CHAPTER 106

Process Mapping to Identify and Minimize Wastes in Formwork Operations

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ABSTRACT

Low productivity in construction processes is a major concern which significantly impacts project outcomes and reduces their overall value. Process mapping is an important tool in the Lean construction approach which involves breaking down a workflow into clearly defined, visual steps to enhance understanding. It establishes a common framework for analyzing the process and identifying opportunities for improvement. Formwork is one of the significant expenses in reinforced concrete structures. However, formwork operations often involve non-value-adding activities, leading to inefficiencies and waste. Addressing these issues is crucial for improving productivity and reducing costs. Process mapping helps identify inefficiencies in formwork operations, optimize workflows, and reduce waste, leading to better project outcomes. The findings in this study demonstrated that the implementation of process mapping can minimize waste in formwork operations while enhancing the overall value of construction. This approach offers a fresh perspective on improving efficiency in formwork processes.

Keywords: Lean construction; Process mapping; Formwork; Process waste.

1.0 Introduction

1.1 Background

The construction sector is a vital part of the global economy and contributes substantially to infrastructure, development and growth (Adinyira & Agyekum, 2021). Within this vast sector, concrete construction and formwork activities stand out as fundamental components. Formwork is a temporary structure used to hold concrete in place while it sets and hardens. The process includes setting up the formwork, pouring the concrete, and then removing the formwork once the concrete has fully cured (Mantri, 2023). Formwork operations are complex and labour-intensive, involving multiple activities such as material procurement, preparation, assembly, erection, and dismantling. Inefficiencies in these operations often lead to excessive material wastage, increased labor costs, and extended project timelines. Thus, the identification and minimization of wastes in formwork processes have emerged as critical imperatives within the construction industry (KO & KUO, 2015).

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The construction industry struggles with low productivity (McKinsey, 2017). By identifying and removing wasteful activities that don't add value for the final product can significantly improve productivity (Unnikrishnan & Sudhakumar, 2024). Therefore, it becomes paramount to optimize the practices associated with these integral construction phases. Thus, the aim of the study is to take a closer look at the step-by-step processes involved in formwork operations and identify where resources are not being used appropriately.

1.2 Process mapping

It is a visual technique used to outline and analyse the tasks and decisions which are generally involved in a specific process. It helps organizations understand how workflows from start to finish, identifying inefficiencies, redundancies, and opportunities for improvement (LCI, 2025). By visually representing each phase of the formwork process from material procurement and assembly to inspection and dismantling project teams can pinpoint bottlenecks, streamline workflows, and improve coordination among workers (Ko *et al.*, 2011). Various types of maps like flowchart, value stream and swim lane diagram can be employed depending on the complexity and focus of the process (Aslam *et al.*, 2022). For example, value stream mapping, often used in lean construction, helps differentiate between value added and non-value-added activities, enabling more efficient resource utilization (Espinoza *et al.*, 2021). In formwork construction, this could involve visualizing the workflow from receiving design plans and procuring materials to assembling different formwork elements, concreting, and eventually dismantling of different structures (Pothen & Ramalingam, 2018). By using process mapping, construction teams can reduce material wastage, improve labour efficiency, and ensure timely project completion, making it a vital tool in adopting lean construction practice (Ramani & Lingan, 2022).

1.3 Current state map

This map is a visual tool that illustrates how a process currently functions, detailing all existing steps, activities, and workflows. It highlights both essential tasks that add value and those that do not add any value, providing a clear and complete view of material movements, information flow, time demands, and resource use (Espinoza *et al.*, 2021). In construction, particularly in formwork operations, a current state map is instrumental in identifying inefficiencies such as material delivery delays, redundant labor activities, and bottlenecks in the assembly or dismantling phases (Pothen & Ramalingam, 2018). By thoroughly documenting the present process, stakeholders can pinpoint sources of waste, including overproduction, idle time, unnecessary transportation, or surplus inventory (Wu & Feng, 2014).

1.4 Future state map

The Future State envisions how a workflow should function after targeted improvements are put in place. It focuses on designing an optimized workflow that eliminates

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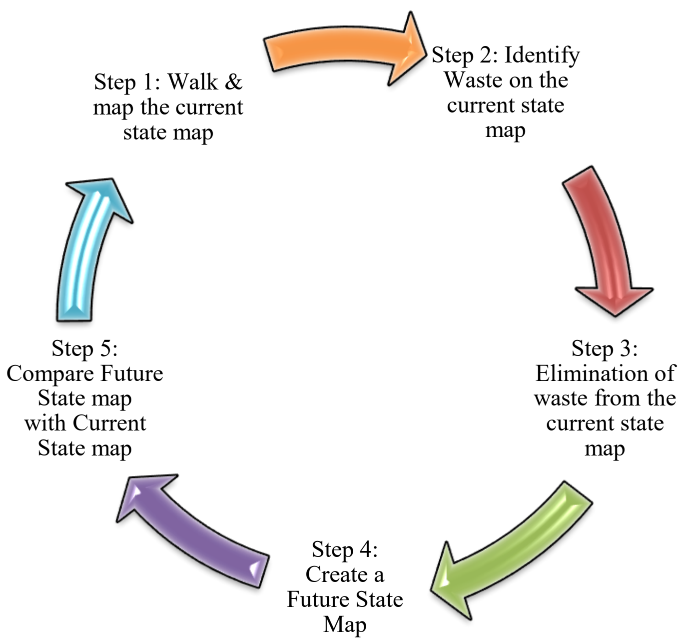
waste, reduces inefficiencies, and enhances overall productivity (Ramani & Lingan, 2022). The future state map redefines the process to minimize delays, streamline material handling, and improve team coordination. Strategies may include timely material deliveries, eliminating unnecessary movements, standardizing procedures, or integrating automation where feasible (Unnikrishnan & Sudhakumar, 2024). The primary objective is to create a lean, efficient process that maximizes value while minimizing waste (Aslam *et al.*, 2022). When there is comparison between the current and future state maps it helps us identify strategies to bridge the gap between existing practices and the ideal, streamlined workflow, resulting in more efficient and cost-effective project execution (Ramani & Lingan, 2022).

Figure 1: Steps of Process Mapping



1.5 Classification of activities

In process mapping, activities within a workflow are typically categorized into three groups: value added (VA), non-value added (NVA), and non-value added but necessary (NVAN) (Ramani & Lingan, 2022). Knowing these categories is crucial for spotting inefficiencies and streamlining procedures, especially in sectors like construction where time and resource management are crucial. Value-Added activities are tasks or processes that directly contribute to meeting customer requirements or enhance the final product or service. As they give the result physical or perceived value, these actions turn materials, information, or components into something the client is willing to pay for (Pothen & Ramalingam, 2018).

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Activities that directly contribute to the construction or improvement of a structure, including pouring concrete, setting up formwork, or finishing surfaces, are considered value-adding in the construction industry. Activities that take up time, money, or effort but don't go towards the finished good or service are known as non-value-adding activities. These procedures are frequently regarded as waste because they don't alter the final product in a way that the consumer finds desirable (Han *et al.*, 2007).

One of the fundamental ideas of lean construction and lean techniques is the removal of non-value-adding activities. NVA activities include unnecessary movements, waiting times, overproduction, rework, and excess transportation (Ramani & Lingan, 2022). These activities inflate project timelines and costs without enhancing the quality or functionality of the final structure (KO & KUO, 2015). Identifying and eliminating NVA activities is essential to streamline processes (Han *et al.*, 2007). However, completely eradicating them may not always be possible due to practical constraints on-site. Activities that are necessary for the process to run smoothly or to satisfy legal requirements but do not directly contribute to the finished product are known as non-value adding but necessary activities. These tasks are required for safety, compliance, coordination, or other operational requirements even when they don't bring value from the standpoint of the client (Pothen & Ramalingam, 2018). NVAN activities occupy a unique space in process mapping, as they cannot be classified purely as waste but still do not enhance the product's intrinsic value. While these activities may not directly advance construction progress, they are crucial for ensuring project safety, meeting industry standards, and avoiding costly legal or operational setbacks (Ramani & Lingan, 2022). Lean principles recognize that while NVAN activities should be minimized where possible, they often represent unavoidable aspects of responsible and compliant construction management (Han *et al.*, 2012).

2.0 Methodology

Formwork operations are a critical component of construction projects, affecting cost, time, and overall efficiency. To achieve a comprehensive understanding of formwork operations and to identify potential inefficiencies and wastes, a detailed observational study was conducted on active construction site. The methodology combined direct observation with data collection techniques based on Lean Construction principles, facilitating the development of accurate process maps to highlight value-adding and non-value-adding activities. The method in Lean where participants are observed without their knowledge is called "shadowing" or "unobtrusive observation". This approach is often used to gather insights about how processes are carried out in real-life settings without influencing behavior due to the observer's presence. By avoiding direct interference, you can obtain a more accurate and unbiased understanding of inefficiencies, wastes, or deviations in the workflow. The project involved a 13-story building on area of approximately 1400 square meters. The foundation of the building is an open pit foundation and constructed in traditional way upto plinth level.

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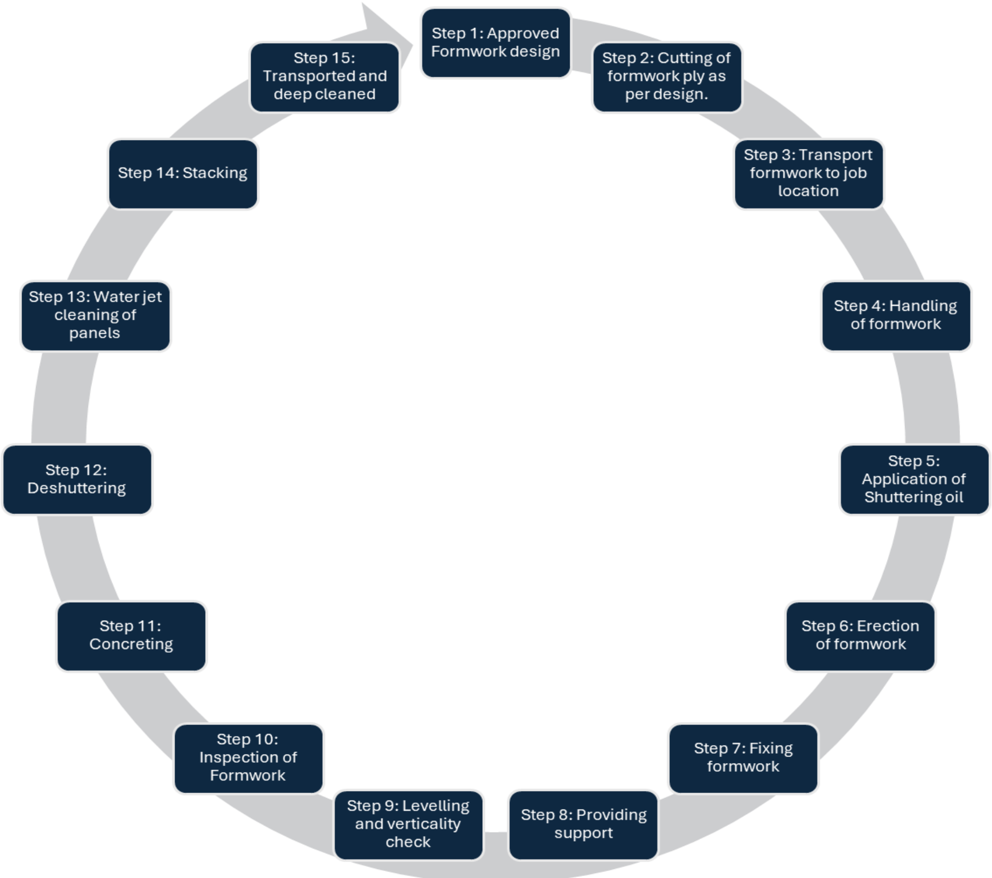
Figure 2: Steps in Formwork Operations



Upon completion of the plinth level, precast elements including columns, slabs were used for the construction of all 13 floors. The focus of this study is on the formwork construction carried out in foundation. The formwork for the foundation was completed using a combination of Timber and Steel Formwork. The study focused on capturing detailed information on time consumption, labor movements, material handling, and the sequence of tasks. Time-motion studies were conducted using video recordings to capture the duration of specific tasks and the transitions between them. This allowed for precise measurement of time spent on each activity, facilitating the identification of bottlenecks or delays in the workflow. The observational data collected was analyzed through the lens of Lean Construction principles to identify various forms of waste inherent in the formwork process. The observation process was structured around a fifteen-step formwork operation flowchart, which served as the backbone for monitoring activities on-site.

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3.0 Findings and Data Analysis

For our research, we extracted time-based data from multiple video recordings to analyze task durations and optimize workflow efficiency. The methodology involved segmenting each video into distinct operational activities, such as assembling formworks, material searching, and waiting periods. Each activity was categorized into motion types (e.g., walking, searching, waiting) to understand how time was distributed across different tasks. Using video playback we recorded the duration of each activity and calculated the percentage contribution of each action to the total recorded time.

Table 1: Analysis of Labor Working on Formwork Operations

Activities	Total No. of Labors	Value Added (VA)	Non-Value Added (NVA)	Non-Value Added but Necessary (NVAN)
1.Drilling	3 Labors	1	2	-
2.Curing	1 Labor	1	-	-
3.Unwinding Wire	4 (2 Supervisor+2 Labors)	3	-	1
4.Formwork Measurements	3 (1Supervisor+2 Labor)	2	1	-
5. Concreting for Tower Crane Foundation	10	5 labor	-	5 (4 labor, 1 supervisor/engineer)
6.PCC for Footing	13	4 labor	5 labor	4 (1 labor, 1 surveyor, 2 supervisor/engineer)
7.Formwork for Footing	4	1 labor	1 labor	2 labor

The collected data was systematically compiled into an Excel sheet, with columns detailing the motion type, description and time taken. This structured approach enabled us to compare time utilization across different operational scenarios, providing insights into inefficiencies and potential areas for process improvement.

Table 2: Formwork Operation Analysis

Operation	Motion	Description	Time (in seconds)	Time(in %)
Assemble & machine formworks	Walk	Walk to the formwork storage area	30	5.43
	Search	Search for appropriate materials	127	23.01
	Wait	Wait while an assistant looks for materials	40	7.25
	Measure	Measure the size of the required formwork	63	11.41
	Machine	Cut materials	65	11.78
Transport molds	Pass	Pass formwork to worker	15	2.72
	Move	Move the stripped molds to the next area	57	10.33
Erecting	Fix	Position & Fix formwork	95	17.21
	Fix	Final Positioning and Verticality	60	10.87
Total			552	100.00

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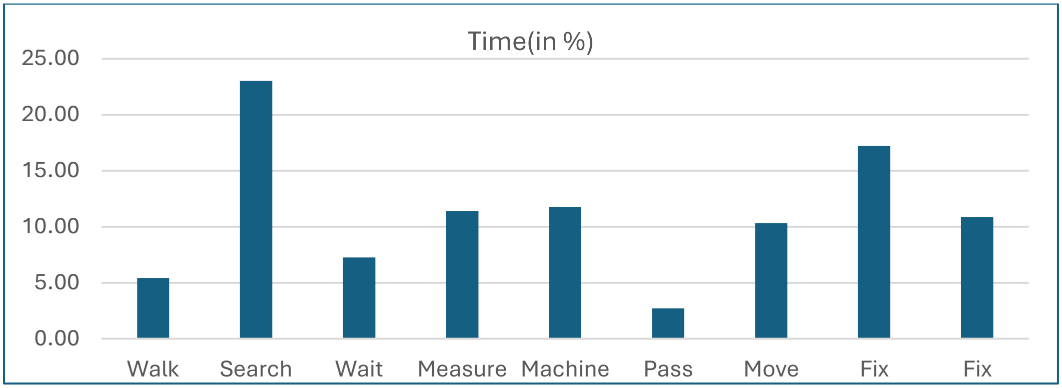
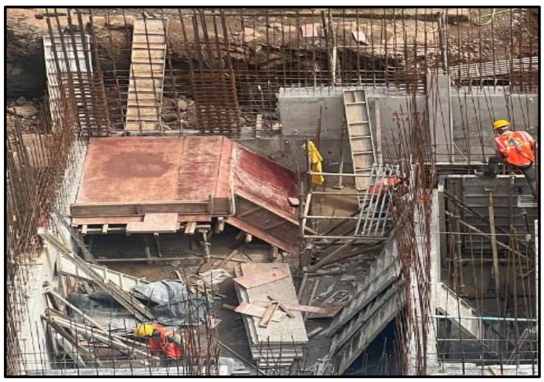


Figure 3: Graphical Representation of Time taken by each Formwork Operation

Improper stacking of formwork has resulted in workers searching for the required size of board

Workers are waiting for the cleaning task to be completed.

Some workers are cleaning and preparing the surface of formwork while others are standing idle.



Formwork boards are improperly stored in workplace instead of dedicated storage area.

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A lot of formwork boards are stored near the working area making it difficult for the workers to move.

During concreting operation some workers are engaged in the task while some are sitting idle waiting for their turn.

Table 3: Current State Map

Sr. No	Pre Construction	Symbol	PM Metric	During Construction	Symbol	PM Metric	Post Construction	Symbol	PM Metric
1	Material Selection		VA	Concrete Pouring		VA	Formwork Removal (Stripping)		VA
2	Formwork Fabrication		VA	Rework Due to Concrete Spillage or Formwork Failure (Defects)		NVA	Formwork Storage and Maintenance.		VA
3	Formwork Setup and Installation		VA	Regular Inspection and Monitoring		NVAN	Excessive Delays in Formwork Removal (Waiting)		NVA
4	Material Handling & Movement		NVAN				Unnecessary Double Handling of Formwork (Motion)		NVA
5	Unnecessary Adjustments and Rework (Excess Processing)		NVA				Formwork Cleaning and Repair		VA
6	Site Preparation and Leveling		VA						
7	Inspection and Quality Checks		NVAN						
8	Safety Measures (Scaffolding, PPE, etc.)		NVAN						

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This map establishes a baseline for process improvement, serving as a reference point to measure the effectiveness of future improvements. It categorizes activities into Value Addition (VA), Non-Value Addition but Necessary (NVAN), and Non-Value Addition (NVA) across pre-construction, construction, and post-construction. Issues include rework due to defects, excessive handling, waiting times, and unnecessary adjustments. Solutions focus on optimizing material selection, reducing delays, improving inspection, and minimizing excess movement. Addressing these inefficiencies enhances productivity, reduces waste, and improves workflow standardization. Implementing Lean Construction techniques will lead to cost savings, reduced timelines, and sustainable resource management.

Table 4: Future State Map

Sr. No	Pre-Construction	Symbol	PM Metric	During Construction	Symbol	PM Metric	Post Construction	Symbol	PM Metric
1	Material Selection	■	VA	Concrete Pouring	⬬	VA	Formwork Removal (Stripping)	⬬	VA
2	Formwork Fabrication	⬬	VA	Regular Inspection and Monitoring	■	NVAN	Formwork Storage and Maintenance	▼	VA
3	Formwork Setup and Installation	⬬	VA				Formwork Cleaning and Repair	⬬	VA
4	Material Handling & Movement	➡	NVAN						
5	Site Preparation and Leveling	⬬	VA						
6	Inspection and Quality Checks	■	NVAN						
7	Safety Measures (Scaffolding, PPE, etc.)	■	NVAN						

This Map outlines an optimized workflow for formwork operations. Key improvements include better material selection, structured fabrication, efficient setup, and streamlined movement. Waste reduction is achieved by minimizing waiting times, unnecessary movement, and rework. The strategy enhances workflow efficiency through clear process standardization,

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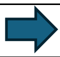
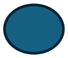
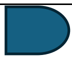
improved logistics, and stakeholder coordination. Ultimately, these optimizations contribute to cost savings, reduced project timelines, and sustainable construction practices.

Table 5 Current Vs Future State Map Savings Analysis

Symbol	Process	Original (CSM)	Improvement (FSM)	Savings
	Storage	1	1	0
	Transportation	2	1	1
	Operation	7	6	1
	Delay	2	0	2
	Inspection	4	4	0
	Total	**16**	**12**	**4**

By analysing the differences between the Current State and the Future State, the research uncovered potential areas for improvement.

- Storage: Steps reduced from 1 to 0, eliminating unnecessary material stockpiling.
- Transportation: Steps reduced from 2 to 1, minimizing excess movement of materials.
- Operations: Optimized from 7 to 6, reducing over-processing waste.
- Delays: Reduced from 2 to 0, eliminating unnecessary waiting times.
- Inspection: Maintained at 4, ensuring that quality remains uncompromised.
- Overall Process Waste Reduction: The total number of steps reduced from 16 to 12, indicating a 25% improvement in efficiency.

4.0 Conclusion

This research set out to analyse the various processes involved in formwork operations through process mapping, aiming to identify and minimize different types of waste. By employing Lean Construction principles and techniques such as Process Mapping (PM), the study provides an in-depth assessment of existing inefficiencies and proposes a structured approach to optimizing formwork workflows. Through a detailed classification of activities into productive (VA), unproductive (NVA), and essential but non-value adding (NVAN) tasks, the research identified key problem areas such as excessive transportation of materials, waiting time due to poor coordination, frequent rework due to improper assembly, and inefficient labor distribution. The study also revealed that unstructured workflows and a lack of standardized procedures led to unnecessary movement and delays, further reducing operational efficiency. To address these inefficiencies, the research developed a Future State Map, envisioning an optimized process flow that reduces waste and improves productivity. The proposed lean-based improvements are:

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- *Minimization of waiting times:* Establishing clear coordination protocols for timely material supply and workflow scheduling.
- *Reduction of excessive movement:* Optimizing site layouts to ensure that materials and tools are stored closer to workstations, reducing unnecessary transportation.
- *Process standardization:* Implementing structured guidelines for formwork erection, dismantling, and reassembly to minimize errors and rework.
- *Improved resource utilization:* Ensuring that labor is effectively assigned to critical tasks, avoiding underutilization or workforce congestion at specific process points.

The limitation of the research is that it primarily investigates formwork operations and does not extend to other critical construction processes such as reinforcement, concreting, and finishing works. Since construction activities are highly interdependent, optimizing formwork alone may not yield maximum efficiency gains without addressing related processes. Further, the study focuses on process identification and optimization but does not include real-time implementation and performance evaluation of the proposed improvements. Future research could focus on piloting the recommended solutions in active construction projects, tracking their impact over extended project timelines. The effectiveness of Lean Construction techniques depends heavily on workforce skills, training, and adaptability. Since different sites have varying levels of expertise among laborers and supervisors, the implementation of lean strategies may not be uniform or equally effective across all projects. Many construction firms and project managers are unfamiliar with Lean Construction principles or are reluctant to modify traditional work practices. The lack of awareness, towards new methodologies, and minimal exposure to lean training programs may hinder successful implementation.

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