Lean for Sustainability: A Focus on The Preventive Maintenance Process for Construction Equipment

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Abstract

Lean thinking is an essential concept that has emerged in most organizations and industries. This is due to its proven outcomes in improving the process by removing waste and delivering value to the customer. Applying lean has also benefited the process by making it more sustainable by reducing the waste that negatively affects the three pillars of sustainability (Environment, Economy, and Society). Although lean has been established as a concept to improve the manufacturing process, it has extended to cover the maintenance process with reliance on established maintenance principles like Total Productive Maintenance (TPM) and existing lean methods. This paper aims to study and analyze a preventive maintenance (PM) process of a construction company in Qatar and implement lean maintenance methods with TPM to improve the process by minimizing lean waste with a focus on improving process sustainability. The methodology has been assessed through a real case study from a construction project of the company selected. The project equipment preventive maintenance process was analyzed, sustainability indicators were identified, and lean maintenance tools were implemented. The results have revealed that the process has been improved, and sustainability wastes have been minimized.

Keywords: Lean Thinking, Sustainability, Lean Maintenance, Total Productive Maintenance, 5S, Computerized Maintenance Management System

1. Introduction

1.1 Lean Thinking Concept

Lean thinking is nowadays an essential concept that has emerged in most organizations and industries. The concept was first introduced in 1991 by James P. Womack, Daniel T. Jones, and Daniel Roos in the book The Machine That Changed the World. Lean introduces five principles: value, value stream, flow, pull, and perfection. Lean thinking refers to adopting certain principles and techniques to reduce waste in production and manufacturing processes. This aims to achieve better workflow and added value to the production process by increasing customer satisfaction. Lean, in the long run, aims to build a system based on management principles that can eliminate all types of waste in the organization, which can be achieved through continuous planning and improvements at both macro and micro levels (Womack & Jones 2003).

In 1930, the concept of lean was first established by Toyota in its production process and showed successful results, which expanded its reach past the manufacturing process. The Toyota production system represents the pinnacle of lean thinking globally and establishes the company as the largest auto manufacturer in terms of sales (Cusumano et al. 2021). With time, lean thinking expanded to every sector worldwide and goes beyond manufacturing to include logistics, services, distribution, healthcare, government, construction, and maintenance. This is because lean thinking has contributed to increased production capacity through concepts that minimize resource usage. Not only does it improve customer satisfaction, but resource conservation is becoming increasingly important in working toward sustainable development.

Lean and Sustainability

Sustainable development describes the advancement and progression of humanity in such a way that does not hinder the development of future generations (Elliott 2013). The sustainability framework encompasses the pillars of social, economic, and environmental development and relies on sustained economic growth combined with improvements in social welfare and minimal irreversible environmental impacts. In 2015, the United Nations published 17 goals that structurally detail the key areas society has to work towards to achieve sustainable development (*Take Action for the Sustainable Development Goals* 2018). Initiatives arising from such goals include commitments by companies to have net-zero carbon footprints, circular economies to reuse products to bridge economic development gaps, and a greater focus on diversity and inclusion among corporations. Such initiatives are emerging in line with the increasing significance of corporate social responsibility (CSR), whereby companies are expected to address social and environmental stakeholder concerns in their business operations (Coombs & Holladay 2011).

Entities actively working towards enhancing their CSR can improve their reputation, attract a wider range of customers, and become more competitive while contributing to improvements in social welfare and minimizing their carbon footprint (Coombs & Holladay 2011). However, to demonstrate sustainability improvements, they first have to be quantified.Sustainability metrics are rarely standardized and vary by complexity and industry. They can range from simple metrics representing one pillar of sustainability, such as the absolute quantity of greenhouse gas emissions, to more complex indicators covering all three pillars (Sikdar 2003). Although measures that reflect all three sustainability aspects are more holistically representative of a process's impacts, the data required to establish such a metric may not always be readily available. Furthermore, one-dimensional metrics provide value in process benchmarking, especially when the intention is to focus on improving one specific parameter. Water use in a manufacturing process is an example where it may be desirable to reduce water consumption due to external factors, such as new regulations or a limited water source.

As mass manufacturing establishes itself as the norm, lean thinking is becoming more relevant in improving processes without compromising sustainability. Applying lean thinking to improve a process sustainably can lead to reductions in operating costs, lead times, and flow rates while considering the impact on environmental quality (Vinodh et al., 2011). Aside from the typical benefits of waste minimization, other outcomes of lean can be lower energy consumption, efficient land usage, and limited hazardous waste (Vinodh et al. 2011). In addition, such an approach has been demonstrated to improve worker morale and company loyalty, overall reducing turnover. One example is Boeing's plant in Everett, WA, which eliminated 350 ft^3 of airplane wing-panel packing material and reduced chemical consumption per airplane by 11.6% by applying the Kanban and point-of-use inventory systems, respectively (US EPA 2022). Another is General Motors, which applied value stream mapping (VSM) and 5Y to eliminate 7 tons of emissions and all hazardous waste associated with a painting process associated with one of their suppliers (US EPA, 2021). Hence, the benefits of incorporating a lean-based framework to process improvement are apparent. This is especially so for processes that rely extensively on the procurement, transportation, and installation of physical resources, such as equipment maintenance.

Lean Application in Maintenance

As the lean principle was established essentially for the improvement of manufacturing industries, the need to implement lean in maintenance is essential to ensure the smooth operation of machines and equipment in any production line, manufacturing process, construction project, or any process where mechanical equipment is involved in delivering value to the customer. Therefore, the maintenance process significantly contributes to achieving organizations' strategic objectives. Traditionally, maintenance focused on corrective actions executed in emergency conditions. However, this mindset is no longer accepted, as the role of maintenance has been considered an element of revenue generation for many companies (Mostafa et al. 2015).

Lean maintenance was founded by TPM (Smith & Hawkins, 2004). TPM, according to Wireman (2005), are maintenance activities that are productive and are implemented by everyone in the organization. This involves all employees working together on equipment improvement, from operators to the higher management level. However, TPM alone is not lean. To achieve lean maintenance improvement effectively, some key lean concepts with lean maintenance methods must be employed. Examples of these typical lean methods include VSM, 5S, Poka-Yoke, and Kaizen. Examples of lean maintenance tools are TPM and computerized maintenance management system (Mostafa et al. 2015).

This paper aims to study and analyze a PM process of a construction company in Qatar and implement lean maintenance methods with TPM to improve the process by minimizing the lean wastes with a focus on improving the sustainability of the process.

The rest of this paper is organized as follows: Section 2 describes the proposed methodology for lean-based sustainability improvement of the process. Next, section 3 presents an illustrative example of the current and future states of the PM process under consideration. Finally, section 4 concludes the results of section 3 and provides recommendations for future improvement of the methodology used.

2. Methodology

The below methodology has been adapted from Mostafa et al. (2015), with an addition of sustainability indicators to evaluate the sustainability improvement of the process. The first step of the methodology starts with collecting the data by conducting interviews with the company maintenance department. The second step is identifying sustainability indicators for the process. The third step is analyzing the current state of the process using process mapping. The fourth is identifying the wastes using value stream mapping method. The fifth step is eliminating the waste by implementing TPM, 5S, and CMMS to the PM process. The sixth step is to analyze the future state and calculate values of the new process parameters. The seventh and last step is benchmarking where a quantitative comparison of process parameters and sustainability indicators is conducted between the current and improved process. Figure 1 below summarizes the methodology:

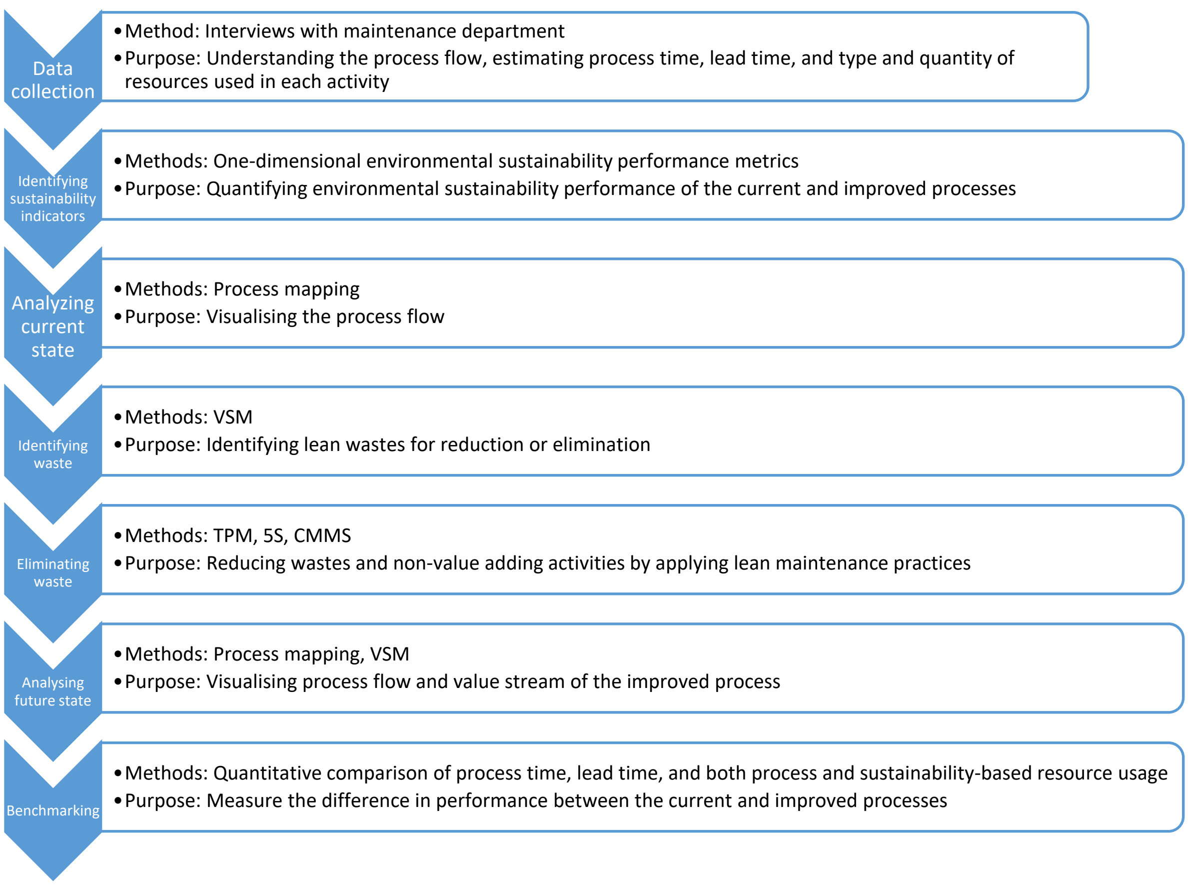

Figure 1. Lean-based sustainability improvement methodology for construction equipment PM

2.1 Data Collection

To obtain the process steps, parameters, and resources used, interviews and meetings were conducted with the company's workshop department. The company manages its equipment maintenance through its workshop, which sends service teams to the project's equipment to do the required PM and corrective maintenance (CM) at site. An interview with the workshop manager and meetings with the service engineer and service team technician were conducted to collect the required data.

2.2 Sustainability Performance Indicators

Two sustainability performance indicators were selected based on the process studied in this paper. Both indicators are one-dimensional and are measured by the mass of carbon dioxide equivalent ($m \cdot CO_2e$) emitted. The CO_2e unit is an industry-standard approach to representing emissions by accounting for greenhouse gases aside from CO_2, and normalizing them based on their global warming potential relative to a CO_2 molecule (Jones & Mayfield, 2016). One-dimensional indicators were chosen as the focus of this study was on applying lean thinking to process improvement as the core focus, supplemented by simple sustainability indicators for benchmarking the current against the proposed future state.

The first indicator is reported in $kgCO_2e$ emitted by maintenance service vehicles operating on diesel fuel. Emissions are calculated by multiplying a constant, 3.473 $kgCO_2e/L$, by the total liters of diesel consumed on a trip (Lean & Green Europe 2016).

The second indicator is reported in gCO_2e emitted through the production of a piece of office paper. Emissions are calculated by multiplying a constant, 4.755 gCO2e/sheet, by the number of sheets used (Sun et al. 2018). Literature shows various emissions associated with bulb paper production, which also depends on the system's boundaries. The basis for the constant used in this study is an average value among 45 studied cases of paper manufacturing across several continents and considers a cradle-to-gate approach (i.e., from raw pulp extraction through to transportation and manufacturing of paper, excluding further emissions from transportation to customers and eventual landfill, incineration, or recycling; Sun et al. 2018).

2.3 Value Stream Mapping

The value stream mapping method was used to identify and categorize the wastes of the process. The following are the steps of value stream mapping (Langstrand, 2016):

1. Identification of the value stream that requires improvement
2. Generation of the current value stream map
3. Evaluating the current value stream map and identifying the waste to remove them from the process
4. Generation of the future value stream map
5. Implementation of the final plan

2.4 Lean Maintenance Practices

Three lean maintenance practices tools were used to eliminate waste and improve the process. They are as follows:

2.3.1 Total Productive Maintenance TPM

It is impossible to speak about lean maintenance practices without involving the TPM philosophy. As mentioned previously, TPM is the foundation of lean maintenance. TPM intends to merge the production team (Project), and maintenance team (Workshop) functions to obtain good working practice, teamwork, and continuous improvement (Ahuja & Khamba, 2008). TPM seeks to avoid conflicts between the user and the maintainer; instead, they work together and contribute to maintaining the equipment and increasing its reliability. The following are the core steps of TPM (Ahuja & Khamba 2008):

1. Improve equipment effectiveness by optimizing availability, efficiency, performance, and product quality. In this case study, the product quality can be measured from the output of the construction equipment participating in construction work.
2. Establish a PM plan to cover the entire equipment life cycle.
3. Involve all departments (i.e., project (the equipment user), workshop, procurement) and all staff members, from management to operators.
4. Promote continuous maintenance improvement. This shall include workers and operators who deal with equipment and machinery daily.

TPM is a policy that shall be practiced to reduce equipment downtime and ensure a smooth maintenance process flow. It also emphasizes the need to plan for PM, which many construction companies, including the one in this study, fail to implement, as it simply follows the maintenance frequency recommended by the original equipment manufacturer.

2.3.2 5S Approach

5S is a systematic technique that helps improve the workplace's organization and functionality. The following are the phases of 5S (Kareem & Abu Talib 2015):

1. Seiri (Sort / Organization): The parts and items are organized based on necessity and frequency of usage.
2. Seiton (Straighten / Orderliness): The location of each item is identified based on its category. This involves putting parts and items in a way that increases work efficiency and reduces search time and unnecessary movement.
3. Seiso (Shine / Cleanliness): Cleaning and inspecting parts for defects or contamination. It is important to keep the inventory items, especially for short lifespan items and electronics, clean, out of contamination, and inspected periodically to ensure their effectiveness.
4. Seketsu (Standardize / Create Rules): Rules are created, and a system is established. Procedures and checklists are developed properly to ensure an uncluttered, clean, and organized work environment.
5. Shitsuke (Sustain / Self-Discipline): This is the most important phase ensuring sustaining the 5S effort, continually monitoring the established system, and seeking continuous improvement.

5S is vital for managing the inventory of PM where repetitive orders of similar parts are requested. It is also important to implement 5S for the machines and equipment to access the equipment easily and identify any fault due to leakage, overheating, or wear.

2.3.3 Computerized Maintenance Management System CMMS

A computerized maintenance management system (CMMS) is a powerful tool used to measure, manage, and analyze maintenance processes. It can assist in the following tasks in the maintenance system of the organization's assets (Mostafa et al. 2015):

1. Planning and scheduling of maintenance, repair, and overhauling (MRO)
2. Managing and controlling the inventory
3. Cost accounting of labor and material
4. Recording and analyzing historical data of assets

CMMS is implemented to reduce manual administrative and task documentation processes and lead time by transferring it from manual to automatic. It is also implemented to automate material requisition in repetitive PM jobs. In addition, CMMS can assist in evaluating routine inspection of equipment by algorithmically detecting any fault in the report generated by the maintenance team and assisting in reviewing the equipment's maintenance history.

3. Illustrative Example: Process of PM of Construction Equipment

3.1 Process Description

The case study is illustrated in Figure 2. The PM process of construction equipment of the selected company starts with the project manager (the equipment customer), who sends a request by email to the workshop service engineer to perform PM based on equipment runtime. The service engineer checks the availability of the service team to perform the PM, then requests the PM parts from the store (i.e., filters, belts, oil, grease). The store checks for the availability of materials, issues them, or purchases them if not available, and then issues them to the service team. Finally, the service team collects the material, travels to the site to perform the required PM on the equipment, fills the PM report, and returns to the workshop to hand over the report to the service engineer.

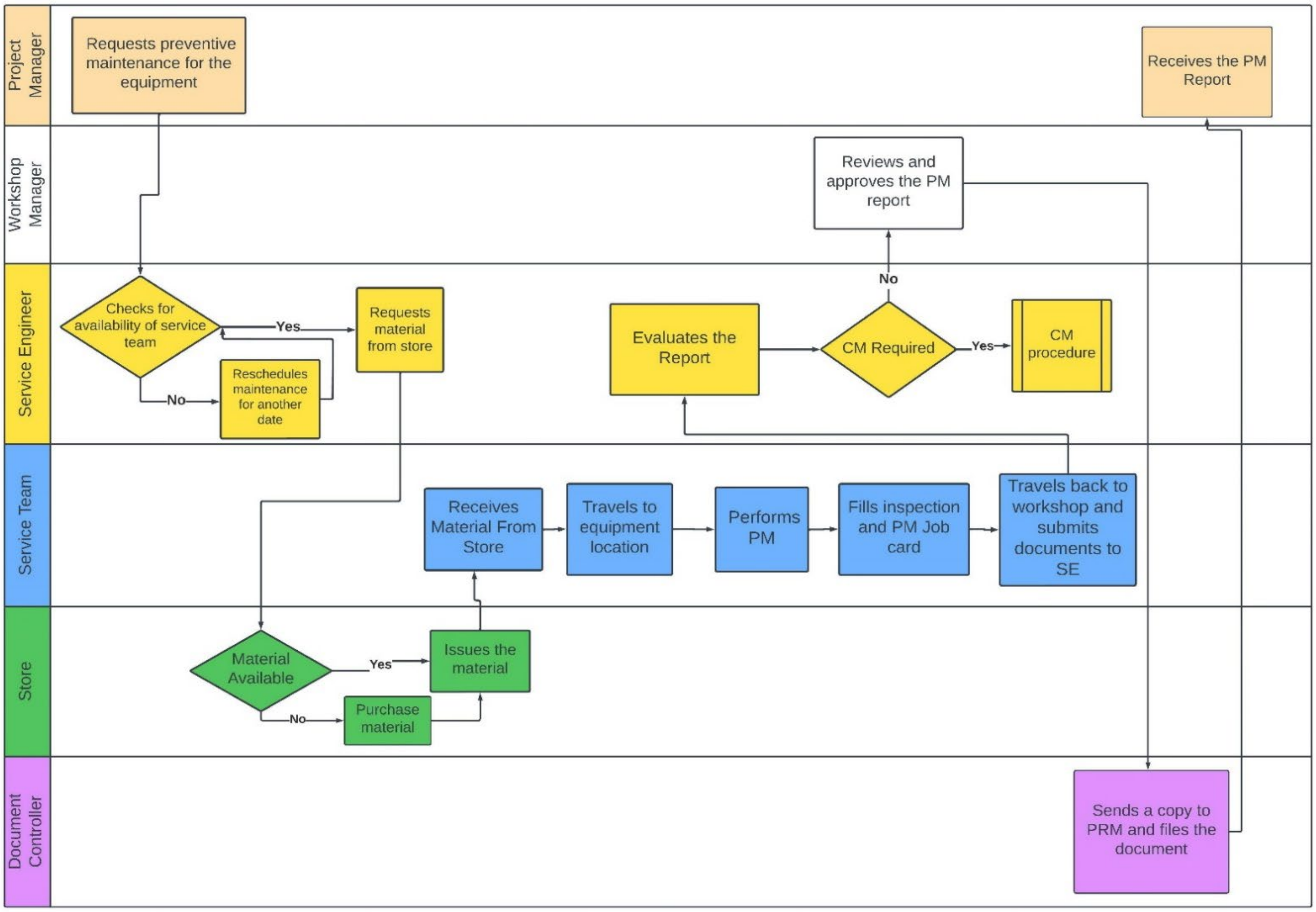

Figure 2. Current PM process flow

The service engineer evaluates the report to confirm if further CM is required. Based on the evaluation performed by the service engineer, the workshop manager reviews the report for approval, then the workshop document controller files the report and sends a copy to the workshop manager.

3.2 VSM of Current State

The PM was analyzed for one project with nine pieces of equipment and located 35 km far from the workshop. The processing time, lead time, material used, and distance traveled were obtained from the service engineer and service team who are directly involved in implementing the PM. This data was used to build the current state value stream map (Figure 3).

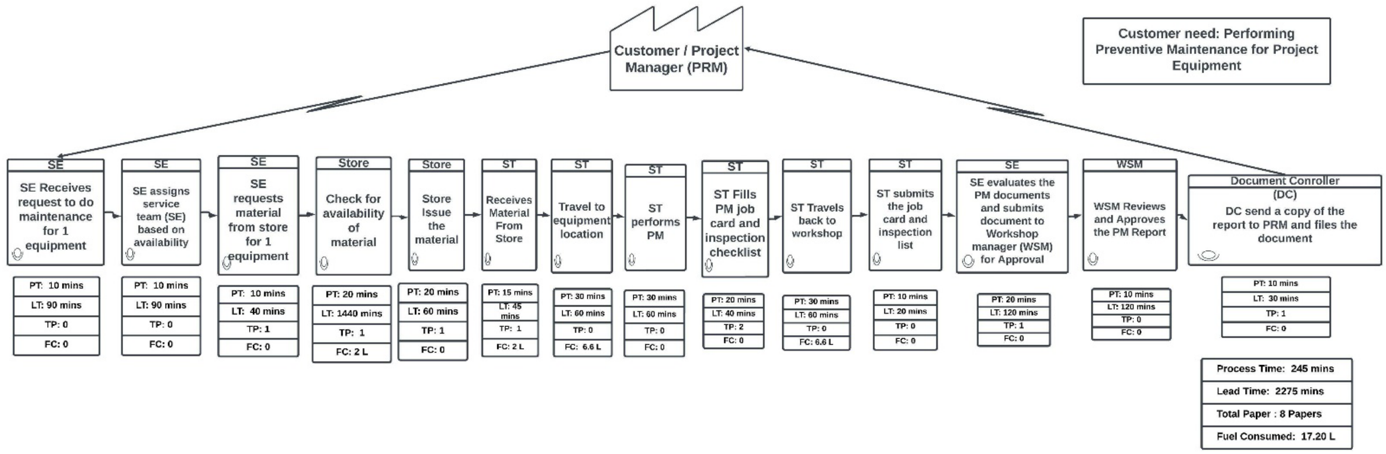

Figure 3. VSM of current state

Because the time and resource consumption vary by the type of equipment considered in a specific PM activity, the values specified in Figure 3 were selected for one specific PM request to ensure consistency. This is in line with comparing the current and future states rather than analysis of absolute values of either state independently.

3.3 Process Waste and Sustainability Indicators

Three types of activities (value added, necessary non-value added, and non-value added) were identified and color-coded in Figure 4. The wastes identified are as follows:

1. Wastes 1 and 2: Long lead time (waiting) between information from the project manager and the first necessary activity due to unplanned scheduling of activities and not assigning specific teams to do certain types of tasks, which led to having a long waiting time and a possibility of variation in performing the maintenance.
2. Waste 3: Possibility of variation while requesting the material from the store due to inconsistency in doing repetitive manual requestion using paper forms.
3. Waste 4: Taking a long time to check the PM parts' availability is an indicator of suboptimal planning of the PM and unorganized inventory inside the store. Moreover, running out of stock from some parts is possible, which increases the waiting time and requires more resources (overproduction) to search for and purchase the spare parts.
4. Wastes 5 and 6: Repetitive travel to the site for each piece of equipment is the major waste of this process. Although it is a necessary non-value-added activity, it is the major contributor to waste in terms of waiting and fuel consumption (6.6 L per trip). Therefore, this transportation waste must be optimized.
5. Waste 7: Utilization of the service engineer to evaluate the PM inspection is a misuse of resources and skills. A service engineer is overqualified for this task as it can be automated. Moreover, human error in evaluating several repetitive reports is high.

6. Waste 8: An overproduction due to repeating handling, printing, copying, and filing the same document several times. The only value-added activity in the process is sending the PM document to the PRM. Therefore. A more focused method shall be provided to optimize this process time.

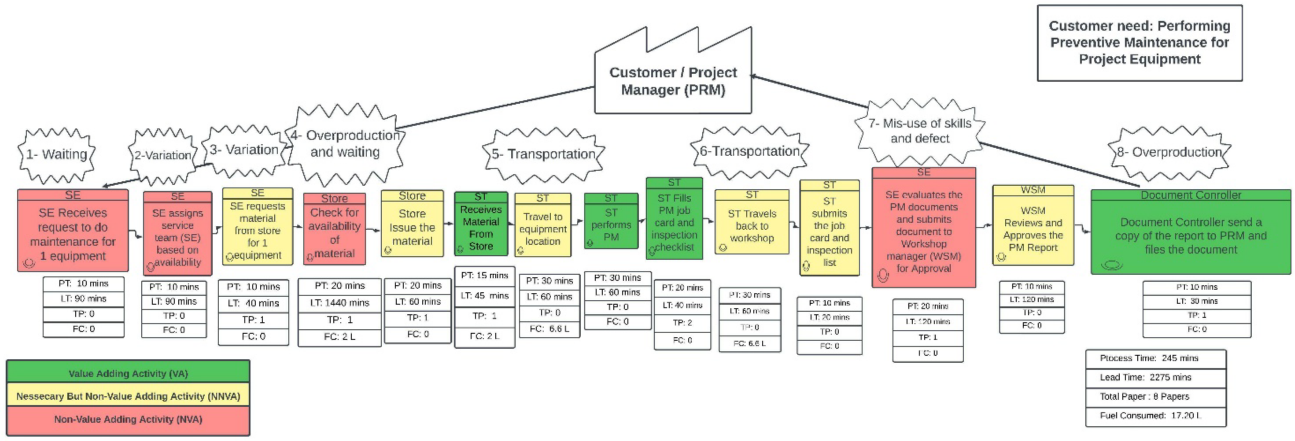

Figure 4. VSM of the current state with categorized activities based on value and waste types in activities

Table 1 summarizes the processing time, lead time, and total usage of paper and fuel to perform one round of PM for all the equipment in this specific project.

Table 1. VSM current state

	Per Equipment	For All Project Equipment
Process Time	245 mins	2205 mins
Lead Time	2275 mins	20475 mins
Total Paper	8 Papers	72 Papers
Fuel Consumed	17.20 Liters	154.80 Liters
CO2e	59.7 kg	537.9 kg

3.4 Lean-based Process and Sustainability Enhancement

After generating the VSM of the current state and identifying the wastes, lean maintenance practices were implemented to remove the waste, improve the process, and enhance its environmental sustainability. The following are the steps for improvement:

1. Implementation of TPM
   a. Establishing PM plan
   Plan for PM for the whole lifespan of the equipment. This includes planning and scheduling for PM and the required spare parts for each PM. This will ensure proper scheduling of maintenance based on estimated working hours which can be fixed for shift-based machines (i.e., generators, diesel pumps) and forecasted for variable working hours machines (i.e., forklifts, excavators). It will also ensure the availability of spare parts when needed and avoid shortage or overstocking of parts in the inventory.
   b. Involving all departments and employees
   Involving the project team in planning the maintenance schedule is essential to fit the PM date in the project schedule. In this way, both project and maintenance activities are not disturbed. However, the project team must also support the technical workshop by preparing for the required maintenance. This can be done by shutting down the equipment proactively to cool down before the arrival of the service team and providing advanced access to the site (i.e., site permits, accessibility to the location of equipment, and equipment isolation from any energy source). This will reduce the lead time for performing the maintenance and inspection. In addition, involving both procurement and stores in inventory stock will ensure material delivery on time.

c. Autonomous maintenance
This is a long-term improvement plan to reduce the number of PM activities by allowing simple jobs to be executed by front-line operators rather than the service team. As a starting point, the service team can set training sessions for the equipment operators to show them how to clean, grease, and check the equipment's oil and coolant levels. This will reduce the effort of the service team and increase the level of responsibility and awareness of the operators. Later on, the operators could be trained for troubleshooting and measuring essential parameters (i.e., voltage, pressure, temperature) of the equipment, which will assist the service team in identifying the faults and the disturbance in the machine in a shorter period.

2. Implementation of 5S
5S should be implemented for the PM inventory as a starting point and must be extended to all inventory items. Initially, all PM items are sorted, categorized, then grouped into bundles of service packages. A periodic cleaning and inspection process shall be applied to the items to ensure their condition. A system should be established to keep grouping the PM parts into service bundles to ensure reachability quickly and minimize retrieval time.

3. Implementation of CMMS
As explained in the methodology, CMMS is the key to improving collaboration between the different entities in the process. The implementation of it will help reduce waste as follows:
   - Eliminate delay of the process due to manual requests and automatically initiate the PM when it is due
   - Automatically distributing the tasks to all departments (workshop, store, project) to work in parallel, which will reduce the total process and lead time
   - Reduce paperwork to a minimum
   - Automate repetitive evaluation and documentation activities

Figure 5 shows the improved process flow structure. The process is initiated automatically from the CMMS when the agreed schedule for the PM of all project equipment is due. The CMMS sends notifications to PRM, SE, and Store. The SE notifies the relevant ST based on the type of PM required, but may require further (manual) selection in case of ST shortage (e.g., during holiday periods). The PRM informs the equipment operators to start preparing the equipment for PM. SE assigns the ST to perform the maintenance. Store issues the pre-prepared service bundles to ST. ST collects the parts and travels to the site to perform PM required. While performing the PM, the ST electronically fills the PM report (job card and inspection checklist). The CMMS evaluates the inspection checklists and notifies the SE of any requirement for CM. If no CM is required, CMMS closes the PM report and sends it to WSM for approval. WSM reviews and electronically signs the report, and CMMS sends a digital copy to PRM. CMMS automatically updates the records and sets the next date of PM of the project's equipment.

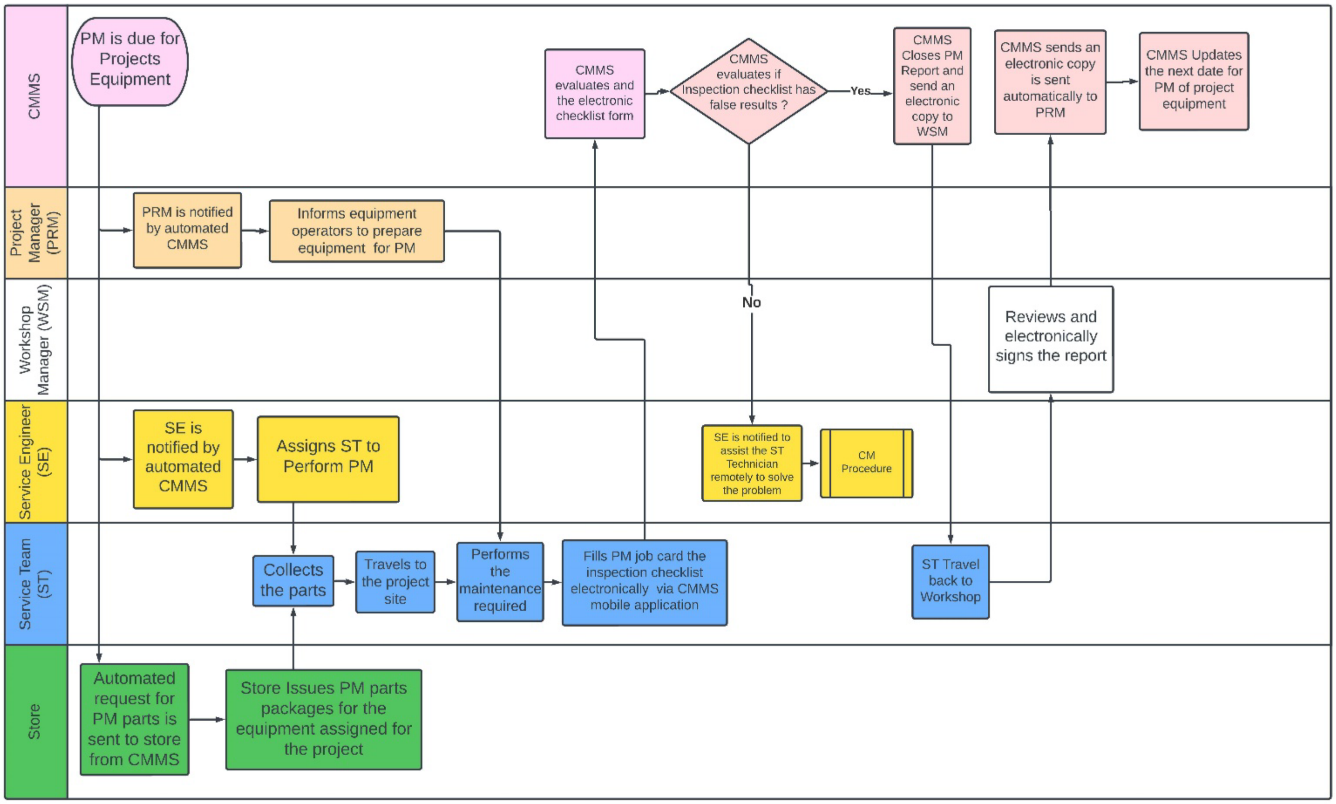

Figure 5. Improved PM process flow

Figure 6 below is the VSM of the improved process:

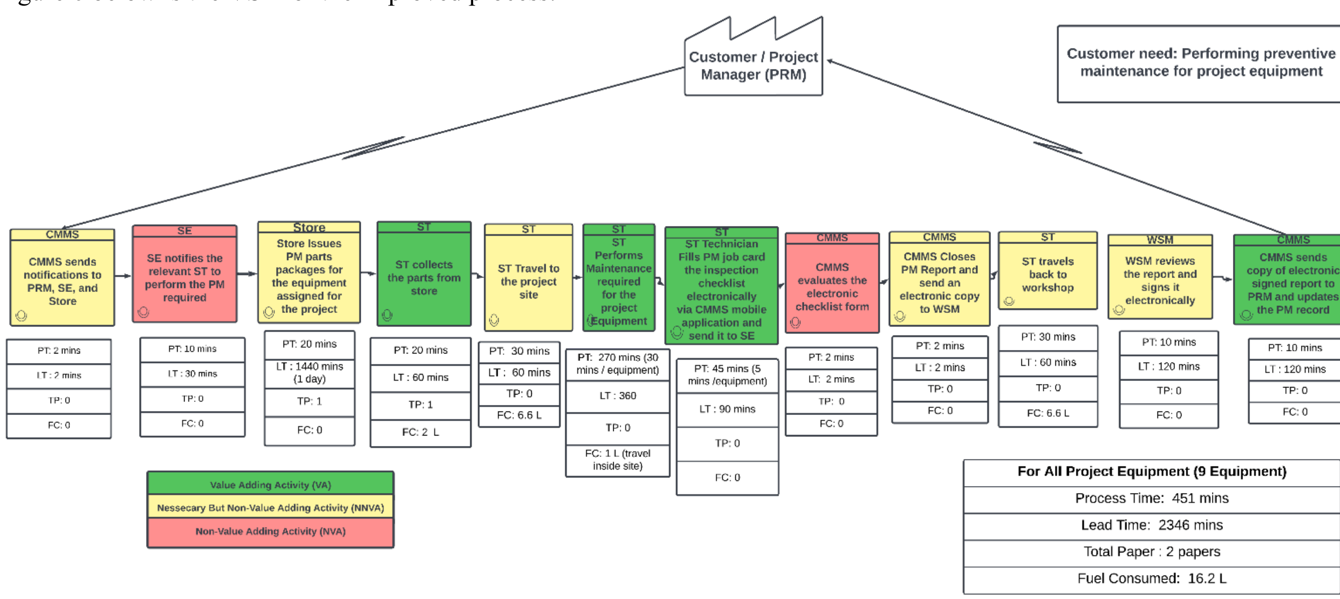

Figure 6. Improved VSM

Table 2 summarizes the improved process's processing time, lead time, and sustainability indicators. Table 3 compares process and sustainability performance between the current and future states for all project equipment in the PM.

Table 2. VSM future state

	Per Equipment	For All Project Equipment
Process Time	49 mins	451 mins
Lead Time	257 mins	2346 mins
Total Paper	2 Papers	2 Papers
Fuel Consumed	1.80 Liters	16.20 Liters
CO2e	6.3 kg	56.3 kg

Table 3. current vs. future state performance comparison

	Current	Future	% Improvement
Process Time	2205 mins	451 mins	80%
Lead Time	20475 mins	2346 mins	89%
Total Paper	72 Papers	2 Papers	97%
Fuel Consumed	154.80 Liters	16.20 Liters	90%
CO2e	537.9 kg	56.3 kg	90%

Although the magnitudes of emissions from paper usage and fuel consumption are significantly different, they are weighed equally since the focus was on the difference in current and future processes instead of the absolute states of either. The improvements made to the process are apparent in Table 3, both in terms of the elimination of process waste and the carbon footprint of the process. However, it should be noted that the study does not consider other practical aspects of the improvements implemented, such as the cost of purchasing and maintaining the CMMS.

4. Conclusion and recommendations

This paper presented a lean-based methodology for enhancing the sustainability performance of a construction company's PM process in Qatar. As can be seen from Table 3, the process and lead times have improved by 80% and 89%, respectively. These are the indications of lean waste reduction which are desirable for the company as it will improve the performance of the PM process, increase the availability, and enhance the utilization of the resources. Regarding sustainability improvement, the results show an improvement of 90% in CO2e emissions compared to the current process. This is one of the measurable indicators which was accessible for this study. Suppose data on the national level, such as road utilization by construction companies' service trucks, is available. In that case, another indicator for sustainability could be used to measure the effect of construction equipment services utilization on roads which has a social and economic impact on the national level. This is due to its effect in increasing the congestion on roads, which affects the mobilization of citizens, concentrates noise pollution, and leads to reduced road capacity, all of which impact quality of life. Eventually, there will be a requirement to upgrade the roads and infrastructure due to more rapid rates of asphalt deterioration, hence influencing government spending. However, other indirect sustainability enhancements in the process are more difficult to quantify, such as fuel consumption reduction on a national level due to the implementation of lean thinking in construction company maintenance processes. In conclusion, this paper aims to deliver a possible solution for enhancing the sustainability of a PM process for construction equipment, which might not show its effect significantly in one company or one project, but creates awareness for decisions makers at a national level to consider adopting this technique in policy planning in the construction sector.

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