Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 9, No. 12, December, 2023

Lean Construction Practice on Toll Road Project Improvement: A Case Study in Developing Country

Mohammed Ali Berawi [1, 2], Mustika Sari [1], Perdana Miraj [1, 3*], Mardiansyah [1], Gunawan Saroji [1, 4], Bambang Susantono [1]

[1] *Center for Sustainable Infrastructure Development (CSID), Universitas Indonesia, Depok 16424, Indonesia.*

[2] *Department of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia.*

[3] *Department of Civil Engineering, Faculty of Engineering, Universitas Pancasila, Jakarta, 12630, Indonesia.*

[4] *Department of Civil Engineering, Politeknik Negeri Bengkalis, Sungai Alam, Bengkalis 28734, Indonesia.*

Received 23 July 2023; Revised 10 November 2023; Accepted 14 November 2023; Published 01 December 2023

Abstract

Construction is a crucial industry that drives a nation's economic growth, yet it often faces inherent challenges related to productivity and waste generation. Lean Construction (LC) has emerged as a promising approach to address these challenges. However, despite its success in various construction projects, some gaps in the practical adoption of LC hinder its widespread practitioner uptake. Therefore, to close the gap, the objective of this study is threefold: identify waste factors of construction activities, determine suitable lean tools for project performance improvement, and assess the impacts of the implementation of lean tools on project completion time and costs. A toll road project in Indonesia was investigated as the case study. A combined research method was employed by administering a questionnaire survey to pertinent project participants, conducting in-depth interviews, and analyzing relevant documents to achieve these objectives. This study discovered 15 non-value-added (NVA) activities that can be eliminated to enhance overall project performance. Most of these activities can be accommodated using coordination and collaboration, while some require a more comprehensive approach, including standardization, the Five S, crash programs, and overlapping techniques. Implementing lean tools resulted in a 19.17% reduction in project completion time, although it contributed to a 5.33% decrease in organizational profit compared to traditional approaches. The findings of this study hold the potential to benefit those facing similar issues, not only in emerging countries but also in developed economies grappling with similar contexts.

Keywords: Infrastructure; Toll Road; Project Performance; Lean Construction; Construction Waste.

1. Introduction

The construction sector has emerged as a pivotal driver of economic growth and bolstered competitiveness on a global scale across numerous countries. Over the past decade, several nations have experienced remarkable success through substantial progress in their construction industries. One of the illustrative examples of this phenomenon is China, where economic growth has witnessed an exponential surge, exceeding 20 times the rate observed in the preceding four decades. This notable growth has not only led to significant improvements in societal assets but has also generated substantial employment opportunities for its citizens [1]. Similarly, construction in India holds a prominent position and contributes 8% to the country's gross domestic product (GDP). This sector has provided a higher

* Corresponding author: perdanamiraj@ui.ac.id

http://dx.doi.org/10.28991/CEJ-2023-09-12-016

opportunity in the real estate market in urban areas [2]. The dependency on construction as a cornerstone of economic activities is not confined to any specific region; it encompasses developed countries in the Global North and developing countries in the Global South, such as South America and Southeast Asia.

Despite the substantial advantages the construction sector can bring to a country's economic development, it is beset by formidable challenges related to sustainability, energy production, and environmental concerns. In 2021, construction and its associated activities will constitute a substantial 37% share of global energy consumption, impacting various sectors [3, 4]. Furthermore, the global annual emissions of carbon dioxide (CO_2) attributable to the construction sector increased to 10 gigatons ($GtCO_2$) in 2021, equivalent to a 5% increase from 2020 levels [3]. These numbers underscore the construction industry's considerable environmental and efficient implications, emphasizing the urgent need for sustainable practices and solutions.

Besides energy consumption and carbon emissions, the construction sector is also globally associated with a significant amount of the consumption of material resources and the generation of environmental waste. This waste category, encompassing a diverse range of materials such as concrete, wood, metals, bricks, plastics, and other substances, collectively represents a substantial fraction of approximately 30% of global waste streams that end in landfills [5]. The careless disposal of construction waste not only presents immediate issues regarding waste management and landfill capacity but also highlights the sector's inefficiency in utilizing resources [6]. The issues of resource consumption and waste production also emphasize the need for sustainable and innovative solutions in this sector.

Numerous scholars and practitioners have tackled the construction industry's challenges related to productivity, energy consumption, and waste generation through various techniques, one of which is Lean Construction (LC). Derived from the manufacturing sector, LC is a systematic approach that aims to enhance supply chains, reduce productivity losses, standardize processes for better value, and minimize waste [7–9]. It has effectively addressed cost overruns and delays in construction [10, 11]. Literature suggests that lean projects outperform projects with traditional approaches or do-nothing scenarios [8]. Its focus on customer satisfaction, waste reduction, and value optimization makes LC an ideal alternative for addressing construction challenges, especially in diverse, fast-growing countries like Indonesia.

Literature has thoroughly examined lean concepts' utilization in the context of toll road or highway construction projects. The focus of the study by Wu et al. [12] is to examine the application of lean management tools in enhancing project efficiency, including the Last Planner System (LPS), Just-in-Time (JIT), and Visual Management (VM), which establishes a relationship between the frequent use of these tools and significant gains in project performance. Pedo et al. [13] explored the integration of lean principles with Building Information Modeling (BIM), particularly in clash management during highway design. The research underscores potential synergies between Lean and BIM, suggesting that using lean principles can effectively minimize waste and improve the clash identification and resolution process.

Other research by Uddin [14] examined quality assurance processes in highway construction, highlighting the importance of cost-effective strategies and innovative testing techniques in light of the financing constraints encountered by the government. Moreover, Nguyen et al. [15] demonstrated the effectiveness of lean concepts throughout many project stages, including design, procurement, and construction. Aligned with them, Mohammadi et al. [16] extended their study beyond initial construction phases, encompassing road maintenance planning and scheduling, where the application of lean concepts plays a crucial role in minimizing non-value-adding operations and optimizing the overall conditions of the network.

While prior studies have showcased successful LC implementation in toll road projects, practical adoption across projects remains challenged, due to variances in the construction industry's nature among different projects and countries [1, 17]. LC's comprehensive and complex framework can hinder immediate implementation [18–20], impeding the rapid success practitioners envision. Therefore, to address these challenges, this study examines LC's implementation and its impact on project performance in the context of toll road projects. The objectives of this study are outlined as follows.

- Identify waste factors of construction activities;
- Determine suitable lean tools to improve project performance;
- Assess the impact of the lean tools on project completion time and costs.

Indonesia's construction sector presents a unique case, accounting for 65% of the country's primary energy consumption [21] and generating about 4.32 million metric tons of waste in 2020 [22]. Consequently, it is crucial to investigate further the intricacies of this sector. This study's selected Indonesian project provides a microcosmic perspective on the broader challenges and opportunities within the nation's construction industry. By implementing LC in this project, this study aims to investigate its benefits in enhancing overall toll road project performance and offer a systematic model for LC adoption in similar global case studies.

The rest of the paper is discussed as follows: Section two elaborates on literature studies published by academics and practitioners on lean practice in construction, construction waste, and the case study. Section three evaluates suitable methodology incorporated in the research that combines quantitative and qualitative approaches. Section 4 presents results on the impact of adopting lean practices on the cost and time completion of the project. Subsequently, Section 5 discusses the findings of the study and its analysis compared to previous studies. The last section presents a conclusion and recommendations for future research directions for lean construction.

2. Literature Study

2.1. Lean Practice in Construction

The lean method was first introduced in the 1990s by the architectural, engineering, and construction (AEC) sector as a means to enhance project performance through the consideration of three key elements: transformation, flow, and value [23, 24]. This concept has been derived from the manufacturing sector, as it has demonstrated the potential to enhance productivity while maintaining competitive costs and minimizing waste formation throughout production processes. The implementation of LC has been empirically demonstrated to yield substantial reductions in construction costs, enhancements in productivity by as much as 50%, and reductions in project time by up to 25% [25–27].

While the implementation of LC may encounter challenges from the perspectives of corporations and policymakers, such as user requirements, stakeholder willingness, educational level, customs, workforce management, project performance, and national policies [1, 28, 29], the ability of LC to address project management concerns regarding delays, cost performance, and quality problems has contributed to its widespread adoption in the construction sector [30].

There are notable distinctions between manufacturing and construction in terms of volume, product, system, automation, and needs [31, 32]. Certain aspects may be deemed unsuitable for implementation in construction projects due to their distinct qualities. Construction projects often exhibit distinct characteristics, such as a varied working environment, a blend of automated and manual labor, project-specific attributes, and diverse objectives set by project owners. Hence, it is imperative to make the necessary adaptations to effectively incorporate and execute the lean concept within the construction sector.

Researchers have identified various tools in the field of LC to aid in the decision-making process and enhance project improvement. In their study, Babalola et al. [33] introduced a comprehensive set of 32 lean tools applicable throughout all stages of a project's life cycle. These tools encompass a range of strategies, such as the LPS, JIT, pull scheduling/planning techniques, visualization tools/management approaches, daily clustering/huddle meetings, concurrent engineering, and many others. The utilization of these instruments is contingent upon the many stages of construction, including design and engineering, planning and control, construction and site management, and health and safety management. For example, utilizing LPS and regular clustering/huddle meetings can be considered suitable methodologies during the design and initial stages. In contrast, JIT and visualization tools/management techniques are commonly employed in construction and site management to attain desired outcomes and meet predetermined objectives.

2.2. Waste in Construction

The construction industry frequently produces large amounts of waste during a project's design, build, operation, and decommission phases. The quantity of waste in this industry is influenced by some factors, primarily those relating to employee skills, knowledge, experiences of organizations, technical skills, machines, methods, and materials employed on the job site. Lean practices are attempted to cope with these factors and minimize waste throughout the project life cycle.

Within the lean production framework, waste is associated with using resources with higher added value to the finished product [34]. The basic idea of lean production is to eliminate all types of waste to deliver the outcomes or goods that the client or owner requires [35]. Several researchers have introduced definitions of waste and asserted that waste is associated with any inefficiency brought on by excess equipment, materials, time, resources, labor, and costs. This loss of material and all unnecessary activities result in additional costs but offer less added value to the end product [7, 36, 37].

Scholars have identified waste in the construction sector that can be effectively utilized to enhance project efficiency and meet consumer demands. The manufacturing method developed by Toyota, which was made well-known by Taiichi Ohno, involved the classification of waste into many categories, including overproduction, waiting, transport, user-processing, inventory, motion, and faults [38]. There is contention among some authors advocating for the inclusion of the eighth category within the framework of production waste regarding employees. According to Womack and Jones [39], one of the identified categories is the underutilization of employees, while Liker [40] recommended the inclusion of unused creativity from employees as the eighth category. Both exhibit similarities regarding untapped potential among staff members, which might serve as valuable chances for improving the project's performance.

In contrast, Bossink & Brouwers [41] proposed waste within the construction sector, delineating six distinct sources: design, procurement, material and equipment handling, operations, residual, and others. In their study, Purushothaman et al. [42] proposed a novel approach to classifying waste that takes into account various factors such as manufacturing (both in terms of production and environmental impact), non-manufacturing (including individual decision-making, functional decision-making, cross-functional decision-making, human resources, enterprise, information technology, and methods), as well as waste related to well-being. de Souza & Carpinetti [43] proposed the inclusion of more comprehensive waste samples within each category, which relevant stakeholders can utilize in addressing waste-related challenges through implementing lean practices.

2.3. Project Case Study

The Trans Sumatera Toll Road (TSTR) is a mega-project infrastructure project in Indonesia to connect the Aceh province in the northern region of Sumatera to Lampung in the southern region. Table 1 summarizes the TSTR project description.

Table 1. Project Description

Project	Toll Road Project, Segment Pekanbaru-Dumai, Section 2 Sta. 9+ 500 – 33+ 600
Package	Underpass Sta 28+150
Location	Minas – Kandis Selatan
Owner	State-owned Enterprise in Construction
Contract Type	Unit Price
Construction Period	24 Months
Operation & Maintenance Period	24 Months since the operation

The TSTR project spans 2,704 kilometers and has 24 toll road sections. It is anticipated to be completely operational by the year 2024. Upon its implementation for public use, this infrastructure will enhance the connectivity and mobility of people and commodities, contributing to the region's economic activity. Given that Sumatera Island accounts for 22.21% of the nation's gross domestic product (GDP) and supports a population of over 55 million people, the development and sustainability of regional economics and activities need to be accommodated. This research's case study focuses on the underpass structure of the TSTR project on the segment of Pekanbaru-Dumai, particularly the plantation underpass (2) STA 28+150.

Figure 1 provides an intricate overview of the project within a broader geographical context. Figure 1-a gives an understanding of the Indonesian archipelago, setting the stage for the subsequent details. Figure 1-b zooms in on Sumatera Island, specifically highlighting the Trans-Sumatera Toll Road (TSTR) project's routes spanning northern to southern regions. This figure also draws attention to one of the completed sections, the Pekanbaru-Dumai Toll Road. Figure 1(c) provides a more detailed illustration of the Pekanbaru-Dumai Toll Road with five sections. This detailed representation aids in visualizing the road's structure and complexity. Figure 1-d offers precise spatial information by pinpointing the location of the plantation underpass (2) STA 28+150, situated within Section 2 of the Minas-Kandis Selatan section of Pekanbaru-Dumai Toll Road.

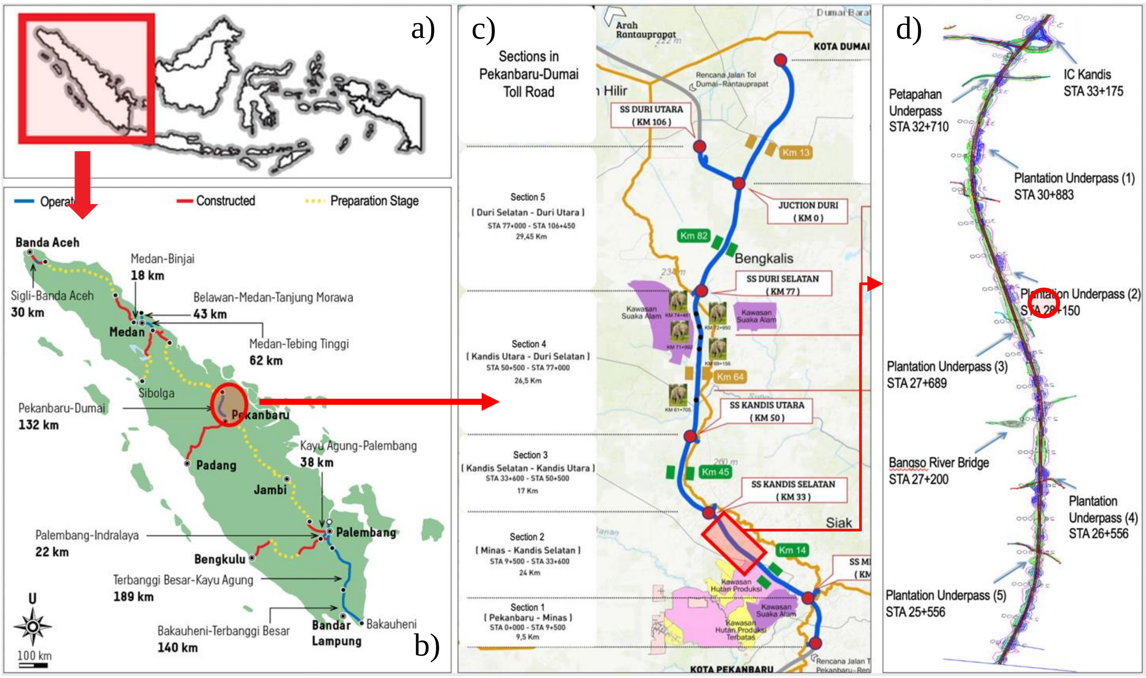

Figure 1. Case Study Research Area: a) Indonesia; b) Sumatera Island; c) Pekanbaru-Dumai Toll Road and its 5 Sections; d) Plantation Underpass (2) STA 28+150

Furthermore, Figure 2 further expands upon the project's viewpoint, offering a full perspective. Figure 2-a shows a bird's-eye view, giving a holistic sense of the project's spatial context. Figure 2-b takes a cross-sectional approach, enabling a closer examination of the toll road's physical dimensions and features. In Figure 2-c, the top view presents the project's layout from an overhead perspective. Lastly, Figure 2-d offers a longitudinal section, offering insights into the project's vertical aspects and variations along its length.

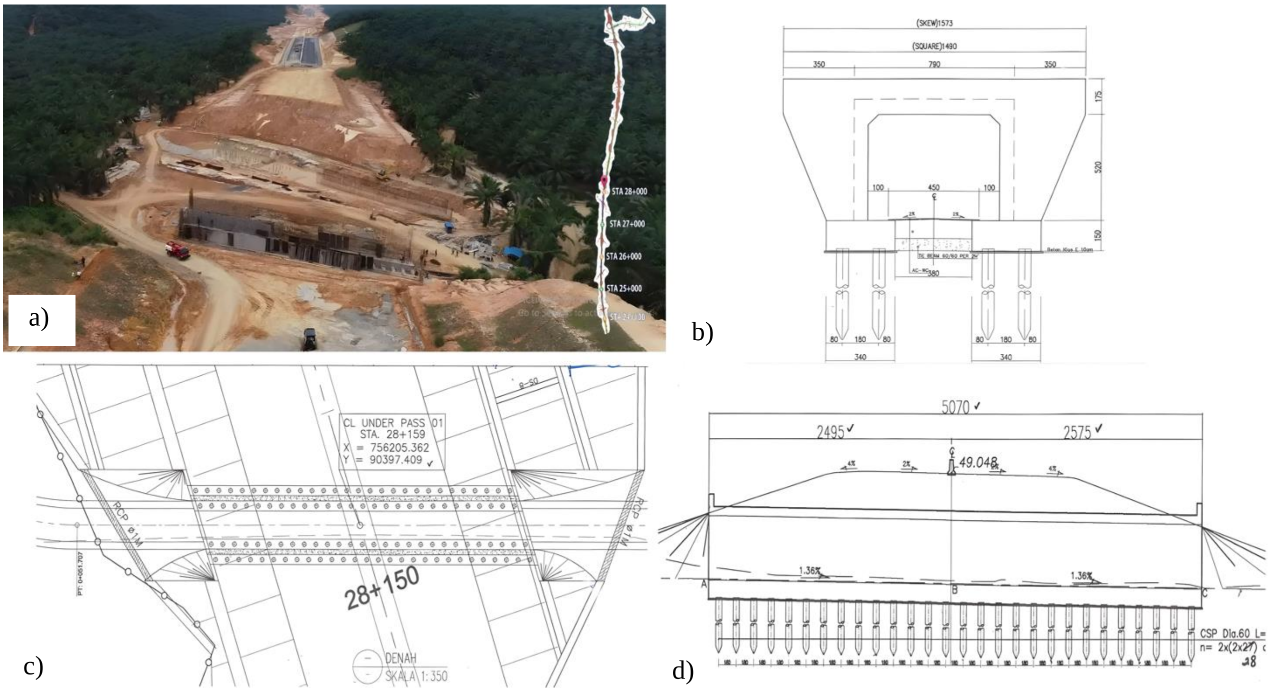

Figure 2. Overview of the Case Study: a) Bird-eye View. b). Cross-section. c) Top View. d) Longitudinal Section

The total expenditure for the underpass project amounted to around US$ 900 million. The main works involved in the project included the procurement of spinning piles, the installation of reinforcing bars, and the process of concreting, which represented 25.3, 27.5, and 37.47% of the overall project expenses, respectively. The construction project is anticipated to span a duration of 120 working days, commencing in November 2018 and concluding in April 2019. The project encountered several natural hazards and challenges in procuring necessary equipment throughout the construction. Flooding occurred on the site due to intense precipitation and the subsequent overflow of the nearby river. Evidently, the construction management team did not effectively plan to provide sufficient machinery to address this situation. The project delay was attributed to the influence of these two causes, necessitating an additional 30 days to fulfill the original timeline.

3. Research Methods

The present study used a three-stage approach to achieve the research objectives, incorporating qualitative and quantitative techniques (see Figure 3). The initial phase involved doing a desk study to acquire research criteria and parameters for LC. A comprehensive review of the literature was undertaken to assess global instances where LC has been effectively adopted or developed, aiming to identify any limitations specific to the context of the case study [44].

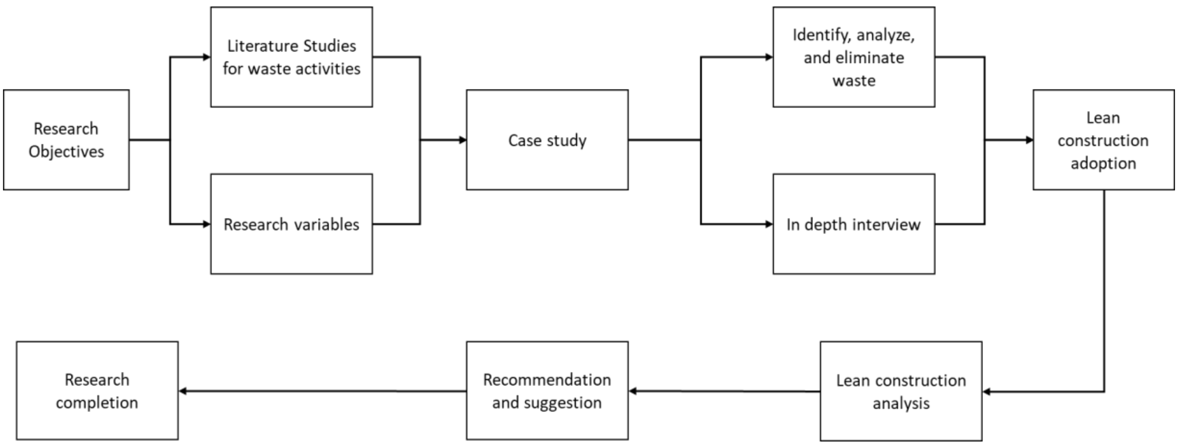

Figure 3. Research flow

The primary objective of the initial phase of this study is to examine the key activities that contribute to the successful completion of the project. These activities, often referred to as waste activities, encompass value-added activities (VA), non-value-added activities (NVA), and essential non-value-added activities (ENVA). The two latter activities must be minimized to expedite project completion and trim insignificant project sequences. Literature studies revealed that waste activities can be classified into eight categories: overproduction, waiting, transportation, unnecessary processes, inventory, unwanted movement, defects, and underutilized human resources. This study additionally found 58 sub-activities regarding the construction of underpasses currently under investigation.

During the subsequent phase, this study aims to identify, analyze, and eliminate waste activities through in-depth interviews with team members who were directly involved in the case study. The study encompassed participants in high-hierarchical positions, including project leaders and managers across engineering and operations disciplines. The individual in question plays a crucial role in the project and possesses extensive expertise in toll road projects, both domestically and internationally (see Table 2). The interviews were done in two distinct phases, each serving different aims. The first phase of the interview involved identifying waste activities based on VA, NVA, and ENVA. The objective of the second phase interview was to determine appropriate lean tools for each VA activity, thereby enhancing project performance and reducing project delays.

Table 2. Respondent Profile

Respondents	Position	Work Experience (Years)
R1	Project Chief	30
R2	Site Administration Manager	12
R3	Site Engineering Manager	11
R4	Site Operational Manager 1	26
R5	Human Resource Manager	7
R6	Site Operational Manager 2	17

In the last stage, the study examines lean tools' impact on project duration and cost performance. Each construction phase may employ various lean tools and strategies to mitigate delays, and each team member may contribute differing perspectives on addressing these challenges. Therefore, this study considers a concession from team members to determine the appropriate lean tools for each waste activity. The research subsequently provides projected conditions based on some factors associated with project duration and cost. These factors encompass the project timeline, potential delays, penalties imposed by the owner, contract value, as well as initial and additional direct and indirect costs. This comparison aims to show the relationship between the implementation of LC techniques and their impact on project duration and costs.

4. Results

This section is divided into three sub-sections: waste identification, lean tool identification, and the influence on project time completion and associated costs.

4.1. Identifying Construction Activity Waste Factors

The identification of waste is generated from the input provided by individuals directly engaged in developing the project. The participants were queried on the classification of each sub-activity according to VA, ENVA, and NVA categories, as indicated in Table 3. The category of sub-activities was established based on the highest proportion of respondent comments. A subsequent survey was performed to select one type of waste activity from the chosen sub-activities. The study identified a total of 58 sub-activities, with the majority (40%) falling under the category of ENVA, followed by VA (34%) and NVA (24%) in descending order.

Table 3. The proportion of Identified Waste

Stages	Sub-activities	R1	R2	R3	R4	R5	R6	Proportion		
								VA	ENVA	NVA
Preparation	***Shop-drawing process***									
	Create shop-drawing	1	2	2	1	2	2	66.67	33.33	-
	Propose shop-drawing	1	1	1	1	1	1	-	100	-
	Discussion of shop-drawing	1	1	3	1	2	1	16.67	66.66	16.67
	Approval of shop-drawing	2	1	2	2	2	1	66.67	33.33	-
	Shop-drawing checklist	3	3	3	1	3	1	-	33.33	66.67
	Archiving and stamping shop-drawing	1	3	1	1	1	3	-	66.67	33.33
	Distribution of shop-drawing	1	1	1	3	1	3	-	66.67	33.33

	Supplier/subcontractors' procurement									
	Checklist of supplier/sub-contractors	3	3	1	3	1	3	-	33.33	66.67
Delivery	Coordination with supplier/sub-contractors	1	2	1	1	3	1	33.33	66.67	-
	Delivery of required materials at the site	3	1	3	3	3	3	-	16.67	83.33
	Offering and negotiation of supplier/sub-contractors	2	2	1	2	2	3	66.66	16.67	16.67
	Work permit proposal	2	1	2	2	2	2	66.67	33.33	-
	Checking installed foundation	1	1	1	2	1	1	-	83.33	16.67
Construction	Reinforcement installation	2	2	2	2	2	2	100	-	-
	Scaffolding's installation	2	2	2	2	2	2	100	-	-
	Curing and formwork uninstall	3	1	1	3	3	3	-	33.33	66.67

Note: R = respondent; 1 = ENVA; 2 = VA; 3 = NVA.

There are fifteen (15) sub-activities in NVA that can be inserted into other activities. Most of the 12 activities are in the delivery category, followed by two activities falling under the category of construction and one activity on preparation. Four out of the eight waste categories in construction were identified from the in-depth interview. The unnecessary processes encompass seven activities, which are present in both the preparatory and delivery stages. On the other hand, waste construction relates to three transportation activities, while inventory is situated within two delivery activities. The activities waiting for production and construction, as outlined in Table 4, provide a comprehensive account of these activities.

Table 4. Type of Waste

Main Activities	Sub-activities	Type of Waste
Preparation	**Shop drawing checklist**	**Unnecessary processes**
	List of material based on Bill of Quantity (BoQ)	Unnecessary processes
	Stamped for approved material and achieving	Unnecessary processes
	Checklist of supplier/subcontractors	Unnecessary processes
	Delivery of required materials at the site	Unnecessary processes
	Unloading material to the storage	Transportation
	Material arrangement in the storage	Transportation
Delivery	Updating the list of items in the storage	Waiting
	Preparing for reinforcement workshop	Inventory
	Checking workshop equipment	Inventory
	Loading and transporting material to the workshop	Transportation
	Checklist of fabricated materials at the site	Unnecessary processes
	Updated volume delivery to structure operator	Unnecessary processes
Construction	Checking installed foundation	Waiting
	Curing and formwork uninstall	Waiting

The targeted project completion is 150 days, which has been running for 60 days (see Figure 4) for a summary of the project duration). Without eliminating and inserting NVA into other activities, the project was extended to 180 days or equal to 30 days of delays. As the rescheduling occurred on NVA, the project delays have been minimized from 30 to 15 days.

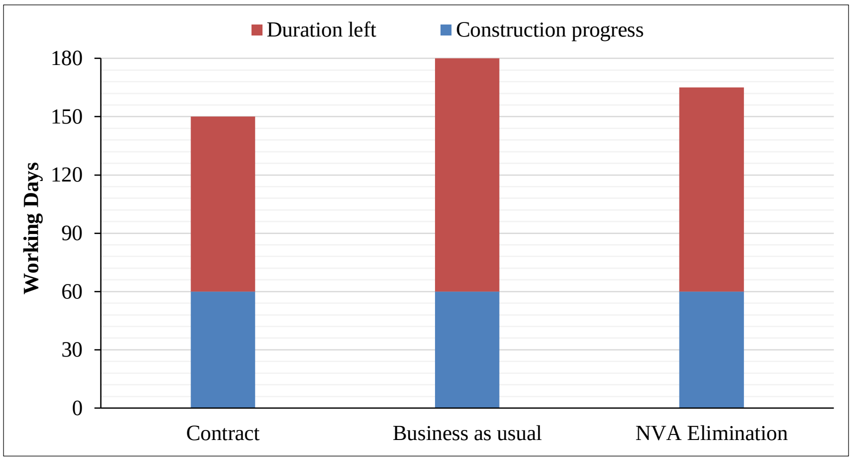

Figure 4. Comparison of Duration Between Each Condition

Based on these findings, VA and ENVA must be compressed using lean tools. The VA consists of 20 distinct activities with a duration of 36.5 days. On the other hand, the ENVA has 23 activities with a duration of 155 days. The combined duration of both categories amounts to 191.5 days, necessitating a rescheduling to fit inside a 90-day timeframe to align with the anticipated project completion schedule.

4.2. Determining Lean Tools to Improve Project Performance

The second round of in-depth interviews was done with the respondents to identify the most suitable lean tools for each of the 43 activities, encompassing both VA and NVA. Ten lean tools can be utilized: standardization, the Last Planner System, getting quality right the first time, coordination, just in time, collaboration, the Five S, prefabricated material, crash programs, and overlap. These lean tools were disseminated to the respondents. In contrast to the waste reduction approach from the previous section, which used the majority scenario, all lean tools provided by the respondents were to improve identified activities.

The results of the study revealed that a selection of nine lean tools were utilized for particular activities. Various lean tools can be utilized for some activities, while others can only be approached with a single lean tool. For instance, the "create shop drawing" in the preparation stage is considered a component of VA. In response, respondents have proposed the adoption of three lean tools, namely standardization, coordination, and collaboration, as means to streamline these activities. On the other hand, "delivery of approved materials" can be accommodated through standardization.

In general, by implementing daily meetings and monitoring protocols, most activities can be effectively managed through interdepartmental and interpersonal coordination involving internal and external stakeholders. According to the respondents, collaboration emerged as the second most preferred lean tool option, potentially facilitating the execution of 15 different activities. The four lean tools, such as standardization, the Five S, crash programs, and overlap, make comparable contributions to the resolution of various activities. The lean tools that exhibit lower levels of preference in this case study include just-in-time, getting quality right the first time, and prefabricated material. All the tools consist of fewer than five items. The overview of the findings is depicted in Figure 5.

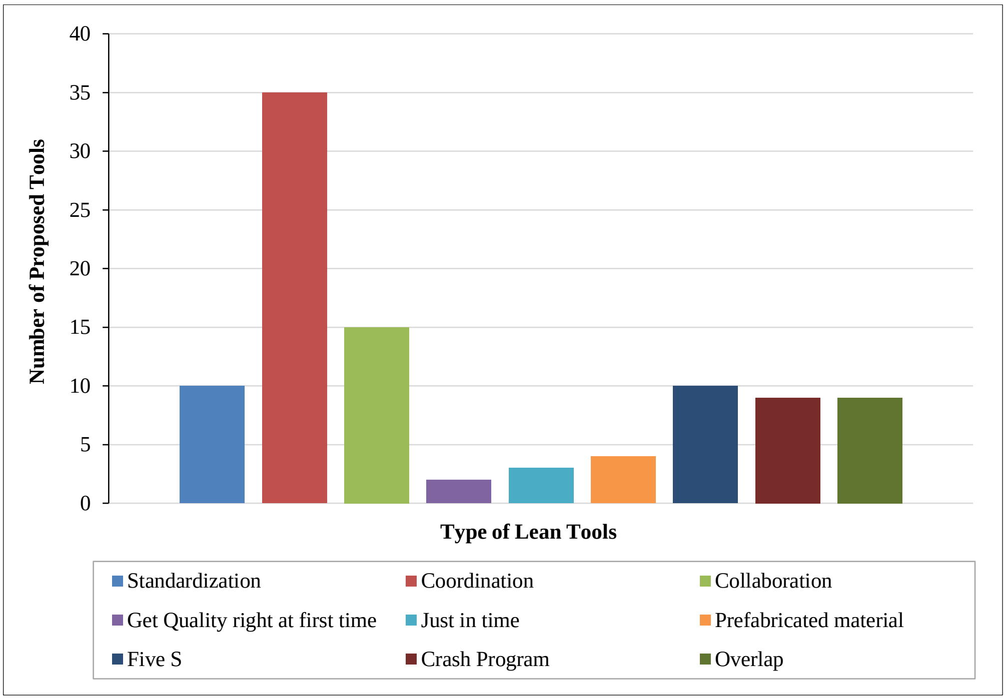

Figure 5. Frequency of Lean Tools Proposed for Case Study

Based on the previous discussion of waste elimination and lean tools evaluation, there are some changes to the current state map into the future state map for three activities in the preparation, delivery, and construction stages. The future map of the three activities can be seen in Figures 6 to 9.

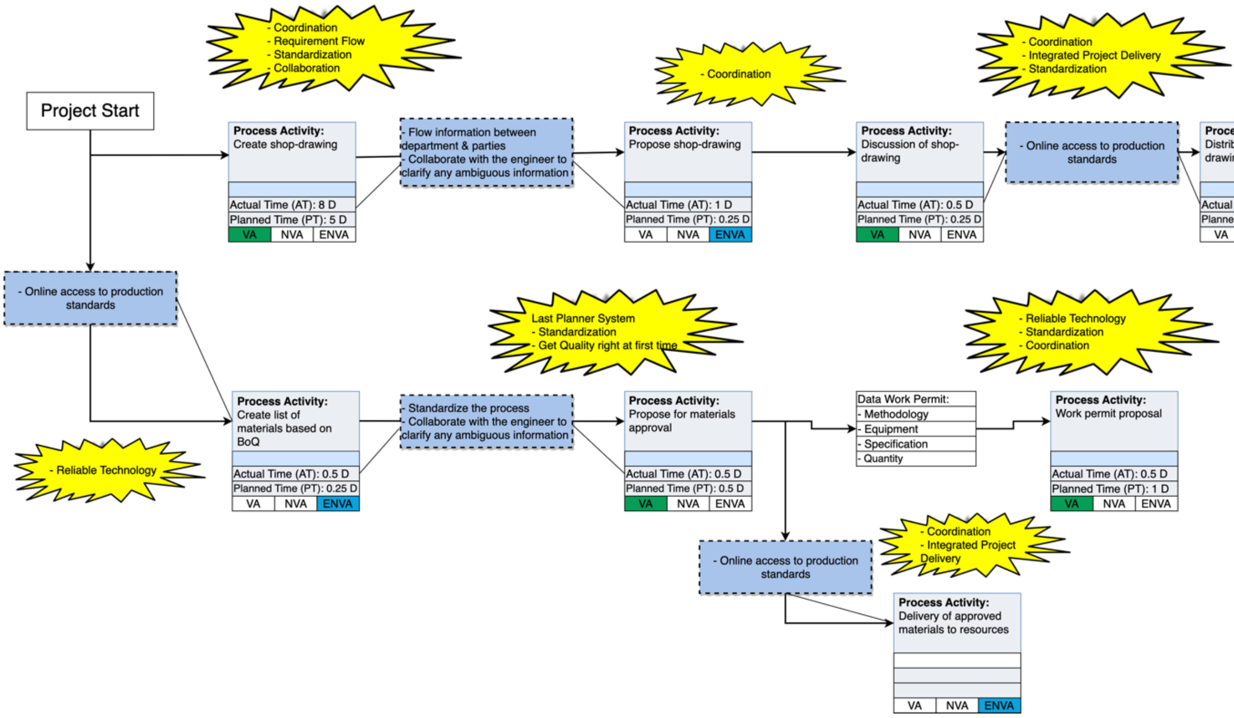

Figure 6. Future State Map of Preparation

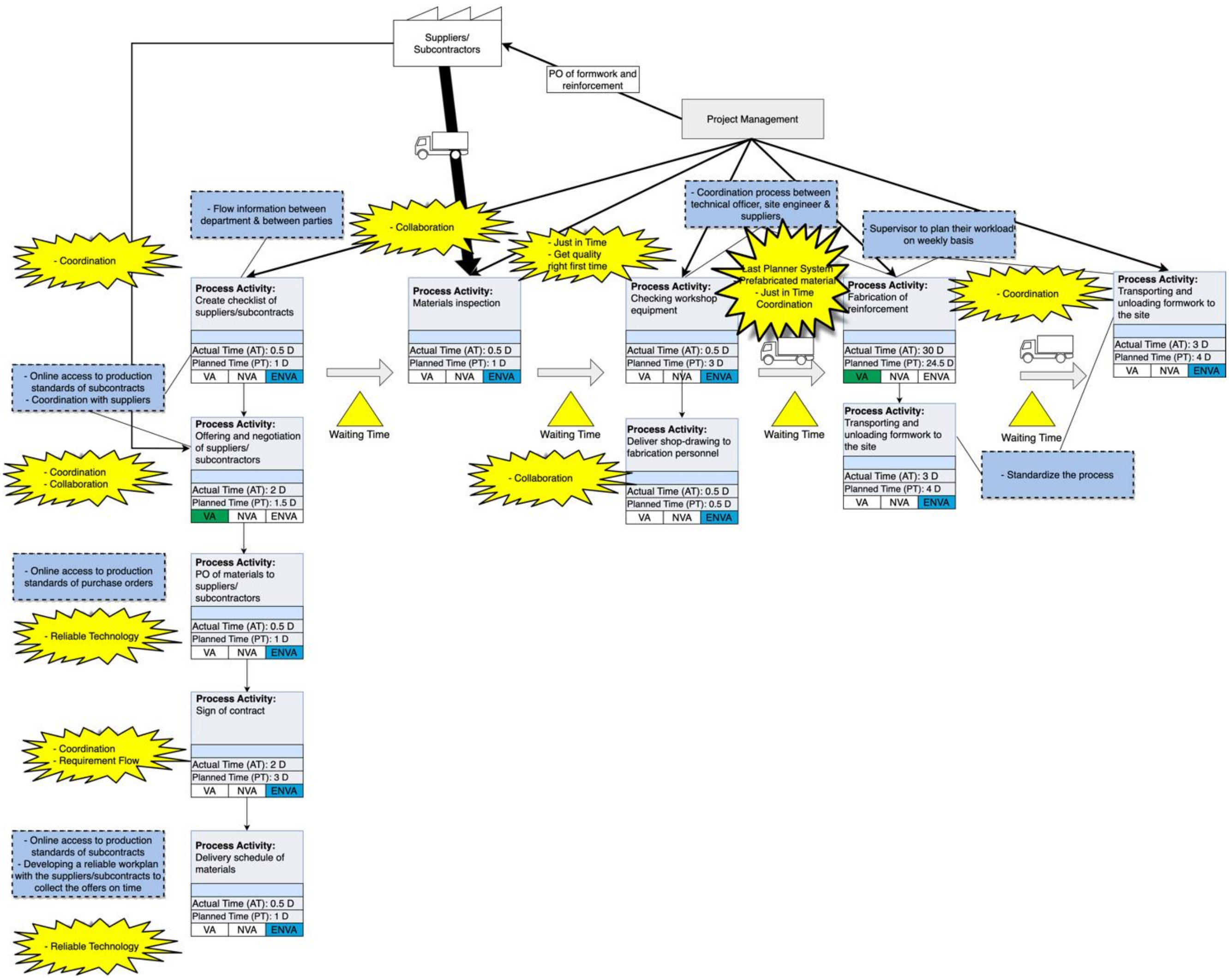

Figure 7. Future State Map of Delivery

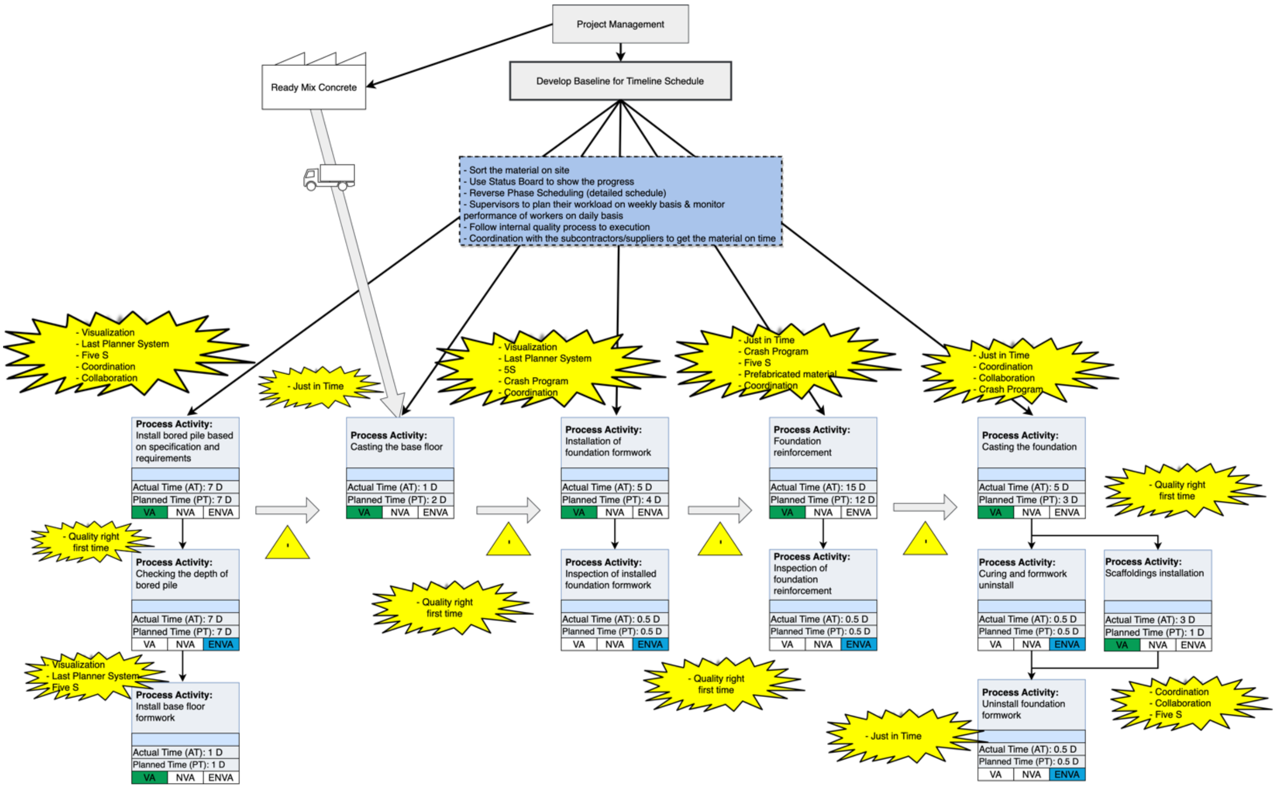

Figure 8. Future State Map of Construction: Stage 1

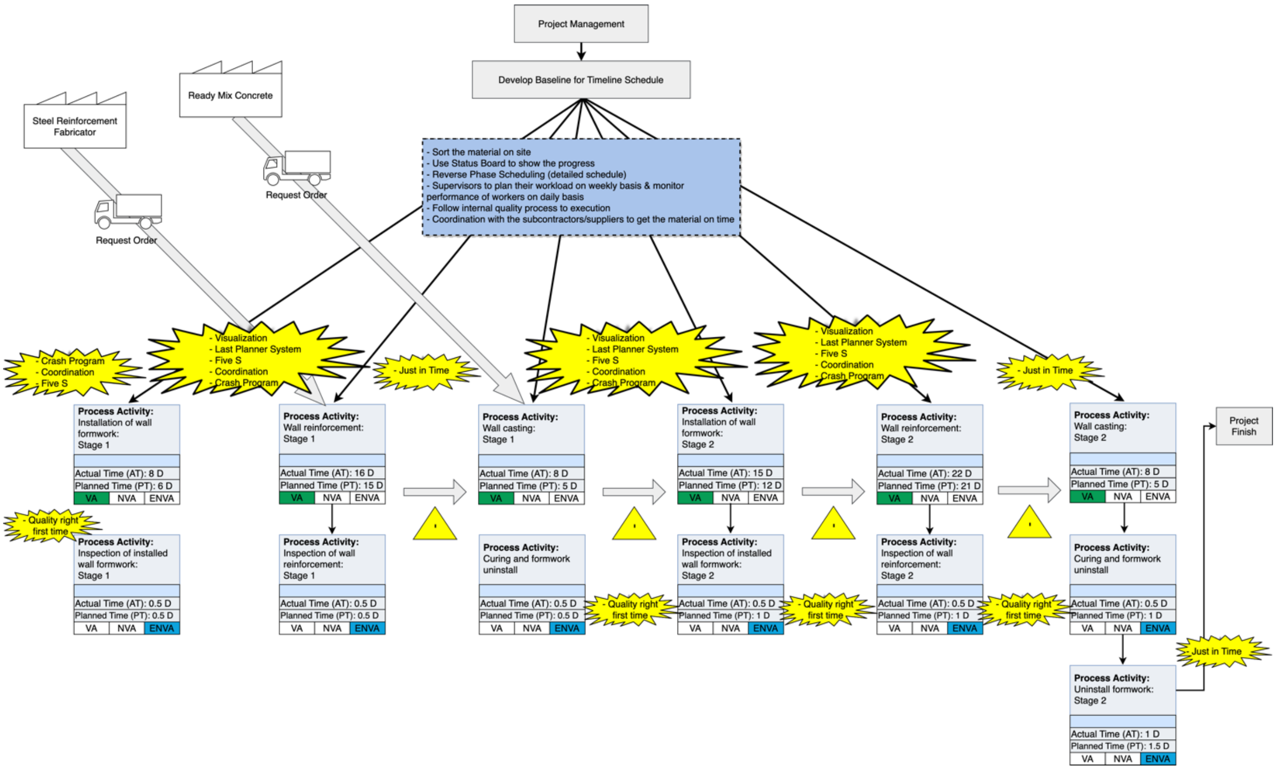

Figure 9. Future State Map of Construction: Stage 2

4.3. Assessing the Impact of Lean Tools on Project Completion Time and Costs

Although there are various lean tools available for improving project performance, certain solutions are preferred for their capacity to effectively reduce delays by employing a quantitative approach. One strategy employed to reduce the time of a project involves implementing a project that crashes on a critical path. The proposed technique aimed to enhance project productivity by augmenting the workforce with more resources. Nevertheless, the project should consider a well-balanced equation that encompasses the allocation of additional resources, the associated costs, and the projected timeframe for completion resulting from the implementation of this particular technique.

Table 5. Comparison between Planning and Project Crashing

Activities	Planning		Project crashing		
	Duration (days)	Workforce (person)	Forecasted Duration (days)	Duration Savings (days)	Additional Manpower (person)
Installation of foundation formwork	5	30	4	1	5
Foundation reinforcement	15	30	7.5	7.5	30
Installation of wall formwork: stage 1	8	30	5	3	10
Wall reinforcement: stage 1	16	30	8	8	30
Installation of wall formwork: stage 2	15	30	12	3	10
Wall reinforcement: stage 2	22	30	11	11	30
Total Duration Savings (days)				**33.5**	
Total Additional Manpower (person)					**115**

This study identified six activities that can be reduced in duration from their initial planning, with timeframes ranging from one to eleven days (see Table 5). The implementation of this key construction activity has the potential to reduce the initial duration of 81 days to 47.5 days, resulting in a time savings of 33.5 days. However, it should be noted that achieving this reduction would necessitate the deployment of an additional 115 workers. Overall, this strategic approach enables a more expeditious completion within a timeframe of 4.5 days, thus fulfilling the initial contractual obligations and mitigating the risk of any punitive measures imposed by the owner. Figure 10 presents a comparison of the duration of work as stipulated in the contract, the actual duration, the period without NVAs, and the duration after implementing the project crashed.

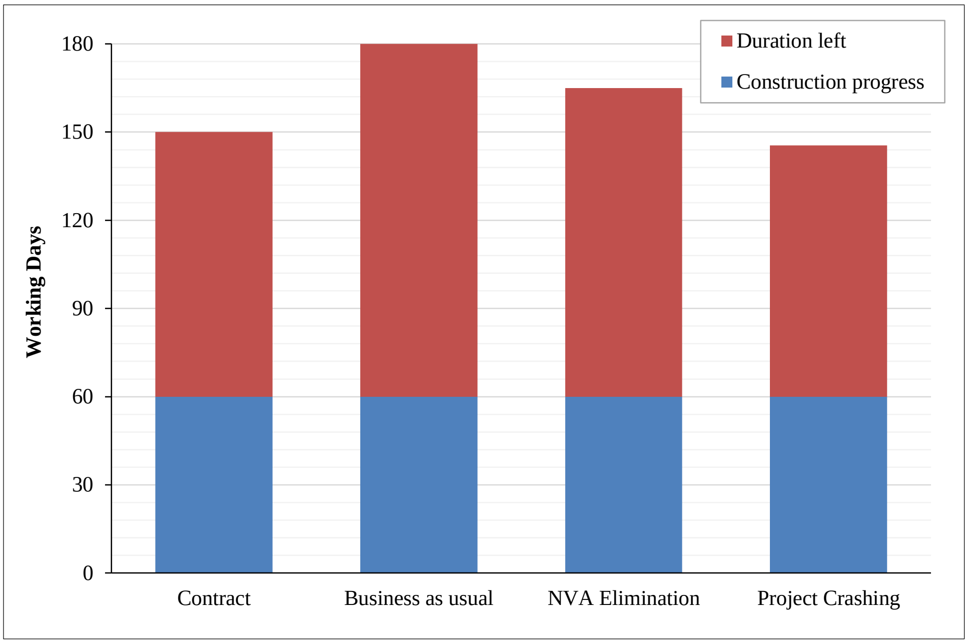

Figure 10. Working time comparison between contract and lean tools methods

The inclusion of additional resources for project crashing affected both the direct and indirect cost components. The reduction in the duration of construction work leads to a decrease in indirect costs, although direct costs see exponential growth due to the allocation of new resources. The present study has determined an additional expenditure of roughly US$ 44,710 associated with the implementation of project crashing. The majority of the cost, amounting to 87.27%, is allocated towards the workforce, while the remaining portion is assigned to equipment and materials. Nevertheless, reducing the duration of a project can also yield cost-saving benefits in terms of workforce and equipment expenses. The total expected savings is estimated at US$ 4.493.

This study identified three supplementary conditions, as shown in Table 6. First, business as usual, where the project encountered delays. This condition extends the project's duration by an extra 30 days, incurring an additional cost of US$ 32,815. While the contractual terms have remained unchanged, there has been a significant decrease in profitability, with the percentage declining from 17.88% to 14.46%. The second condition, in which the NVA was eliminated, presents a reduced occurrence of delays lasting for a duration of 15 days. This particular condition necessitates an additional cost of US$ 16,407, but the profitability remains competitive at a rate of 16.17%. The last condition had a shorter completion time of 4.5 days than the other scenarios. The presence of both direct and indirect expenses contributes to a certain level of efficiency. However, it is important to note that this particular scenario incurs the highest additional cost, amounting to US$ 44,710, and significantly impacts profit by 13.69%. Nevertheless, the owner has the authority to enforce a penalty of one per mil per day based on the contractual arrangement and may even consider blocklisting due to inadequate project performance caused by delays.

Table 6. Comparison between Contract and Alternative Conditions

Description	Contract	Condition 1	Condition 2	Condition 3
Project completion (days)	150	180	165	145.5
Delays (days)	None	30	15	Faster
Potential penalty	None	Blocklist (1% per day)	Blocklist (1% per day)	None
Additional costs (US$)	None	32,815	16,407	44,710
Efficiency	None	None	Indirect	Direct and indirect
Profit (%)	17.88	14.46	16.17	13.69

5. Discussion

The findings of this study provide a comprehensive understanding of waste identification, lean tool identification, and the impact of lean tools on project time completion and associated costs in the context of construction projects.

5.1. Waste Identification

The waste identification process holds significant importance in comprehending the inefficiencies within the construction process. Prior research has examined the identification of waste and the adoption of lean tools within the construction sector. For instance, Ali et al. [45] proposed a project management approach to identify the cost overruns associated with waste components. In a similar vein, Rivera et al. [46] conducted a study on 25 non-value-adding structural engineering companies (SECs) in Chile to identify waste and suggest productivity strategies for improvement. This study aims to explore the categorization of sub-activities further using the variables VA, ENVA, and NVA. The utilization of this granular approach facilitates a more comprehensive comprehension of inefficiencies within the construction process.

The input obtained from those actively engaged in the project development offers a comprehensive understanding of the various activities involved and their categorization. The majority of the sub-activities were classified as ENVA, signifying the presence of important activities that do not directly contribute value but are indispensable for the successful NVA sub-activities, implying the presence of processes that might be eliminated or incorporated into other activities to improve efficiency. The categorization of these activities into several types of waste, including unnecessary processes, transportation, waiting, and inventory, offers a strategic framework for targeted interventions. The high prevalence of unnecessary procedures, particularly during the preparation and delivery stages, indicates potential areas for optimization that can result in substantial reductions in both time and expenses.

The research findings regarding waste activities across the various stages of a project's life cycle, including planning, delivery, and construction, have corroborated the findings of prior studies undertaken by other researchers in the field of construction waste [41–43, 47]. The findings revealed particular waste activities, such as unnecessary processes, transportation, inventory, and waiting, significantly contributing to the project's delays and cost overruns. Reducing unnecessary processes takes precedence, as most of these can be consolidated into other related activities. In contrast, transportation and waiting waste are often associated with redundant activities, excessive paperwork, inadequate coordination, and non-standardized work [48].

5.2. Suitable Lean Tools to Improve Project Performance

Lean tools provide effective strategies to mitigate the identified waste and enhance project effectiveness. Insights into the most appropriate lean tools for different activities are derived from the feedback obtained during the second round of interviews with the respondents. The prevalence of coordination as the preferred lean tool indicates that improved interdepartmental communication and collaboration have the potential to enhance project efficiency greatly. The utilization of collaboration, standardization, and the implementation of the Five S were also identified as favored strategies, highlighting the need for teamwork, standardized processes, and well-structured workspaces.

The allocation of lean tools across various activities, such as "creation of shop drawings" and delivery of authorized materials," presents a distinct approach to implementing lean methodologies in specific areas of the construction process. The future state maps, which pertain to the preparation, delivery, and construction stages, visually represent the optimized processes resulting from implementing lean tools.

Therefore, it became evident that implementing suitable lean tools is necessary to achieve targeted objectives in terms of timely project completion and efficient budget allocation. This research product offers practical implications for construction organizations, advocating for the adoption of lean principles in their project development processes. The challenges associated with a lack of knowledge about implementing lean techniques can be mitigated by establishing collaborative efforts among relevant stakeholders. It can be achieved through many means, such as training sessions, workshops, focus groups, and other forms of communication and distribution. This study provides systematic recommendations for facilitating the deployment of lean construction techniques to reduce waste and increase performance, thereby addressing the complexity associated with lean adoption. This study also demonstrates evidence of the implementation of lean practices in developing economies, validating the substantial benefits of adopting lean thinking observed in several countries across Europe, South America, the United States, and other regions [49–51].

5.3. Impact of Lean Tools on Time of Completion and Costs

The primary objective of applying lean tools is to improve project performance in terms of both time and cost. The implementation of project crashing, a technique that entails augmenting more resources to expedite project completion, has emerged as a viable resolution. Although this approach has the potential to yield substantial time efficiencies, it also necessitates the allocation of additional resources, resulting in increased costs.

A thorough understanding of the trade-offs involved can be achieved by comparing different scenarios, including business as usual, elimination of NVA, and project crashing. Although eliminating NVA and implementing project crashing techniques can reduce project durations, it is important to acknowledge that these strategies are not without their associated costs. Nevertheless, these costs might be mitigated through the possible cost savings derived from penalty avoidance and preserving favorable standing with the project owner.

The present study aims to fill the current gap in knowledge regarding the application of lean techniques within the construction industry, with a particular focus on the perspective of developing economies. This research comprehensively examines waste activities and lean tool preferences, thereby providing valuable insights for enhancing project management efficiency in similar settings. From a practical standpoint, this research provides recommendations for construction business organizations to implement lean practices, highlighting the significance of training, workshops, and collaboration. The results of this study offer a systematic guide for construction firms seeking to adopt lean methodologies to reduce waste and improve project performance. This study contributes to the current theoretical framework by offering valuable insights into the categorization of sub-activities and the impact of lean tools on project performance. The comprehensive analyses and findings establish a foundation for further research in this field.

6. Conclusion

The construction sector, renowned for its complex processes and intricate workflows, has been a topic of examination due to its inefficiencies and wasteful practices. This study aimed to examine the inefficiencies, categorize them, and propose lean tools as solutions to improve the overall project performance in terms of time completion and associated costs. The study focused on an infrastructure development initiative in Indonesia, specifically a toll road project, to gain a deeper understanding of waste reduction strategies and the implementation of lean techniques. By employing methods such as document analysis, expert interviews, and structured questionnaires, this study identified the predominant ENVA activities, particularly unnecessary processes in the preparation and delivery stages, as key factors contributing to project delays.

This study has successfully identified fifteen activities related to ENVA that are deemed redundant and should be avoided. These activities primarily involve unnecessary processes, transportation, waiting, and inventory within the preparation, delivery, and construction stages. Out of the ten lean tools assessed, it was determined that nine of them are advisable for improving project performance. These recommended tools include getting quality right the first time, coordination, just in time, collaboration, the Five S, prefabricated material, a crash program, and overlap. When strategically implemented, these tools have the potential to enhance communication, facilitate teamwork, and promote efficient workflows. The findings of the study revealed that the implementation of lean practices resulted in a reduction of project completion time by 19.17%. However, it was also observed that this improvement was accompanied by a corresponding increase in organizational costs, amounting to 5.33%.

Nevertheless, it is important to acknowledge the limits of the research. The findings of this study, which largely focus on a Southeast Asian environment and involve predominantly national stakeholders, may not have general applicability. Future studies should consider diverse geographical conditions, stakeholder backgrounds, and varying policies to enhance the generalizability of the results. Despite these limitations, the study provides significant alternatives to lean tools for construction companies seeking to enhance operational efficiency. This research paper presents a robust framework for waste identification and implementing lean tools within the construction industry. By effectively addressing the disconnect between theory and practice, this approach promotes the importance of ongoing training and collaboration, propelling the industry toward enhanced performance and cost-efficiency.

7. Declarations

7.1. Author Contributions

Conceptualization, M.A.B. and B.S.; methodology, M.; software, M.; validation, M., P.M., and M.S.; formal analysis, M.; investigation, M.; resources, M.; data curation, G.S. and M.; writing—original draft preparation, P.M.; writing—review and editing, M.S.; visualization, M.S. and G.S.; supervision, G.S.; project administration, M.S.; funding acquisition, M.S. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7.3. Funding and Acknowledgements

The authors would like to thank Universitas Indonesia for supporting this research through the PUTI Q1 2020 program (contract number: NKB-1419/UN2.RST/HKP.05.00/2020).

7.4. Conflicts of Interest

The authors declare no conflict of interest.

8. References

[1] Xing, W., Hao, J. L., Qian, L., Tam, V. W. Y., & Sikora, K. S. (2021). Implementing lean construction techniques and management methods in Chinese projects: A case study in Suzhou, China. Journal of Cleaner Production, 286. doi:10.1016/j.jclepro.2020.124944.

[2] Singh, S., & Kumar, K. (2020). Review of literature of lean construction and lean tools using systematic literature review technique (2008–2018). Ain Shams Engineering Journal, 11(2), 465–471. doi:10.1016/j.asej.2019.08.012.

[3] United Nations Environment Programme. (2022). 2022 Global Status Report for Buildings and Construction: Towards a Zero‑emission, Efficient and Resilient Buildings and Construction Sector. United Nations Environment Programme, United Nations, New York, United States.

[4] Berawi, M. A., Kim, A. A., Naomi, F., Basten, V., Miraj, P., Medal, L. A., & Sari, M. (2023). Designing a smart integrated workspace to improve building energy efficiency: an Indonesian case study. International Journal of Construction Management, 23(3), 410–422. doi:10.1080/15623599.2021.1882747.

[5] Crawford, R. H., Mathur, D., & Gerritsen, R. (2017). Barriers to Improving the Environmental Performance of Construction Waste Management in Remote Communities. Procedia Engineering, 196, 830–837. doi:10.1016/j.proeng.2017.08.014.

[6] Fitri, L., Hatmoko, J. U. D., & Hermawan, F. (2019). Managing Construction Waste in Developed Countries: Lessons Learned for Indonesia. IOP Conference Series: Earth and Environmental Science, 366, 012016. doi:10.1088/1755-1315/366/1/012016.

[7] Sarhan, J. G., Xia, B., Fawzia, S., & Karim, A. (2017). Lean construction implementation in the Saudi Arabian construction industry. Construction Economics and Building, 17(1), 46–69. doi:10.5130/AJCEB.v17i1.5098.

[8] Heigermoser, D., García de Soto, B., Abbott, E. L. S., & Chua, D. K. H. (2019). BIM-based Last Planner System tool for improving construction project management. Automation in Construction, 104, 246–254. doi:10.1016/j.autcon.2019.03.019.

[9] Francis, A., & Thomas, A. (2020). Exploring the relationship between lean construction and environmental sustainability: A review of existing literature to decipher broader dimensions. Journal of Cleaner Production, 252. doi:10.1016/j.jclepro.2019.119913.

[10] Jørgensen, B., & Emmitt, S. (2008). Lost in transition: The transfer of lean manufacturing to construction. Engineering, Construction and Architectural Management, 15(4), 383–398. doi:10.1108/09699980810886874.

[11] Maraqa, M. J., Sacks, R., & Spatari, S. (2023). Strategies for reducing construction waste using lean principles. Resources, Conservation and Recycling Advances, 19(200180), 2023. doi:10.1016/j.rcradv.2023.200180.

[12] Wu, X., Zhao, W., Ma, T., & Yang, Z. (2019). Improving the efficiency of highway construction project management using lean management. Sustainability (Switzerland), 11(13), 3646. doi:10.3390/su11133646.

[13] Pedo, B., Tezel, A., Koskela, L., Whitelock-Wainwright, A., Lenagan, D., & Nguyen, Q. A. (2021). Lean Contributions to BIM Processes: The Case of Clash Management in Highways Design. Annual Conference of the International Group for Lean Construction, Lima, Peru, 116–125. doi:10.24928/2021/0164.

[14] Uddin, M. M. (2020). Lean Construction Quality Assurance Opportunities in Highway Construction. Annual Conference of the International Group for Lean Construction, California, United States. doi:10.24928/2020/0013.

[15] Nguyen, P., Lines, B., & Tran, D. (2020). Exploring the Adaption of Lean Principles to Highway Construction. Construction Research Congress 2020. doi:10.1061/9780784482889.031.

[16] Mohammadi, A., Igwe, C., Amador-Jimenez, L., & Nasiri, F. (2020). Applying lean construction principles in road maintenance planning and scheduling. International Journal of Construction Management, 1–11. doi:10.1080/15623599.2020.1788758.

[17] Aslam, M., Gao, Z., & Smith, G. (2020). Exploring factors for implementing lean construction for rapid initial successes in construction. Journal of Cleaner Production, 277. doi:10.1016/j.jclepro.2020.123295.

[18] Green, S. D., & May, S. C. (2005). Lean construction: Arenas of enactment, models of diffusion and the meaning of "leanness." Building Research and Information, 33(6), 498–511. doi:10.1080/09613210500285106.

[19] Tiamaz, Y., & Souissi, N. (2019). A domain model for capturing knowledge of the lean approach. Journal of Industrial Engineering and Management, 12(1), 83–96. doi:10.3926/jiem.2660.

[20] Arlbjørn, J. S., & Freytag, P. V. (2013). Evidence of lean: A review of international peer-reviewed journal articles. European Business Review, 25(2), 174–205. doi:10.1108/09555341311302675.

[21] Miraj, P., Berawi, M. A., & Utami, S. R. (2021). Economic feasibility of green office building: combining life cycle cost analysis and cost–benefit evaluation. Building Research and Information, 49(6), 624–638. doi:10.1080/09613218.2021.1896354.

[22] Fitriani, H., Ajayi, S., & Kim, S. (2023). Analysis of the Underlying Causes of Waste Generation in Indonesia's Construction Industry. Sustainability (Switzerland), 15(1), 409. doi:10.3390/su15010409.

[23] Koskela, L. (1993). Lean Production in Construction. Automation and Robotics in Construction X: Proceedings of the 10th International Symposium on Automation and Robotics in Construction (ISARC), 47-54. doi:10.22260/isarc1993/0007.

[24] Alves, T. D. C. L., Milberg, C., & Walsh, K. D. (2012). Exploring lean construction practice, research, and education. Engineering, Construction and Architectural Management, 19(5), 512–525. doi:10.1108/09699981211259595.

[25] Erol, H., Dikmen, I., & Birgonul, M. T. (2017). Measuring the impact of lean construction practices on project duration and variability: A simulation-based study on residential buildings. Journal of Civil Engineering and Management, 23(2), 241–251. doi:10.3846/13923730.2015.1068846.

[26] Bamana, F., Lehoux, N., & Cloutier, C. (2019). Simulation of a Construction Project: Assessing Impact of Just-in-Time and Lean Principles. Journal of Construction Engineering and Management, 145(5), 05019005. doi:10.1061/(asce)co.1943-7862.0001654.

[27] Ballard, G., & Kim, Y. (2007). Implementing lean on capital projects. Proceedings of the 15th IGLC conference, 6-12 July, Michigan, United States.

[28] Martinez, E., Reid, C. K., & Tommelein, I. D. (2019). Lean construction for affordable housing: a case study in Latin America. Construction Innovation, 19(4), 570–593. doi:10.1108/CI-02-2019-0015.

[29] Ahmed, S., & Sobuz, M. H. R. (2020). Challenges of implementing lean construction in the construction industry in Bangladesh. Smart and Sustainable Built Environment, 9(2), 174–207. doi:10.1108/SASBE-02-2019-0018.

[30] Evans, M., Farrell, P., Mashali, A., & Zewein, W. (2021). Critical success factors for adopting building information modelling (BIM) and lean construction practices on construction mega-projects: a Delphi survey. Journal of Engineering, Design and Technology, 19(2), 537–556. doi:10.1108/JEDT-04-2020-0146.

[31] Liker, J. K., & Lamb, T. (2002). What is lean ship construction and repair? Journal of Ship Production, 18(3), 121–142. doi:10.5957/jsp.2002.18.3.121.

[32] Ballard, G., & Howell, G. A. (2003). Lean project management. Building Research and Information, 31(2), 119–133. doi:10.1080/09613210301997.

[33] Babalola, O., Ibem, E. O., & Ezema, I. C. (2019). Implementation of lean practices in the construction industry: A systematic review. Building and Environment, 148, 34–43. doi:10.1016/j.buildenv.2018.10.051.

[34] Ramaswamy, K. P., & Kalidindi, S. N. (2009). Waste in Indian building construction projects. Proceedings of the 17th Annual Conference of the IGLC, 15-17 July, 2009, Taipei, Taiwan.

[35] Womack, J. P., Jones, D. T., & Roos, D. (1992). The machine that changed the world. Business Horizons, 35(3), 81–82. doi:10.1016/0007-6813(92)90074-J.

[36] Bajjou, M. S., & Chafi, A. (2020). Identifying and Managing Critical Waste Factors for Lean Construction Projects. EMJ - Engineering Management Journal, 32(1), 2–13. doi:10.1080/10429247.2019.1656479.

[37] Issa, U. H., & Alqurashi, M. (2020). A model for evaluating causes of wastes and lean implementation in construction projects. Journal of Civil Engineering and Management, 26(4), 331–342. doi:10.3846/jcem.2020.12323.

[38] Sugimori, Y., Kusunoki, K., Cho, F., & Uchikawa, S. (1977). Toyota production system and kanban system materialization of just-in-time and respect-for-human system. International Journal of Production Research, 15(6), 553–564. doi:10.1080/00207547708943149.

[39] Womack, J. P., & Jones, D. T. (1997). Lean Thinking—Banish Waste and Create Wealth in your Corporation. Journal of the Operational Research Society, 48(11), 1148–1148. doi:10.1057/palgrave.jors.2600967.

[40] Liker, J. K. (2004). The 14 principles of the Toyota way: an executive summary of the culture behind TPS. The Toyota way, 14(1), 35-41.

[41] Bossink, B. A. G., & Brouwers, H. J. H. (1996). Construction Waste: Quantification and Source Evaluation. Journal of Construction Engineering and Management, 122(1), 55–60. doi:10.1061/(asce)0733-9364(1996)122:1(55).

[42] Purushothaman, M. babu, Seadon, J., & Moore, D. (2020). Waste reduction using lean tools in a multicultural environment. Journal of Cleaner Production, 265. doi:10.1016/j.jclepro.2020.121681.

[43] de Souza, R. V. B., & Carpinetti, L. C. R. (2014). A FMEA-based approach to prioritize waste reduction in lean implementation. International Journal of Quality and Reliability Management, 31(4), 346–366. doi:10.1108/IJQRM-05-2012-0058.

[44] Berawi, M. A., Miraj, P., Saroji, G., & Sari, M. (2020). Impact of rail transit station proximity to commercial property prices: utilizing big data in urban real estate. Journal of Big Data, 7(1), 71. doi:10.1186/s40537-020-00348-z.

[45] Ali, S. A. A., Arun, C., & Krishnamurthy, K. (2021). Re-defining flow in construction process for facilitating the identification and quantification of generic overruns existing in construction industry today. International Journal of Construction Management, 21(2), 113–130. doi:10.1080/15623599.2018.1511236.

[46] Rivera, F. M. La, Vielma, J. C., Herrera, R. F., & Gallardo, E. (2021). Waste identification in the operation of structural engineering companies (SEC) according to lean management. Sustainability (Switzerland), 13(8), 4249. doi:10.3390/su13084249.

[47] de Magalhães, R. F., Danilevicz, Â. D. M. F., & Saurin, T. A. (2017). Reducing construction waste: A study of urban infrastructure projects. Waste management, 67, 265-277. doi:10.1016/j.wasman.2017.05.025.

[48] Klein, L. L., Tonetto, M. S., Avila, L. V., & Moreira, R. (2021). Management of lean waste in a public higher education institution. Journal of Cleaner Production, 286. doi:10.1016/j.jclepro.2020.125386.

[49] Sarhan, J., Xia, B., Fawzia, S., Karim, A., & Olanipekun, A. (2018). Barriers to implementing lean construction practices in the Kingdom of Saudi Arabia (KSA) construction industry. Construction Innovation, 18(2), 246–272. doi:10.1108/CI-04-2017-0033.

[50] Tortorella, G. L., Narayanamurthy, G., & Thurer, M. (2021). Identifying pathways to a high-performing lean automation implementation: An empirical study in the manufacturing industry. International Journal of Production Economics, 231. doi:10.1016/j.ijpe.2020.107918.

[51] Koseoglu, O., & Nurtan-Gunes, E. T. (2018). Mobile BIM implementation and lean interaction on construction site: A case study of a complex airport project. Engineering, Construction and Architectural Management, 25(10), 1298–1321. doi:10.1108/ECAM-08-2017-0188.