Adopting Lean Principles for Cost Saving and Waste Minimization in Manhole Construction and Backfilling Process

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Abstract

Lean-based sustainability refers to studying and analyzing a current process and improving it. The process can be improved by indicating the non-value-added activities that delay the process and eliminating, combining, or simplifying these non-value-added activities. In this manner, waste has been reduced to a minimum, and overall process efficiency and customer satisfaction are augmented. The paper aims to oversee the current process of Manhole construction and work in a manner to reduce the time taken, materials used, and general resource wastes. Specifically, it has been observed that the Manhole backfilling process can be broken down into key activities. The process can be improved and made more efficient by linking lean-based tools to sustainability. The results have revealed that the overall process time and total lead time have been improved by around 17.6% and 41.2%, respectively. Furthermore, waste production has been significantly reduced by approximately 83.5%. The waste mentioned above reduction percentage has been obtained without sacrificing or compromising the quality and standards.

Keywords
Lean Construction, Sustainability, Lean based Sustainability, Value stream Mapping, Manhole Construction, Waste Minimization.

1. Introduction

1.1. Lean Concept

Lean is widely known as the waste elimination approach. The “Lean” methodology originated in Japan and has since been related to separating wasteful activities from those that bring value to a business and its supply chain. Waste is responsible for roughly 95% of the total cost (Kilpatrick 2003). The lean process was not new when broken down into its component elements, but it was new. Lean provides us with a concept concentrated around understanding value. It gives us a methodology to prioritize value-creating actions and arrange the entire process more efficiently. In addition, lean thinking provides help to reduce the human effort required and reduce time and space (Womack and Jones, 1996). Therefore, lean methodology is essential and fundamental. These days, manufacturing industry globally, business executives are applying the lean concept in many operational areas inside their organizations to achieve optimal performance and satisfied customers.

1.2. Sustainability Concept

In the Brundtland Report, the United Nations (UN) defined sustainable development as meeting the needs of the present without compromising the ability of future generations to do the same. In addition to natural resources, both social and economic resources are required. Sustainable living is not just about natural resource conservation but also includes economic growth and social equality.

The economic component refers to a system of production, distribution, and consumption of wealth, generally understood as the way to meet people's material needs by money, owning assets, or possessing anything with economic value in terms of price Kucukvar et al. (2022), Kutty et al. (2020 c)

The social component reflects a way of living or interacting that prioritizes maintaining and improving people's standard of living. It considers the continual satisfaction of basic human needs and important social and cultural necessities (Brown et al. 1987). The social dimension does not consider wealth in terms of buying, selling, or storing goods for the future. Rather, it advocates for equal treatment regardless of gender or race, access to basic health care, workplace safety, food standards, artistic and cultural exposure, financial success, entertainment opportunities, and a fulfilled personal life, among other things.

The environmental component ensures the health and preservation of ecosystems (Sadler et al. 1990). It relates to an ecosystem's enduring productivity and functionality (Brown et al. 1987). An environmental perspective is a scientifically based outlook on preserving the biological and ecological conditions that enable development (Shearman. et al. 1900).

1.3. Relationship between Lean and Sustainability

Lean thinking and sustainability have a common goal of optimizing the process by the judicial use of resources. Many research studies have demonstrated that lean principles complement sustainability's primary aims and achieve its primary objective related to processes because of its methodology to improve waste, improve the entire process, and reduce the harmful effect of construction projects. Isabelina and Laura (2012) introduced a case study showing the practical significance of lean thinking to achieve sustainability. They examined the effect of using one of the lean tools to achieve sustainability in all three dimensions by evaluating three modular dwelling construction case studies. The results showed that material waste was reduced by 64% during the gypsum board hanging process, and working hours by 31% during the interior painting process was achieved using the lean tool. In addition, the social dimension of sustainability was also applied by improving the worker's safety and adding value-added activities by 15%.

This paper aims to apply lean-based tools to improve the process of Manhole construction & backfilling to eliminate wastes and non-value-added activities linked to sustainability in the construction field. The rest of the paper is organized as follows: Section 2 presents the methodologies and procedures used. Section 3 reports an illustrative example of the Manhole traditional backfilling and improved process and compares both approaches.

2. Methodology

2.1. Value Stream Mapping (VSM)

The VSM is a lean tool that uses a flowchart to document each process phase and then analyze or optimize them. As a result, the VSM helps to identify waste, non-value-added activities, shorten process cycle time, and improve processes.

2.2. Root Cause Analysis

Root cause analysis is a method for systematically identifying and investigating the underlying causes of problems to determine what can be done to remedy or prevent them.

Lean construction (LC) is a method of designing production-related processes to minimize the waste of materials, cost, and effort (Garcia and Murguia 2021). Proper planning, sound decision-making, and data accessibility can eliminate non-value-added activities (Akinradewo et al. n.d.). This research adopted and identified an appropriate methodology for applying LC in one of the most common methods in the field of construction, which is backfilling of stormwater drainage (SWD) Manholes. Much of the cost is attributable to non-added-value activities, referred to as waste (Helmold M. 2019).

One of the primary goals of lean construction is to maximize value. Similarly, in this case, implementing lean construction requires several lean tools to be used, of which we have used Value Stream Mapping (VSM) and Root Cause Analysis in our case.

This work improvement study focuses on eliminating unnecessary activities or resources by selecting the right process through employing lean tools in the backfilling process. Figure 1 below illustrates the methodology proposed to complete the objectives of this study.

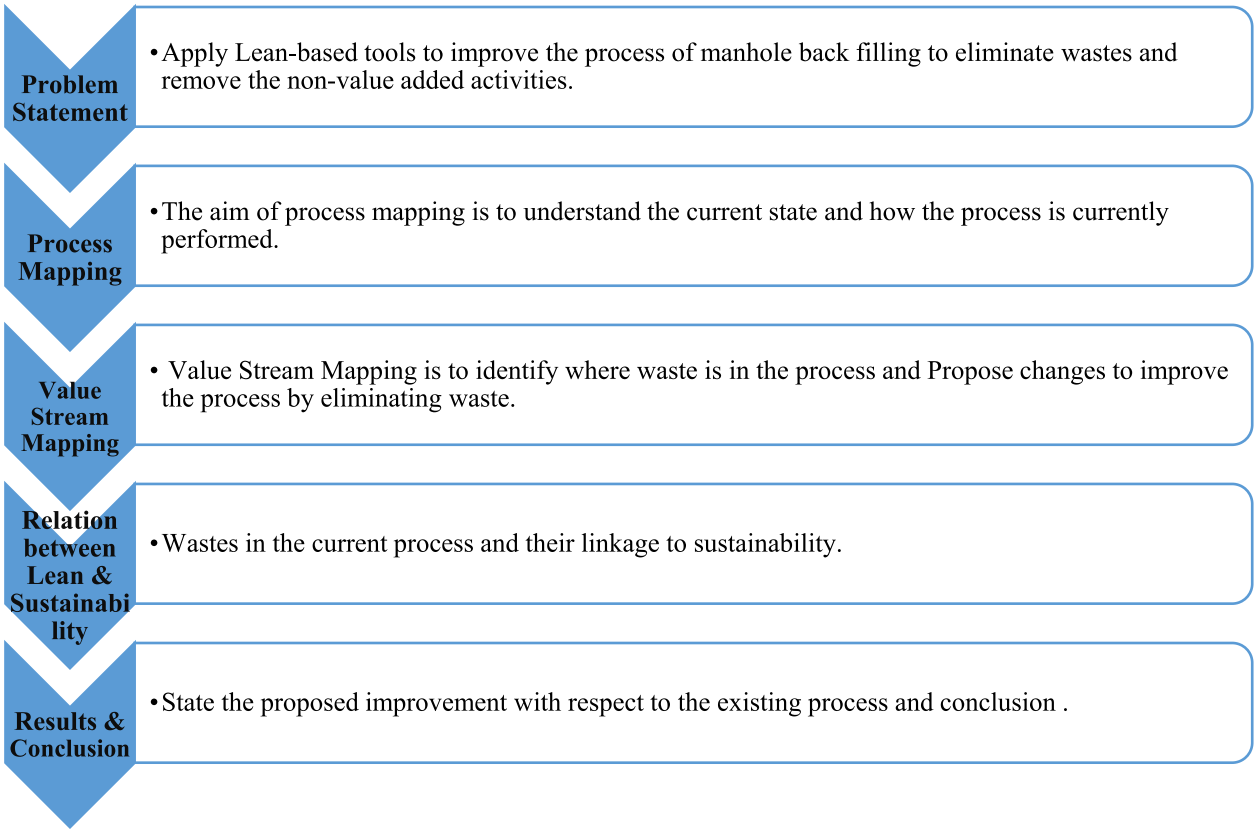

Figure 1. Research Methodology

Root Cause Analysis has been applied to understand how to analyze the foam concrete backfilling process to identify the excess quantity of foam concrete used in the SWD Manhole surround.

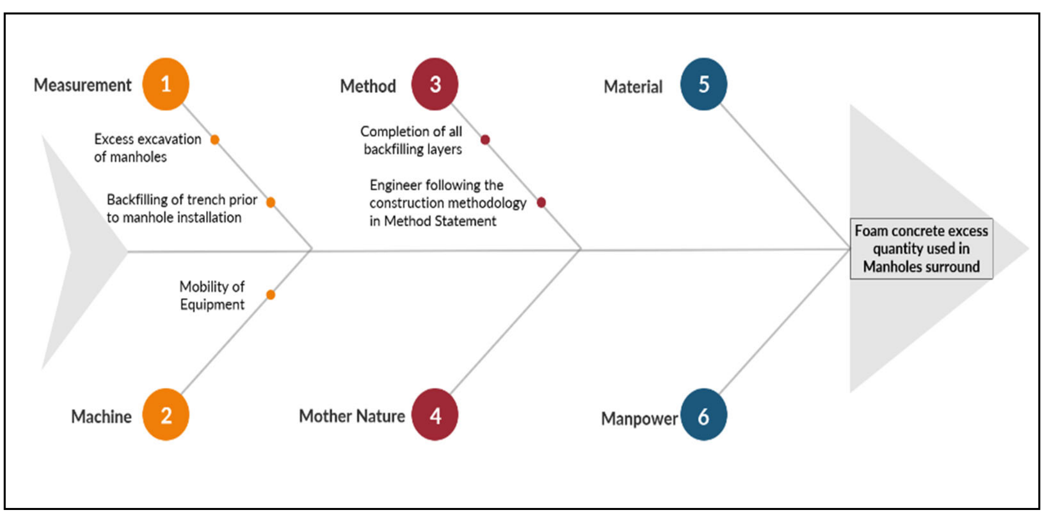

Figure 2. Root Cause Analysis: Fish Bone Diagram

3. Construction of Manholes

3.1. Process Description- Existing Approach

Manhole construction is integral to underground services in cities or even rural areas. They serve as access points for inspections, repairs, and system upgrades. Foam concrete is used as a surrounding material for the constructed Manholes. Using such a construction sequence, we need huge concrete to surround the Manhole.

Figure 3 shows the process mapping in the Manhole construction and lists all the steps required for the Manhole construction and Backfilling process.

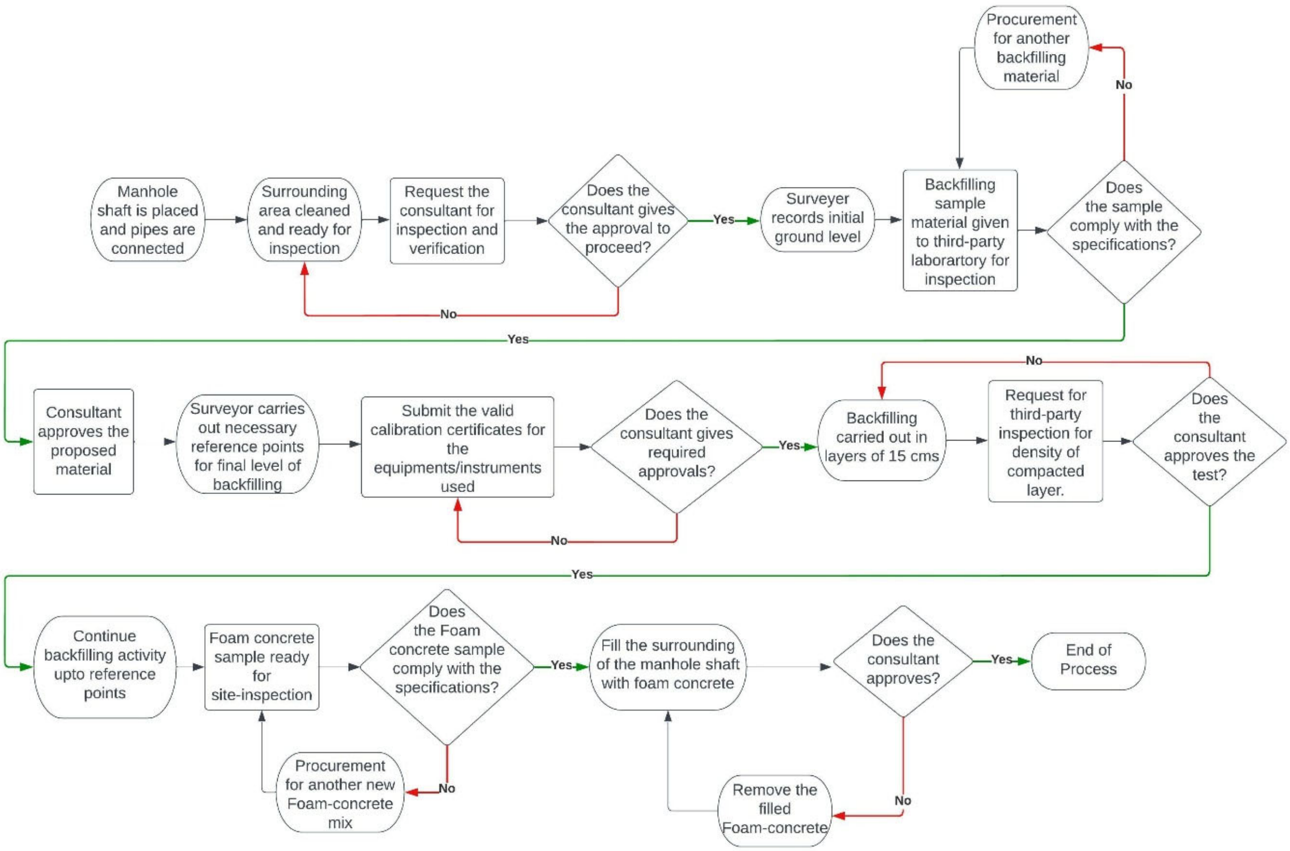

Figure 3. Process Mapping for Manhole construction

As clear from the process mapping of the Manhole construction process, there are several steps and protocols to be followed at each stage according to the existing method statement of the project. First, the aim is to discover tasks or steps that do not add value to the process. Then these can be either simplified, removed, or combined to arrive at a new methodology that is more efficient, faster, and has minimum possible non-value-added activities.

To identify non-value-added activities, we plotted the VSM of the whole process, which helped us identify the non-value-added activities and hence the course of action for a better methodology for the process of Manhole construction. In addition, Kaizen Burst, a tool in VSM, helps to identify the areas where improvement is needed. The VSM of the existing process, along with the Kaizen Burst, has been illustrated in Figure 4.

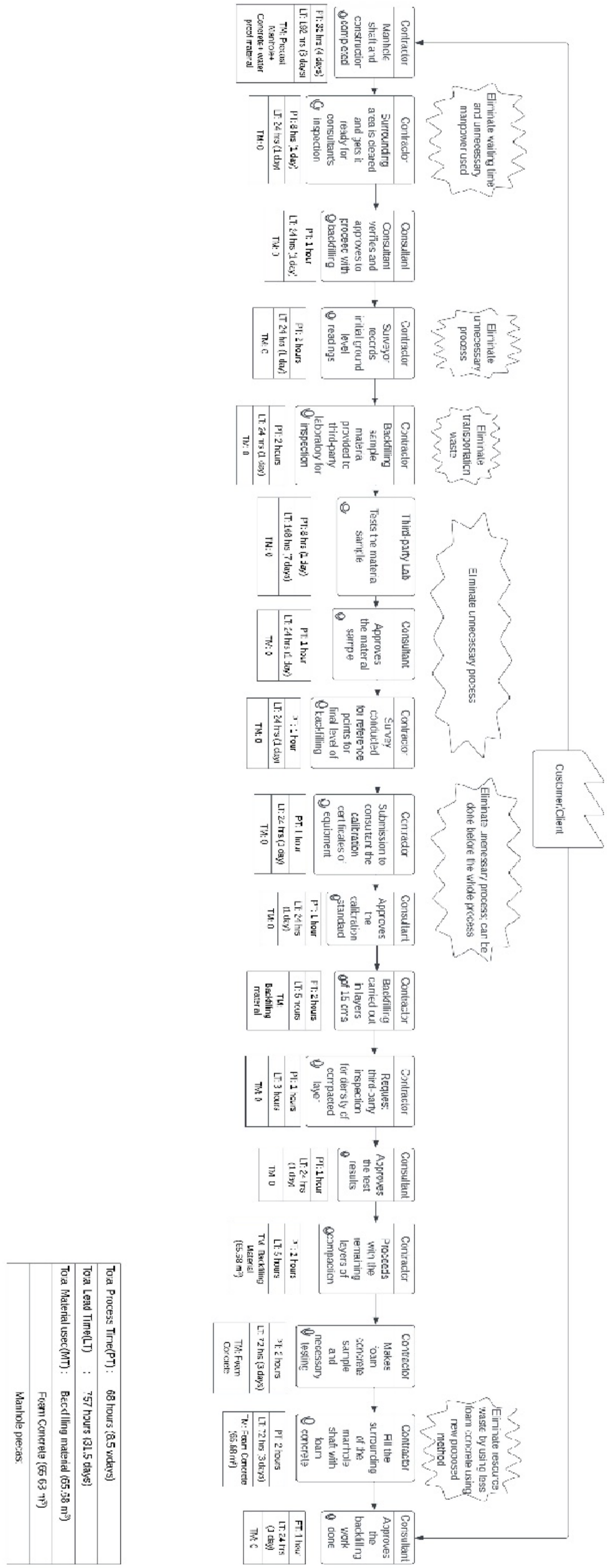

Figure 4. Value Stream Mapping of the Current Process

3.2. Improved Approach

The suggested improvements are as follows:

1. Foam concrete surround for Manholes will be executed in multi-stages.
2. In the initial stage, concrete will be poured with a length of 50 centimeters on each side to protect the box from the Manhole.
3. In the following stages, foam concrete surround will be accomplished after the compaction of 3-4 layers of trench backfilling.
4. The surrounding concrete will be in a zigzag shape around the Manhole instead of using a long triangle shape. Figure 2 describes it below.
5. The proposed foam concrete quantity will be around 10.87 m^3 for an average depth of 4.65 meters and a Manhole diameter of 1.5-2.0 meters.

The proposed methodology for backfilling process in Manhole construction is carried out in stages instead of pouring the concrete at once in large amounts. Moreover, the amount of concrete required in the new process is much less than the existing method of backfilling process. Therefore, the new methodology helps to save a large amount of concrete used in the backfilling process. Moreover, the process is simplified and more efficient than the previous one. The strength and robustness of the Manhole are not affected due to the new methodology being followed. Hence, the new methodology projects itself as a better alternative to the existing process. Figure 5 shows the Value stream mapping for the improved process.

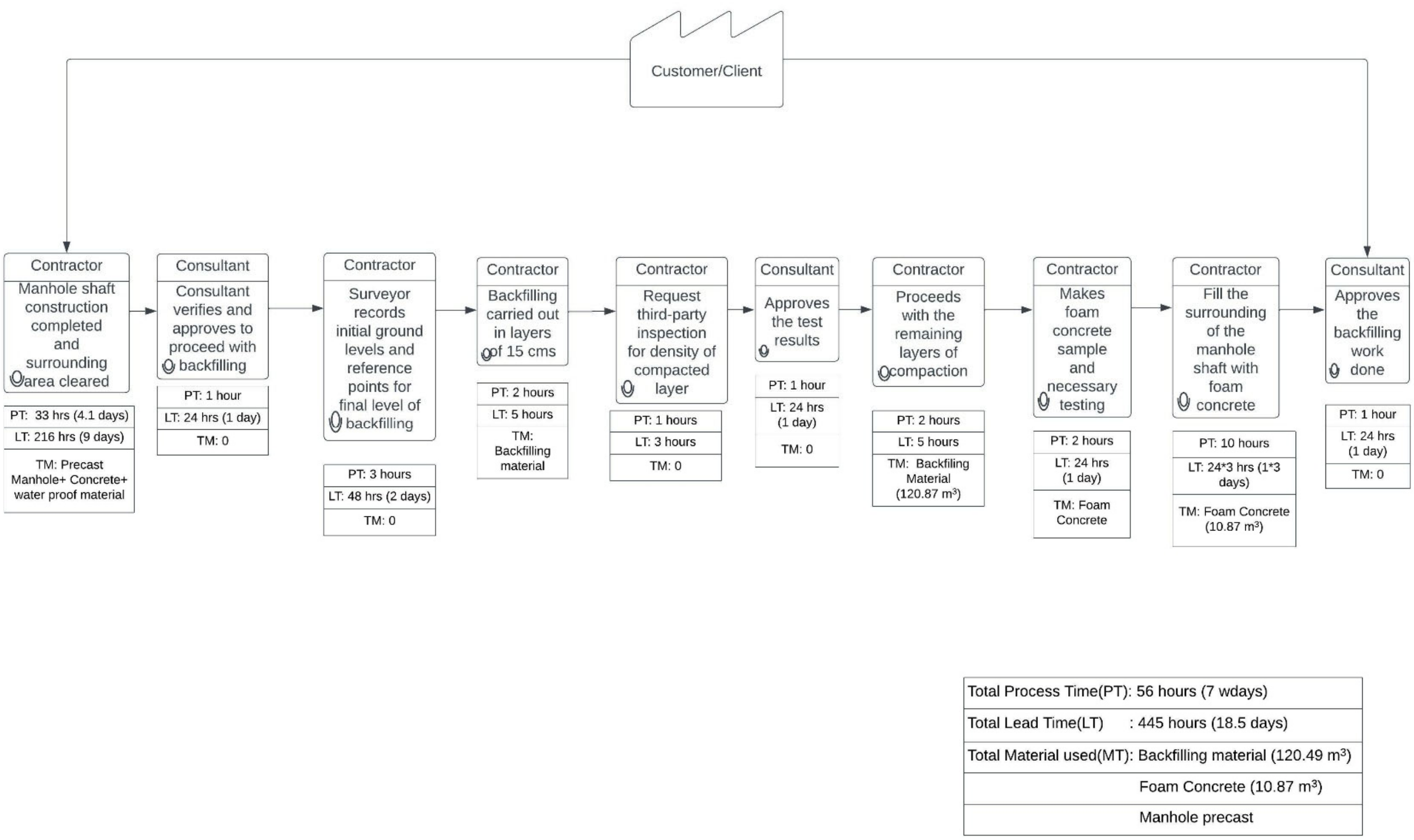

Figure 5. Value Stream Mapping of the Improved Process

3.3. Process Waste and Sustainability Indicators

Based on the current state of the VSM, the existing waste in the current method of Manhole construction has been identified and described below:

3.3.1. Manhole shaft, construction, and cleaning for the inspection are done separately

Manhole shaft construction can be organized, and the surrounding area can be cleared of waste simultaneously. As a result, unnecessary motion and transportation of labor and waste will be reduced. In addition, laborers can perform the task on the same day, ultimately saving energy consumption on transportation and machinery. Completing both tasks simultaneously also means saving Waiting Time and ultimately increasing the efficiency of the work.

3.3.2. Surveyor carries out his work at two different times rather than doing it at once

The surveyors can only come to the site once to record the initial ground level and the reference points for the final backfilling level. This will minimize over-processing by reducing the process steps and time necessary to meet the customer's needs. Executing the surveyor duties on two days ultimately increases the waiting time for the processes and delays the construction. In addition, finishing the surveyor duty on the same day prevents unnecessary motion on the part of the surveyor and the machinery associated with the work. Unnecessary transportation can also be prevented by undertaking surveying jobs on the same day rather than doing it on two different days.

3.3.3. Backfilling material sample test and approval

Backfilling material samples can be prepared and tested before the start of the backfilling process. This offloads the construction process from unnecessary delays in the form of Waiting Time. Moreover, it removes waste like overprocessing, making the construction process smoother and more efficient.

3.3.4. Equipment calibration certification and approval

The calibration of equipment and its approval from the consultant can be done before the backfilling process starts. Adjustments like this will reduce waste in the form of over-processing, waiting time, and unnecessary transportation. Although these tasks should be done, it is not essential to perform them during backfilling. Performing these activities during the process will delay the process, increase the energy usage and emissions from transportation, as well as equipment and workforce that remains under-utilized energy while waiting to proceed with the next activity, ultimately creating a waste called under-utilized resources.

3.3.5. improvement in the construction process

Instead of filling the whole space around the Manhole shaft with foam concrete, a new method is proposed to reduce the amount of foam concrete usage while filling without compromising the quality of work. Underutilization of talent, over-processing, and Unnecessary transportation is the type of waste in this activity. They were minimized in the proposed method, as ideas and suggestions were collected from engineers to be more sustainable by reducing concrete usage and contributing to the environment by reducing pollution from concrete factories and excessive raw material usage. The new method utilizes less Foam concrete; it saves on not only the material's transportation costs but also the production costs associated with the material and, thereby, sustainable use of the resource.

Moreover, lean waste and its linkages to sustainability have been identified in Table 1. The sustainability indicators have also been identified as a measure of effectiveness.

Table 1. Lean waste Examples in the current process and their linkages to sustainability

S. No.	Waste	Examples	Link to sustainability	Sustainability Indicators
1	Waiting Time	Waiting for the area to get cleared before the inspection	Potential loss of time and underutilization of machinery and workforce	Excess energy used and air emissions generated due to waiting time (in tons/%change)
		Waiting for the Backfilling material sample to get approval		
		Waiting for consultant approval for Calibration certificates		

		Waiting for the surveyor to record points at two separate times rather than doing it at once		
2	Overprocessing	Manhole shaft and cleaning of surrounding areas for approval done as a separate process.	More use of natural resources and energy consumption for transportation and instrument use	Excess energy used and air emissions generated due to waiting time (in tons/%change)
		The surveyor records measurements at two distinct stages rather than at once.		
		Backfilling material sample approval by the consultant can be done before the Backfilling process.	Potential loss of time and underutilization of machinery and workforce	
		Calibration certificate approval can be done before the start of the Backfilling process.		
3	Unnecessary Transportation	Unnecessary transportation to send the workforce on site to clean the site for inspection	More energy usage and more harmful effluents as a result, along with the increased cost	Air emissions generated from vehicles (in tons/%change)
		Unnecessary transportation to send Backfilling samples to the laboratory		
		Unnecessary transportation to send Calibration certificates to the consultant		
		Unnecessary transportation to bring extra Foam Concrete materials on site		
4	Excess Raw materials	Excess foam concrete is needed to fill the Manhole shaft	More use of natural resources	Amount of Foam concrete used in m^3/Manhole
			Effect of mineral extraction, processing, transportation, etc., on nature	Amount of CO_2 and various other harmful gases emissions (in tons/%change)
5	Under-utilized talent	Not using the better method to fill the Manhole shaft with less foam concrete	Fewer suggestions/Fewer opportunities for pollution prevention	% change in the amount of Foam concrete used in m^3/Manhole
6	Unnecessary motion	The surveyor takes the readings two times at different stages rather than doing it once	More use of natural resources and energy for transportation and instrument use	Air emissions generated from vehicles and Energy use due to the use of machinery
		Unnecessary motion to send the workforce on site to clean the site for inspection		

4. Results and Discussion

The results reveal motivating outcomes for opting to use the newly developed method rather than the outdated methodology used for Manhole backfilling. Choosing the given optimized methodology has aided in reducing the time utilized for backfilling Manholes, a noticeable reduction of waste (amounts of materials being wasted and harmful gases emitted in the process), and a major cost reduction.

The different aspects for which the new methodology aids in improving performance and reducing the cost and waste associated with the process are described in detail.

4.1. Time Reduction

The activity time for foam concrete backfilling will be increased. Nevertheless, this will not affect the overall process timing since it will be reduced by eliminating and combining other activities. Overall, the total process time for the whole process will be reduced from 68 hours to 56 hours (17.6% improvement); see Figure 6. Moreover, the total lead time for the process will also be reduced from 757 hours to 445 hours (41.2% improvement).

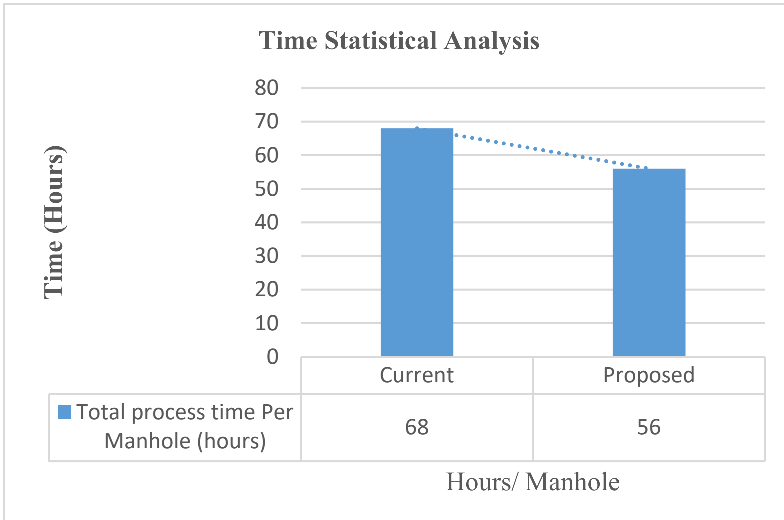

Figure 6. Time comparison between the current process and the improved process

4.2. Waste Reduction

The total amount of concrete used will be reduced from 65.68 m^3/Manhole to 10.87 m^3/Manhole (83.5% improvement); see Figure 7. Moreover, the amount of CO_2 and other harmful gas emissions will be reduced due to following the new methodology for constructing the Manhole and backfilling process.

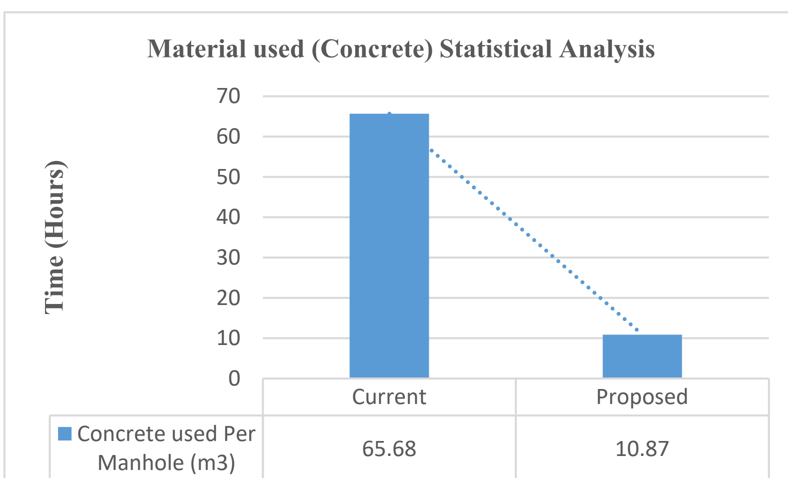

Figure 7. Material used (Concrete) comparison between the current process and the improved process

4.3. Cost Reduction

The cost of constructing a Manhole is drastically decreased from 12,186.20 QAR to 2,337.05 QAR. The improvement registered is a staggering 521% less than the old process; see Figure 8.

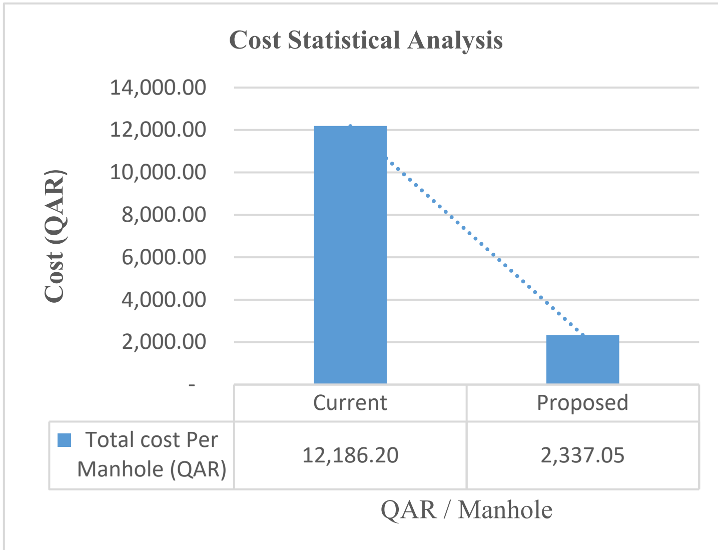

Figure 8. Cost comparison between the current process and the improved process

5. Conclusion and Recommendation

This paper presented a lean-based methodology for enhancing the sustainability performance of one of the major processes for Manhole construction, the backfilling process. Non-value-added activities have been identified and reduced waste to a minimum by combining, eliminating, or simplifying the actions taken. In turn, the process's overall duration and the drastic saving of material utilization have decreased, which works hand-in-hand with the sustainability concept without compromising the standards and quality of work being done. Cost reduction was also a major factor in optimizing this process rather than the traditional backfilling procedure. Continuous improvement by implementing these methodologies on a larger scale will incentivize a more sustainable construction process. However, there is much more room for improving the process, and further analysis is needed for continuous development and improvements. Using different eco-efficiency indicators to assess the proposed approach is a future research trend; for instance, Abdella et al. (2020, 2021); Kucukvar et al. (2020); Kutty et al. (2020 a,b)

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