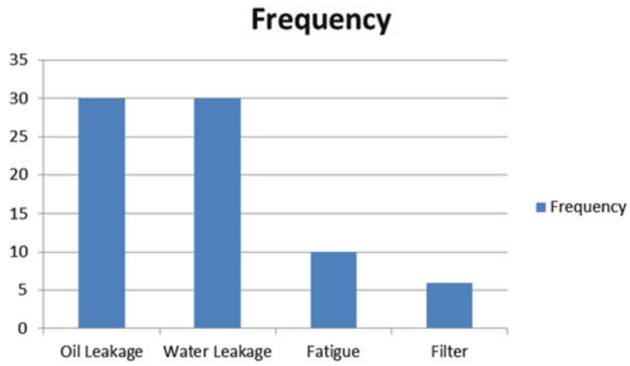

Fig. 3 Pareto analysis of engine failures

significant cost of the PM and also deviations from the customer satisfaction targets. The project was scoped down to oil and water leakage since they contribute to about 60% of the total failure cost as determined through the use of Pareto analysis, as shown in Fig. 3.

3.2 *Measurement*

Step_M1: To measure the factors that contribute to the process and failures on the subject engine, a number of tools from the Six Sigma toolbox are used such as process mapping and fishbone diagram. The process map (Fig. 4) provides a visual view of all maintenance and operation steps that take place from the time an engine failure is detected through putting it back to service all the way to operation and monitoring until it fails again.

Step_M2: Since the CTQ characteristics, i.e. oil and coolant leakage, are identified in the Define phase, a data collection plan needs to be developed. The measurement system should be examined prior to data collection. In this case, the existing service report is used to facilitate the collection of primary data. Monthly reporting is particularly useful in monitoring the maintenance tasks performed by the maintenance personnel and calculating the maintenance cost. Also, each vehicle has its own maintenance history book to record the repairs/replacement done to it. From these records, the data on the maintenance history of the engines can be extracted. To quantify the problem, data gathering was initiated on the failures costs of engines.

Step_M3: For a specific CTQ characteristic, the sigma level can be calculated from DPMO (defect per million opportunities) as:

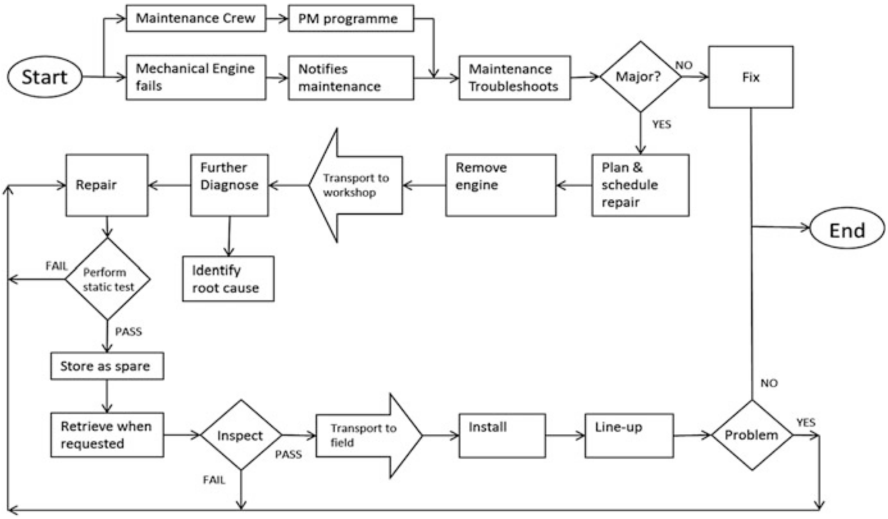

Fig. 4 Process map of engine maintenance

Table 2 Initial process capability

CTQ	No. of units	No. of opportunities	No. of defects	DPMO	Sigma level	C_{pk}
Oil leakage	1000	7	30	4285	2.45	1.4
Coolant leakage	1000	3	30	10,000	2.3	1.2

$$DPMO = \frac{total\ number\ of\ defects}{number\ of\ units\ x\ number\ of\ opportunities}$$

The process capability indices C_{pk} and the corresponding sigma levels are summarised in Table 2. The sigma level of a process can be used to express its capability as to how well it performs with respect to specifications.

3.3 Analysis

Step_A1: To ascertain the root cause(s) of key engine failures, an analysis using the cause-and-effect diagram is therefore carried out during a brainstorming session of the LSS team. Figure 5 shows the root causes of the engine failure problems.

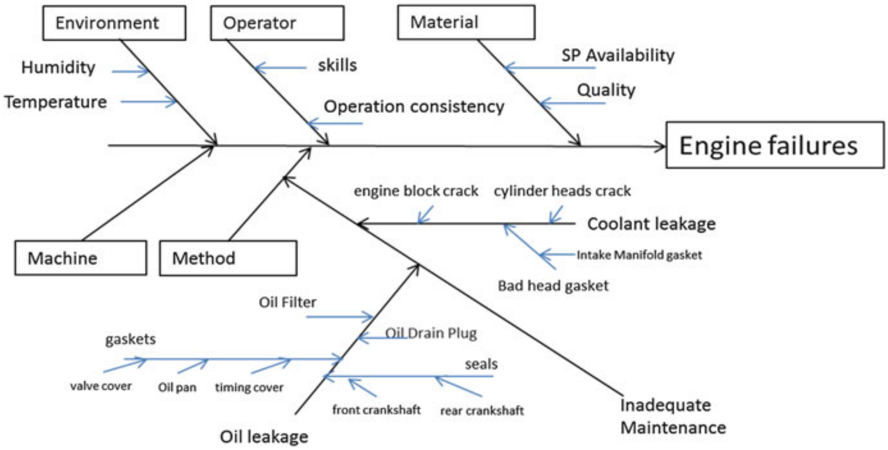

Fig. 5 Fishbone diagram for engine failures

Table 3 Initial OEE

Process	*A%*	*PE%*	*Q%*	*OEE%*
Engine repair	86	80	97	66
world-class performance	90	95	99	85

Step_A2: According to [8], OEE measurement is an effective way of analysing the efficiency of a single machine or an integrated system. It is a function of availability, performance rate and quality rate, and can be expressed as follows:

$$\mathrm{OEE} = \mathrm{Availability}\ (\mathrm{A}) \times \mathrm{Performance\ rate}\ (\mathrm{PE}) \times \mathrm{Quality\ rate}\ (\mathrm{Q})$$

On average the engine maintenance workshop can complete 20 engines monthly. The records have shown the number of defective engines for both causes (oil and coolant leakages) was 7 annually. Hence, the quality rate (Q) which is the percentage of the working engines out of the total produced can be calculated as 97%. The maintenance workshop normally runs for 30 days with 4 days break scheduled, so the Planned Maintenance Time is 26 days. On average, 4 days will be lost in maintenance each month due to unavailable parts or equipment, and the Operating Time is thus 22 days per month, with an availability (A) of 22/26≈85%. The standard cycle time for the engine maintenance is 25 units/month or 0.88 days/unit. As the workshop can actually complete 240 units during the year or 20 units per month, which gives the actual cycle time of 22 days/20 unit = 1.1 days/unit. The performance rate (PE) is thus 0.88/1.1 = 80%. The initial OEE is therefore about 66%, well below the word class performance (Table 3).

3.4 Improvement

Step_I1: Four levels of maintenance have been implemented in the maintenance division. Level 1 is carried out by the autonomous maintenance teams (drivers or operators). These teams apply basic maintenance, including regular daily cleaning regimes, as well as sensory maintenance tasks (smell, sound, sight, touch, etc.). Level 2 typically involves simple repairs or replacement of components. Level 3 involves more difficult repairs and maintenance, including the repair and testing of components that have failed at the Level 2, and Level 3 maintenance is carried out by the maintenance department, as it is beyond the capabilities of the lower levels, usually requiring major overhaul or rebuilding of end-items, subassemblies, and parts. Level 4 involves the engineering department, becoming more proactive in the development of PM practices, including machine modification and enhancement strategies that allow easier maintenance, among others. Level 4 tasks also entail monitoring maintenance activities and are directed primarily at approaches to increase the MTBF to achieve a higher degree of machine availability. The aim here is to extend the MTBF so that the machinery can remain productive longer, thus providing a greater return on machine performance.

Step_I2: This step is concerned with the implementation of TPM at field study organization. Various pillars of TPM i.e. 5S, Jishu Hozen, Kobetsu Kaizen, Planned Maintenance and OEE have been implemented, as shown in Fig. 6.

(a) 5S: Making problems visible is the first step of improvement. 5S are defined as Sort, Set in Order, Shine, Standardize and Sustain. Table 4 shows some applications of this tool in maintenance process.
(b) Jishu Hozen: it is also called autonomous maintenance. The operators are responsible for keeping their equipment to prevent it from deteriorating.
(c) Kobetsu Kaizen: Kaizen involves small improvements and is carried out on a regular basis, involving people of all levels in the organization. A detailed and thorough procedure is followed to eliminate losses systematically using various Kaizen tools as follows:

- Poka Yoke devices: It is Japanese term in English which means mistake proofing or error prevention. Poka Yoke devices have been developed and used in-house.
- Leakage problem: To identify the reasons for a leakage, a fishbone diagram is prepared, as shown in Fig. 7.

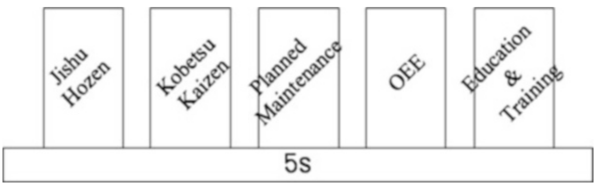

Fig. 6 Pillars of TPM

Table 4 Implementation of 5S

5S	Before	After
Sort	• Rejected parts are kept inside the workshop.	• The parts are removed and the space is freed.
Set in Order	• Earlier patches on the floor disturb material movement using trolley. • Tools are placed randomly in racks and no labelling is done.	• Patches are filled with cement thus helping smooth material flow. • Tools are stored in their respective places identified with labelling.
Shine	• Work place not very tidy and clean.	• Clean and tidy work place.
Standardize	• No operator report is kept. • Operator details are not displayed on the notice board.	• Writing hourly report is compulsory. • Operator details are displayed on the notice board.
Sustain		• Organisation mission and vision statements are displayed in Arabic as well as English. • Suggestion scheme stating that whoever gives the best suggestion will receive a prize.

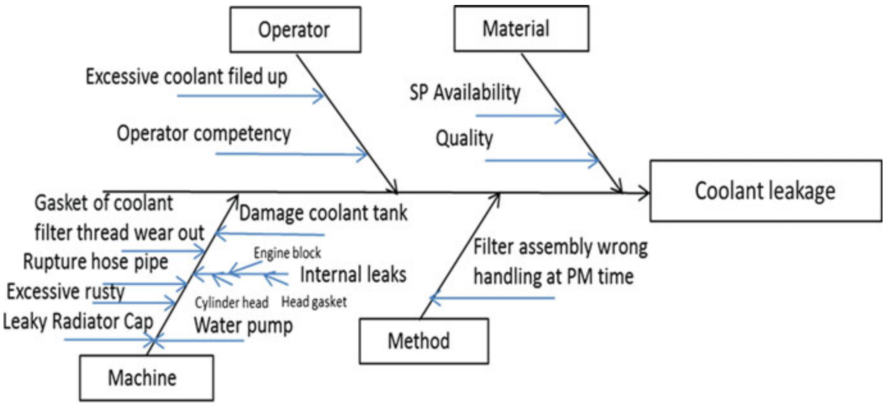

Fig. 7 Fishbone diagram for coolant leakage

- New Layout: A new layout is proposed as shown in Fig. 8. The proposed layout is designed to minimize the handling of parts.

(d) Education and training: TPM education and training programs have been prepared to achieve three objectives:

- Managers will learn to plan for higher equipment effectiveness and implement improvements intended at achieving zero breakdowns and zero defects.
- Maintenance staff will study the basic principles and techniques of maintenance and develop specialized maintenance skills.

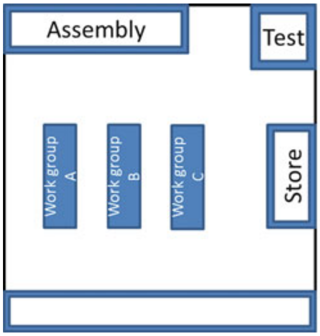

Fig. 8 Layout of engines workshops

Table 5 OEE improvement of engine repair process

	A%	*PE%*	*Q%*	*OEE%*
Initial OEE	86	80	97	66
Improved OEE	92	87	98.5	79
world-class performance	90	95	99	85

- Drivers and maintenance staff will learn how to identify abnormalities as such during their daily and periodic inspection activities.

(e) Planned Maintenance: It is aimed to have trouble free vehicles without any breakdown and ensure components at good quality level giving total customer satisfaction.

(f) OEE is calculated after the implementation. Based on the initial assessment, the availability has increased to 92%, the performance rate 87% and the quality rate 98.5%, with an overall OEE of 79%. Whilst this is still below the world class 85% performance, it has significantly improved the initial OEE of 66% (Table 5). Continual improvement is required to reach the world class performance.

3.5 Control

The Control phase includes the following activities:

- Management of processes of change;
- Documentation and standardization of the improved maintenance process;
- Monitoring of the maintenance process through control charts;
- Identifying opportunities for further improvement of the maintenance process.

4 Discussions and Conclusions

A new model based on TPM and Lean Six Sigma has been presented to provide guidance and support for service organisations who aim to reach world-class standards in maintenance processes through continual improvement. The application of the model has been illustrated using a case study in maintenance of a fleet of military vehicles. The above discussions are largely based on the case study, particularly the engine repair process due to the water and oil leakage problems. However, this approach is very generic in nature and can be applied to any other maintenance or repair process (e.g. engine repair due to heavy friction), and to any service organisations with maintenance functions. Of course, the complexity of the proposed model will depend on the application since the nature and the number of CTQs are application specific. The proposed model as the framework together with the use of common tools emphasize the process approach and will therefore be generally applicable in such service organisations. Use of this model will likely help to achieve high process performance and overall equipment effectiveness. The model also provides a good framework and methodology to continually improve the maintenance performance.

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