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A LEAN PREBID PLANNING MODEL FOR CONSTRUCTION CONTRACTORS: A CASE STUDY IN VIETNAM

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Key words: lean construction, waste, construction contractors, lean prebid planning.

ABSTRACT

Prebid planning is an essential function of construction project management that allows contractors to obtain projects with low cost while achieving other criteria. It also helps contractors during project execution and management. This research applied the manufacturing industry's lean theory to propose a lean prebid planning model (LPPM) for construction contractors. The LPPM can significantly eliminate the main types of waste in construction projects because it effectively combines three important concepts in the manufacturing industry: transformation, workflow, and value generation. This model includes seven arrangement steps, which are described systematically to help contractors with real-world applications. A case study was implemented to demonstrate the accuracy and usefulness of the proposed model. The results showed a reduction of 9.1% in project cost and 37 days in project duration.

I. INTRODUCTION

An effective prebid planning model is important for construction contractors because it helps contractors to obtain projects from owners and improves project profitability. Improved prebid plans reduce cost, shorten schedules, and increase labor productivity [19, 39]. Moreover, in recent years, the construction industry has been one of the largest contributors to the economy. Investment in the construction industry is approximately 10% of the global economy [38]. Unfortunately, the waste level for construction projects tends

to be high. For example, 46% of unproductive working time is due to late arrival or early departure (3%), waiting and idling (32%), waiting for tools or materials (5%), and waiting for instruction (6%) [3]. Up to 30% of construction costs occurs from inefficiencies, mistakes, delays, and poor communication [14]. Furthermore, 10% to 20% of the total project cost is spent on rework [7, 9]. Waste in the construction industry has also seriously contributed to environmental pollution, typically accounting for 15% to 30% of the total urban waste [6]. Therefore, reducing and eliminating waste has become a topic of considerable discussion in the construction field in recent years, with lean construction becoming a widely adopted theory. This theory helps contractors to reduce engineering waste and maximize production value. On the theoretical basis of lean construction theory, contractors can reduce construction time, lower costs, and achieve improved quality [41].

However, there is limited research regarding prebid planning; most research has focused on planning tools and techniques as opposed to the planning process [28]. Moreover, most of the research on planning relates to the environment, transportation, the owner planning process, scope definition, and water planning [39]. Construction contractors tend to not be concerned with the prebid phase. Therefore, many problems related to planning, including wasted time, delays, and poor communication, exist in construction projects [8].

To identify the types of waste that occur in construction projects and to describe an effective approach to eliminate these types of waste before bidding, this research aims to apply the manufacturing industry's lean theory to propose a lean planning process for contractors in the prebid phase. The lean prebid planning model (LPPM) consists of seven steps: (1) the arrangement of task number and order; (2) time arrangement; (3) quality arrangement; (4) quantity arrangement; (5) inventory arrangement; (6) machine and equipment/resources arrangement; and (7) location and path arrangement. The LPPM also combines three important concepts: transformation, workflow, and value generation. Therefore, the main types of waste in construction projects are identified and efficiently eliminated. As a result, the construction contractor can achieve the following three major criteria for the con-

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struction project: lower cost, shortened time, and consistent quality.

II. LITERATURE REVIEW

1. Prebid Planning Process and Models

Construction planning that accounts for all the variables and situations that may arise during a construction project is necessary. Planning for construction allows a contractor to be proactive rather than reactive as problems arise. A proactive contractor can control the direction of the project, while a reactive contractor allows the project outcome to change, attempting to minimize the impact of problems as they occur [35]. Cohenca-Zall *et al.* [10] defined planning as a process of deciding what to do and how to do it before action is required. The planning includes the integration of a set of interdependent decisions. Throughout the life of a project, the planning process can be divided into four identifiable stages: preproject planning, prebid planning, preconstruction planning, and during-construction planning (construction planning). Although there have been some studies regarding the planning process, most of these studies have focused on preproject planning, preconstruction planning, and during-construction planning [10, 16, 17, 19, 28].

There are few studies regarding prebid planning, and most of these studies have focused on planning tools and techniques rather than the planning process. A study was performed that focused on defining the current state of prebid planning in terms of (1) the parties involved, (2) the effort invested, (3) the number of different types of issued plans, and (4) the format used for plans [28]. This study also showed the degree of involvement in the planning process, the proportion of plan issuance, the relative planning effort for various functional plans, and the formats used for issuing. Faniran *et al.* [12] showed a framework for the development of strategies for improving construction planning practices and concluded that planning would be more effective if there were (1) more investment of quality time in preconstruction planning, (2) less emphasis on developing schedules, and (3) more emphasis on developing operational plans. Thomas and Ellis Jr. [39] described a microlevel planning process for construction contractors during the prebid phase that consists of the following eight steps: (1) assess contract risks, (2) develop a preliminary execution plan, (3) develop site layout plans, (4) identify the sequences that are essential-to-success, (5) develop detailed operational plans, (6) develop strategies to assure construction input into design, (7) revise the preliminary plan, and (8) communicate and enforce the plan. This model was determined based on the authors' experiences.

2. Lean Construction

The "lean" production philosophy is rooted in concepts of the Toyota engineers; it was established and developed in post-World War II Japan, and it is now widely known as the Toyota Production System or Lean Manufacturing [30]. Lean

is defined as follows: lean denotes a system that utilizes less, in term of all inputs, to create the same outputs as those created by a traditional mass production system while providing increased varieties for the end customer [40]. Lean focuses on eliminating or reducing waste and maximizing or fully utilizing activities that add value for the customer [2]. Waste is defined as anything that does not add value to the end product from the customer's perspective, so waste can involve any of the following: material, inventory, over-production, labor, complexity, energy, space, defects, transportation, time, and unnecessary motion [2, 32, 33, 37, 40]. The manufacturing industry has seven types of waste: (1) waste of over-production, (2) waste of correction, (3) waste of material movement, (4) waste of processing, (5) waste of inventory, (6) waste of waiting, and (7) waste of motion. The first five wastes refer to the flow of material, and the last two pertain to human work [33]. The lean manufacturing principle includes every facet of the value stream by eliminating waste to reduce cost, generate capital, increase sales, and remain competitive in a growing global market, so the lean principle is highly respected in the manufacturing industry [2].

Although the construction industry has certain characteristics (site production, temporary organization, and one-of-a-kind or "ad-hoc" production), which are different from the manufacturing industry, the following attributes encourage the effective application of the lean theory for improved operation [26, 27, 36, 41, 43]: (1) construction as activities that can be described with flows; (2) controllable production flow; (3) high levels of waste, especially waste in inventory; and (4) high production volume. Hence, the architecture-engineering-construction (AEC) industry has been applying lean theory for research and practice. Since 1993 and 1997, the International Group for Lean Construction (IGLC) and the Lean Construction Institute, respectively, have been advancing lean construction theory and promoting its practical application. The lean concepts have been tailored to suit the AEC industry and concepts of project-based production have been developed [26, 27, 36]. Moreover, lean construction integrates three competing management views: (1) transformation, (2) flow, and (3) value generation (TFV) [26, 27].

III. A LEAN PREBID PLANNING MODEL

1. Defining Types of Waste in Construction Projects

In the construction industry, waste is defined as the loss of any resource, including materials, time (labor and equipment), and capital, that is produced by activities that generate direct or indirect costs but do not add any value to the final product for the client [15]. The issue of waste is not only important for efficiency but also for the impacts of building material waste on the environment. According to Pinch [34], there are seven main types of waste in construction projects: (1) waste from defects, (2) waste from delays, (3) waste from over-production, (4) waste from over-processing, (5) waste from maintaining excess inventory, (6) waste from unneces-

sary transport, and (7) waste from unnecessary movement of people and equipment. These types of waste were not explained in detail by the author or in other related studies, so it is difficult for construction contractors to systematically measure these types of waste in construction projects. To help contractors understand the seven types of waste in construction projects, this research will address these wastes in more detail (definitions, causes, results, and examples) as described below.

1) Waste from Defects

A defect is a lack of performance, which manifests once the building is operational [5]. Certain major causes of defects were shown by [24], which are the stability of the client's organization, client's project control, user involvement, time pressures, composition of the project organization, cost pressures, support by the site organization, and motivation of people. These causes are concretized as below: items in production lines (workflows) without standards (or with unsuitable standards) or unqualified products, unsuitable processes, and unqualified resources such as materials, labor, and machines. These issues lead to the increase of handling, processing, rejecting, and secondary expenses of site materials, manpower, machines, equipment, and resources, which affect the quality of the product and increase the project cost and duration. According to certain studies, the cost for defects is 2.3% to 9.4% of the cost of production [24, 31].

Typical examples of waste from defects include the procurement of electrical wiring or mechanical piping with non-standard parameters (non-standard length or diameter), cutting the pipes or bars shorter than required, unqualified workers, and producing cast-in-place structural elements (slabs, beams, columns) with dimensions larger than the designed dimensions.

2) Waste from Delays

Delay is defined as the time beyond the completion date specified for a contract or beyond the date that the parties agree upon for the delivery of a project [4]. Delay is also defined as an act or event that extends the required time to perform or complete work, resulting in additional days of work [42]. El-Razek *et al.* [1] places the various causes of delay into nine groups: financing, manpower, changes, contractual relationships, environment, equipment, rules and regulations, materials, and scheduling and control. Issues that occur on site, including deficient materials, manpower, and planning cause delays. Adversarial relationships and contract disputes can also cause delays [22, 29].

The delays produce idle operation, in-between events, or work sequences, increasing the cost of manpower, machines, equipment, and other expenses and creating imbalances in production. The United States has a 12.15% scheduled growth for design-build projects [11]. Forty percent of the projects in India are behind schedule by 1 to 252 months [23], and in the UAE, 50% of the construction projects encounter delays and

are not completed in time [13]. Typical examples of waste from delays include available cranes waiting to lift rebar, pouring operations waiting for the completion of reinforcement cages, and workers waiting for materials.

3) Waste from Over-production

Waste from over-production includes products or materials produced earlier than specified by customers or produced beyond the required quantity. Major causes of over-production include poor planning in the distribution of materials and products to execute the project or focus on single tasks without consideration of the overall workflow. Over-production results in excessive manpower, transportation, storage space, materials, and other resources. Typical examples for waste from over-production include excess cutting of steel rods or production of wall panels, mortar, and premixed concrete.

4) Waste from Over-processing

Waste from over-processing is the arrangement and planning of unnecessary processes for a single workflow or the entire project. Major causes of over-processing include lack of process standardization or insufficient contractor knowledge concerning the production process. Over-processing wastes time and resources and can spoil products. Typical examples of waste from over-processing include examining standard products or materials with outside certificates of quality, measuring materials with non-standard tools, and including elements in production that are too large.

5) Waste from Maintaining Excess Inventory

Maintenance of excess inventory includes the improper storage of materials, machines, equipment, finished products, and other resources. Ko [25] showed that the finished goods inventory is regarded as waste. Major causes of excess inventory include the absence of strong inventory plans, suitable storage approaches, and project schedules. Excess inventory increases cost and the consumption of capital and leads to longer lead times. Additionally, excess inventory hides other problems, such as uneven production, supplier delay, defective products, traffic jams of site spaces, and manpower waste. A study showed that if inventory is used correctly, the project schedule can be reduced by 35%, and cost can be reduced by 8% [21]. Typical examples of waste from maintaining excess inventory include having more steel and cement in storage than are required with unsuitable locations on the site and having types of steel that are not classified in the store.

6) Waste from Unnecessary Transport

Waste from unnecessary transport includes unsuitable transport approaches of resources or finished goods in the process flow or for the site. Major causes of unnecessary transport include unreasonable site layout plans, poor site layout plans, and the use of inadequate equipment or poor pathway conditions. These issues produce a waste of time and

Table 1. Seven types of wastes in construction projects.

Number	Waste	Definition	Cause
1	Waste from defects	Incorporating products and materials of non-standard sizes or bad quality into the production line, increasing the amount of unnecessary handling or processing that could affect the quality of the product	Value generation management, tasks management
2	Waste from delays	Idling operation or in-between events	Workflows management
3	Waste from over-production	Producing products earlier than specified by customers or in greater amounts than required	Tasks management, workflows management
4	Waste from over-processing	Improper steps or stages in the workflow	Workflows management
5	Waste from maintaining excess inventory	Improper storage of raw material, WIP (work-in-process), or finished product and improper sequence of use	Workflows management
6	Waste from unnecessary transport	Improper transportation of parts or finished goods in the process flow	Workflows management
7	Waste from unnecessary movement of people and equipment	Unable to make proper use of personnel or machine to add value to work	Workflows management

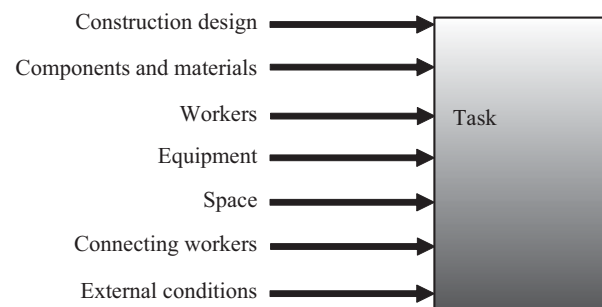
increase manpower, machine usage, cost, and the probability of defective products. Typical examples of waste from unnecessary transport include transporting products to a temporary yard and transporting packages of cement from site A to site B for storage.

7) Waste from Unnecessary Movement of People and Equipment

Waste from unnecessary movement of people and equipment includes the activities of personnel or machines and equipment that do not to add value to the work. Major causes of the unnecessary movement of people and equipment are inadequate working locations for people, machines and equipment as well as ineffective work methods. These operations increase manpower requirements and the times for operation flows while reducing productivity. Typical examples of waste from the unnecessary movement of people and equipment include walking for meters to obtain masonry mortar or building bricks and selecting a plate with a width of 60 cm from a pile of plates with other widths. Table 1 systematically summarizes the seven types of waste and their causes to help construction contractors quickly recognize them.

2. The Traditional Planning Model

Traditionally, construction projects are first separated into activities (or tasks), and the activities are then placed in a logical order. Next, the necessary executing durations and resources are estimated by construction contractors. To reduce total project costs and project execution duration, construction contractors try to reduce costs and duration of each single activity in the workflows. However, workflow concepts and value generation concepts are often ignored, while the workflow concept is an important contributor for planning the construction project because it addresses the high levels of waste in the workflows [27].

**Fig. 1. Input flows for a construction task [27].**

This model is based on the transformation concept in the production industry, with the assumption that the task is a production process. The production process itself is not actually considered, as only the inputs and outputs are addressed [18]. Moreover, the transformation concept hypothesizes that all inputs are available. When the transformation (task) concept is applied in the construction industry, certain problems such as increasing the amount of work-in-process and decreasing productivity occur. These problems are explained as follows: (1) within tasks, non-transformation activities exist; (2) input regarding tasks is defined as flows, and the execution of tasks heavily depends on these flows. In contrast, the progress of flows is dependent on the execution of tasks. Koskela [27] showed seven input flows for a task that include construction design, components and materials, workers, equipment, space, connecting workers, and external conditions, as shown in Fig. 1. Thus, project cost will be added if the construction contractor does not have an approach to eliminate the different types of waste in these flows. As a result, with traditional planning model, it is difficult to achieve low project cost while maintaining other criteria, such as project duration and quality. Additionally, the contractor cannot be competitive in domestic and international markets.

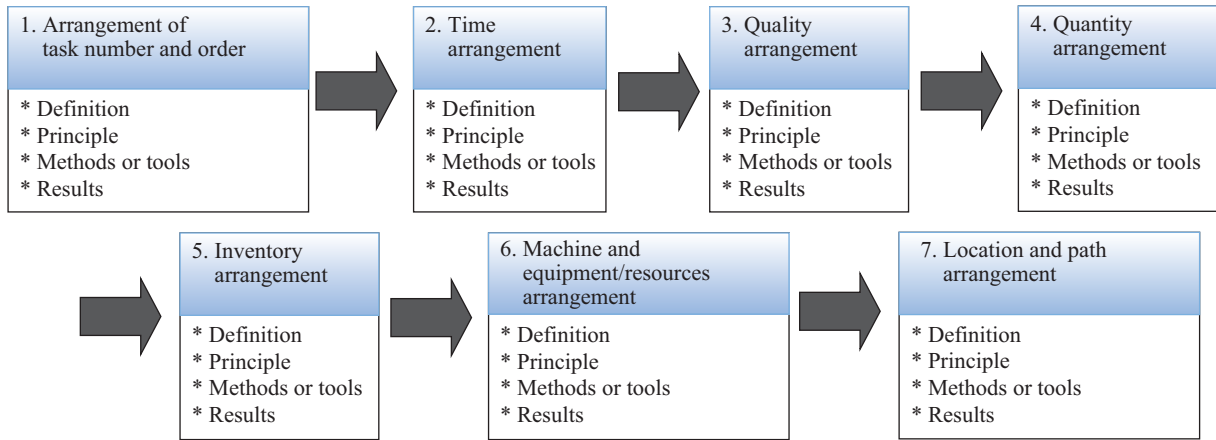


Fig. 2. Flowchart of the seven arrangement steps of the LPPM.

3. Steps in the Lean Prebid Planning Model (LPPM)

From the preceding section, the project cost, offered by construction contractors, includes added expenses due to types of waste. Thus, the most important objective of the proposed model is to eliminate the seven types of waste in the planning process before bidding by defining factors corresponding to the arrangement steps. This research defined seven arrangement steps in the prebid planning process for elimination or reduction. These seven arrangement steps are (1) the arrangement of task number and order, (2) time arrangement, (3) quality arrangement, (4) quantity arrangement, (5) inventory arrangement, (6) machine and equipment/resources arrangement, and (7) location and path arrangement, as described in Fig. 2. In each arrangement step, the definition, principle, methods, and results are shown to increase the speed required for user understanding. With the seven arrangement steps, the seven types of waste in the construction project will be fundamentally eliminated or reduced. Furthermore, the arrangement steps in the LPPM are interrelated. Thus, the steps are located logically and executed in series to improve the lean level of the project. Seven steps are explained in more detail below.

1) Arrangement Step for Task Number and Order

The task number and order need to be defined in each workflow as well as in the overall project, and this definition is especially important if the project is complex or new. The exact task number and the reasonable location of tasks in each workflow and the entire project should be defined. This arrangement step eliminates wastes from over-processing, delays, defects, over-production, and maintaining excess inventory. A construction contractor can use a work breakdown structure (WBS) as a method (tool) to subdivide the project work into smaller, more manageable tasks, and each descending level of the WBS represents an increasingly detailed definition of the project work. The planned work is contained within the lowest-level WBS components, which are called the work package. The contractor can use project schedule

network diagrams, bar charts, and milestone charts as tools. With this arrangement step, the construction contractor will reduce unnecessary expenditures, shorten the project duration, and improve the quality of the product.

2) Time Arrangement Step

A construction contractor needs to calculate the exact duration of each task from the preceding step and appropriately coordinate between their tasks and the tasks of other contractors. The contractor uses expert experience or statistics from familiar projects to calculate duration of tasks, workflows, and the entire project. The contractor can construct detailed work item progress tables and the entire project progress schedule tables. This arrangement step reduces expenses that occur from waiting, such as worker wait time and machine and equipment wait time, and reduces delay time for tasks, workflows, the entire project duration, and waste from maintaining excess inventory. Thus, this step can reduce project cost, shorten project duration, and improve labor productivity.

3) Quality Arrangement Step

The quality of all the resources that are used in the project must be satisfied. Specifications, size and mold of the materials and products are the same as the design diagram when entering a plan. Machines and equipment or tools are the same types as were defined in the drawings or technological documents. This arrangement aims to reduce wastes from defects and delays, and thus, the contractor can reduce expenses required for secondary processing or rework. This step involves carefully listing the quality requirements of resources and subjects in the workflows and then making resource quality lists, especially materials, manpower, and machines and equipment. The arrangement step ensures that the project's quality meets the customer's requirements while reducing project cost and shortening project duration.

4) Quantity Arrangement Step

The quantity of all necessary resources, such as materials,

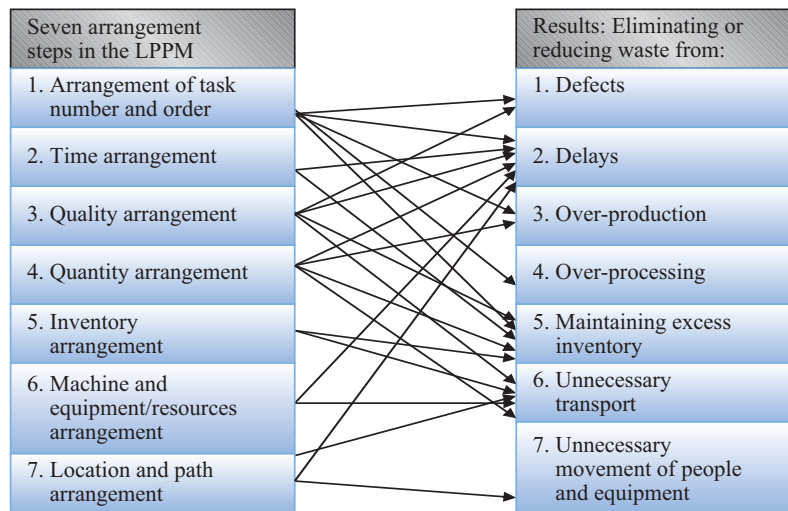


Fig. 3. The relationships between arrangement steps and their potential waste elimination.

machines and equipment, and manpower, must be listed early in the plan for a project. The quantity should be based on the requirements for the work, the employees’ abilities, and the capabilities of the machines. This arrangement step aims to reduce wastes from over-production, delays, and maintaining excess inventory. To perform this arrangement step, the quantity requirements of resources and subjects in tasks, as well as the requirements in the workflows, are carefully calculated, and the resource quantity lists are constructed, especially for materials, manpower, machines and equipment. This step reduces unneeded expenses and resources, and the resources do not affect the moving space and storage areas; thus, the project cost is reduced, and the duration is shortened.

5) *Inventory Arrangement Step*

The appropriate amount of resources, such as materials and machines, that are necessary for production during each time period must be planned. Both the appropriate storage approach and the appropriate storage location need to be studied. This arrangement step reduces wastes from unnecessary storage and transport. The contractor calculates the appropriate stored resources and determines short-term lists. Moreover, the contractor should use appropriate storage approaches, such as classifying resources (materials, machines, equipment, and tools) and having resource diaries to supervise inventory resources. This step reduces inventory costs, storage area, and lead time and maintains more continuous workflow. This step will reduce project cost and shorten project duration.

6) *Machine and Equipment/Resources Arrangement Step*

The quantities of machines, equipment, tools, and other resources, as well as the time usage and transportation methods, are planned by the contractor. This arrangement step reduces wastes from unnecessary transport and delays. The contractor can use calculations and experiences or use 3D simulation to offer the best transport plans for a construction site. This step

reduces wait time, transport time, and expenses for transportation. Moreover, this operation supplies material and other resources to production in time. This step will reduce project cost and shorten project duration.

7) *Location and Path Arrangement Step*

The location and transportation path of resources (materials, machines, equipment, and tools) need to be arranged appropriately to facilitate construction. The location and path arrangement eliminates wastes from the unnecessary movement of people and equipment and unnecessary transport. The contractor can use calculations and experiences or 3D simulation to determine the best location and transportation path for materials, machines, equipment, and other resources on the construction site. This step reduces unnecessary expenditures for secondary actions, the working time of each task, and the entire project duration. This step will reduce projects cost, shorten project duration, and improve labor productivity.

Each arrangement step can eliminate or reduce various types of waste and can be supplemented as showed in Fig. 3. Fig. 3 also shows the links between the proposed steps and the types of waste in the construction project. In the proposed model, arrangement steps are logically arranged; therefore, they improve the possibilities for the elimination or reduction of different types of waste. All of the arrangement steps are systematically presented to help contractors quickly understand and apply them in the real world.

This model applies three concepts from the production industry in the construction industry, as displayed in Table 2. The task concept is concretized by the arrangement step regarding task number and order. This step is necessary because it is difficult to imagine a productive activity where there is no transformation; it is easier to acquire the inputs for these tasks with minimal cost and to perform the tasks as efficiently as possible. The value generation concept is also concretized by the quality arrangement step. The customer’s requirements

Table 2. Definition, principle and application of the seven arrangement steps.

Arrangement	Definition and Principle	Result	Application
1. Task number and order	Appropriate task number and order for construction processes. The task number and order need to be defined in each workflow as well as the overall project	This arrangement step eliminates wastes from over-processing, delays, defects, over-production, and maintaining excess inventory	Task concept
2. Time	Matching the time required for the operation. Resources entering the site must be delivered on time as specified	This arrangement step reduces expenses that occur from waiting, such as worker wait time and machine and equipment wait time, and reduces delay time for tasks, workflows, the entire project duration, and waste from maintaining excess inventory	Workflow concept
3. Quality	Meeting the required specifications of resources. Specifications, sizes, and mold of material and other resources entering the plant should match the design diagram. Reduces the resource and manpower required for secondary processing or reworking (to maintain quality)	This arrangement step eliminates wastes from defects, delays, maintaining excess inventory, and unnecessary transport	Value generation concept
4. Quantity	Maintaining the optimal quantity of resources as required by the operation. Input material and other resources should be delivered in batches based on the planned work procedure. The amount of input material and other resources should not be excessive or delivered all at once so as to avoid taking up extra work space, affecting moving space, and incurring material arrangement expenses	This arrangement step eliminates wastes from over-production, delays, and maintaining excess inventory	Workflow concept
5. Inventory	Appropriate resources storage place and approach. The piling of material (parts) must align with the sequence of operating procedure specific to the site and be stored in a fixed 3D storage space with codes to facilitate search	This arrangement step eliminates wastes from maintaining excess inventory and unnecessary transport	Workflow concept
6. Machine and equipment/resources	Appropriate quantity and quality of resources and time required for transportation. Plan ahead the quantity and quality of machines, equipment, tools, other resources, time usage, and method for transportation	This arrangement step eliminates wastes from unnecessary transport and delays	Workflow concept
7. Location and path	Appropriate location and path of resources for construction, installation or transportation. Specify fixed transportation paths (including paths for horizontal transportation and vertical lifting) on the site of operation. Adhere to the locations of materials, manpower, machines, and equipment planned in advance for construction or installation (material and other resources need be well placed to facilitate retrieval and construction)	The location and path arrangement eliminates wastes from delays, unnecessary movement of people and equipment, and unnecessary transport	Workflow concept

are satisfied by this step. Additionally, the workflow concept is concretized by most of the steps. As a result, the LPPM lowers the project cost, shortens project duration, maintains

quality, and improves contractor competition in the domestic and international markets. Additionally, the LPPM facilitates managers, suppliers, and workers during execution of project.

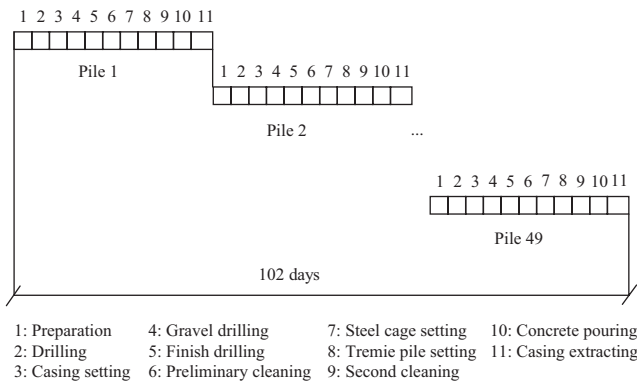


Fig. 4. Original execution plan.

IV. CASE STUDY

The feasibility of the proposed LPPM was illustrated with a case study project, and the model’s steps were applied in the project. The purpose of this section is to verify the ability of the proposed model for different aspects of planning without focusing on execution technologies.

The case study project is a bored pile project from the Housing and Urban Development Company-Headquarters and Office for Lease project (HUDC-HOL). This HUDC-HOL project includes three underground floors and two blocks of buildings with 32 and 28 superstructure floors. Each floor area is 2,674 m²; the area of the three underground floors is 18,884 m². This project was constructed in Hanoi, Vietnam, in late 2009 at a total cost of approximately \$1,900 billion Vietnam Dong (VND). The bored pile project includes 194 bored piles and has a project cost of \$68,183,669,323 VND. The subproject was performed by Long Giang Construction Company, which is one of the most respected companies in the bored pile execution area in Vietnam. The bored pile construction is a critical path in the building block, and all subsequent operations, such as foundation, superstructure, and roof, cannot begin until after completing the bored piles. These bored piles are also important because they are commonly used in multistory buildings throughout the world.

1. Task Number, Task Order, and Time Arrangement Steps

Drilling time is a critical path in a bored pile project. According to Long Giang contractor’s plan, 194 bored piles will be completed in 102 days, and four drilling machines (SANY SR220C) will operate 24 hours per day in sequence from work 1 to 11 (after finishing work 11, the drilling machine moves to another pile) as shown in Fig. 4. This figure also shows the order of steps to a make a bored pile and the duration of these steps for all of the bored piles for a drilling machine. These steps and their order are well known in the construction field. Two drilling machines have to drill 49 piles, and the other machines have to drill 48 piles. This research indicates that the duration of 102 days is too long because the contractor

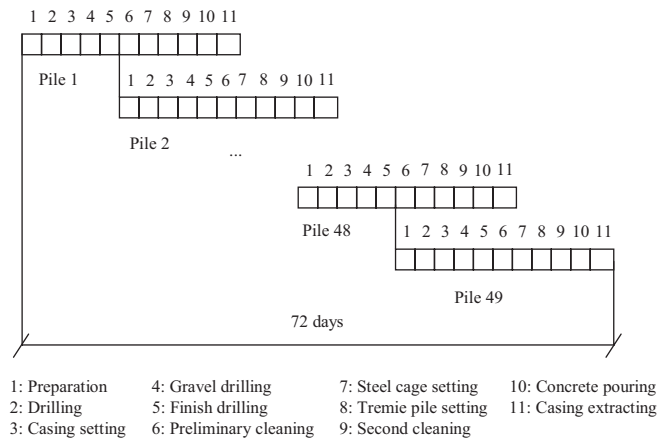


Fig. 5. Proposed execution plan.






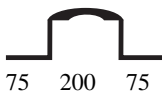
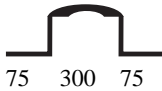


added the time of work from 6 to 11 to the drilling time during planning. Thus, the duration was recalculated. Based on expert ideas and data, such as duration of work, and geology from three experimental bored piles, which were constructed before the rest of the piles, the project duration was shortened to 72 days, as shown in Fig. 5. This result can be explained as follows. After a drilling machine finishes the first five tasks, it is moved to another pile to drill until all 49 bored piles are completed. The last six tasks are performed by other machines. The critical path to make a bored pile for a drilling machine is a sum of the time of the first five tasks (it is about 2100 minutes). Thus, both duration for making a bored pile and project duration will be shortened. Moreover, the bored pile execution order was also calculated again to reduce wasted time from moving drilling machines and workers, material transportation, and others time wastes, such as auxiliary equipment and preparation work. As a result, the project duration can be shortened by 10% from the 72-day schedule. Finally, the project duration is 65 days with these steps.

2. Quality, Quantity, and Inventory Arrangement Steps

In the bored pile project, the costs of materials and machines are significant; therefore, in this part, the research concentrated on examining the quality, quantity, and inventory for each. For steel, concrete, and bentonite liquid, the contractor added waste that occurs during execution in the project cost, so the amount and cost of each material is excessive compared to those values from the design. According to experts, if a contractor has a good plan, the concrete loss rate is 5% or less. By contrast, the contractor calculated a concrete loss rate of 15%, which is a common rate for bored pile projects in Vietnam. For steel and bentonite liquid, although the contractor estimated them with lower waste rates than concrete, they are still high levels of waste. To reduce waste of concrete, steel, and the other materials, this research offers material requirement tables and material list tables, which will be delivered to suppliers and workers.

In the requirement tables, suppliers will know the amount

Table 3. A steel list table for bored pile No. 170.

Steel No.	Shape-dimension (mm)	Diameter (mm)	Length (mm)	Amount	Unit weight (Kg/m)	Total length (m)	Total weight (Kg)
1	 11,700	22	11,700	84	2.984	982.8	2,932.7
2	 5,650	22	5,350	14	2.984	74.9	223.5
3	Hoop  Φ1,300, a150	12	587,658	1	0.888	587.66	521.84
4	Hoop  Φ1,300, a300	12	355,099	1	0.888	355.1	315.33
5	Hoop  Φ1,212	20	4,008	23	2.466	92.18	227.3
6	Steel pipe Φ110, thick 3	110	58.1	1		58.1 mm	
7	Steel pipe Φ60, thick 2.5	60	58.6	3		175.8 mm	
8		12	356	51	0.888	17.85	15.85
9		12	500	17	0.888	8.5	7.55
10	 14,050	25	14,050	4	3.853	56.2	216.54
11	Steel pipe, Φ1,506, thick 12	1,506	6,000	1	296	6	1,176
12	Hoop  Φ1,212	20	4,008	5	2.466	20.04	49.41

and weight of each type of material, so they can develop an early plan to deliver each material on time with the appropriate quantity. Table 3 is an example of a rebar list table for bored pile No. 170 that includes each type of steel and its corresponding weight. This list will be helpful to both contractors and suppliers in manufacturing, transportation, setting, storing, and supplying. The contractor uses tables, such as Table 3, to arrange manpower, machines for production and the transport of rebar. This table also provides a plan for storing materials and tools effectively. This section offers two rebar production locations (A1 and A2), temporary storage, a storing method, and material requirement tables. With these rebar production locations, the moving time and distance for cranes are reduced significantly, and there are no traffic jams in the construction site. Hence, the contractor will save money and time. Table 4 is an example of the quality, quantity, and inventory requirement for steel. Table 4 allows the manager and supplier to understand the status of the materials at the site so that the material will not be interrupted and the execution progress unaffected. Table 4 helps the contractor to eliminate excess inventory. The number of machines and manpower were also studied and arranged to ensure the machines have adequate technical parameters, and the manpower is adequate for professional competence.

3. Machines, Equipment/Resources, Location, and Path Arrangement Steps

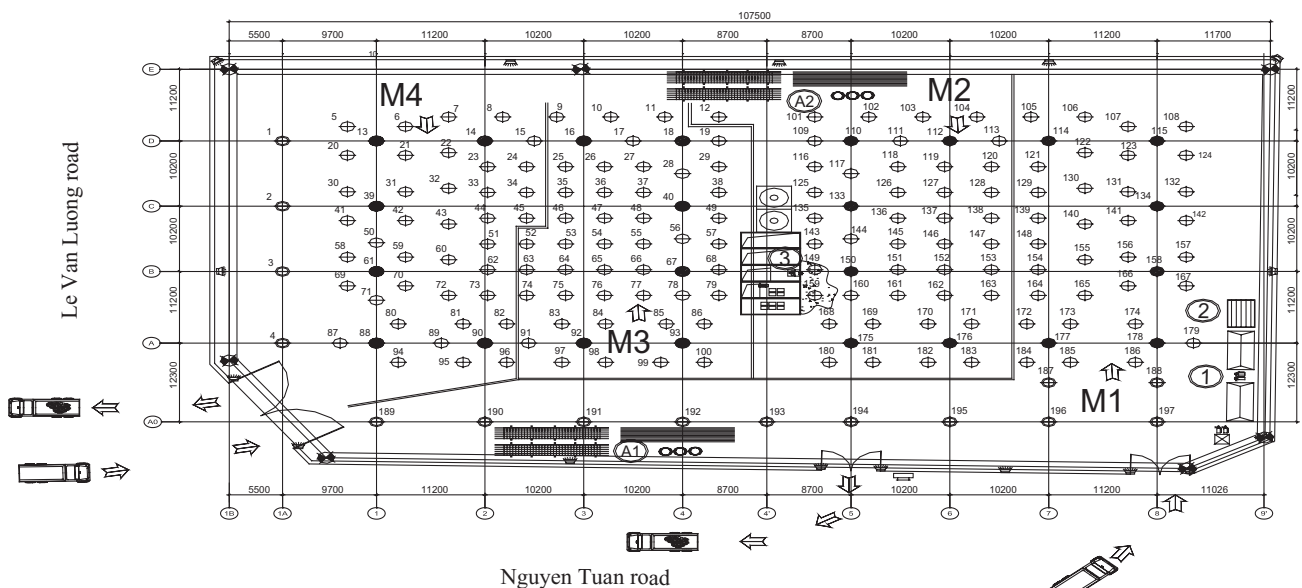
In this section, a plan is proposed for machines and equipment to transport soil from the site to the waste location and to

transport materials into the site. The paths of the drilling machines and vehicles are provided in Fig. 6, which shows the locations of the bored piles, site offices, rebar production location, bentonite liquid system, and temporary storage, as well as the direction of all drilling machines in the construction site. This layout is designed based on as ease of transportation, shortness of distance, and ability for comfortable execution.

M1, M2, M3, and M4 drilling machines move in opposite directions for each pair, and the piles that each drilling machine constructs are limited by double lines. Rebar production is divided into two locations, A1 and A2. As a result, the moving distances of drilling machines and other machines are shortened. One common problem in bored pile construction sites in Vietnam is that they are dirty, so that it is difficult for the vehicles to move. Dirty sites increase time for moving vehicles and manpower and correcting drilling machines. Certain effective solutions are offered in this research including using lined thick steel panels to construct roads and installing tanks to collect all waste soils from the drilling machines and bentonite system. The vehicles enter and leave the site through three gates. These operations can reduce moving time for vehicles and will also reduce traffic jams at the site. The bentonite system is located in the center of the construction site to reduce the transportation time and pressure for bentonite because the distances between the bentonite system and bored piles are shortened. According to experts, with these arrangement steps, the contractor can reduce 15% of the cost required for this work including drilling, moving soil, and other types of work.

Table 4. An example of a rebar requirement table for bored piles.

Work item	Material input specs	Material input time	Material input quantity (Ton)	Storage location	Safety inventory (Ton)	Specs used	Time used	Quantity used (Ton)	Outstanding quantity (Ton)	Cumulative usage (Ton)	Remark	
Rebar of bored piles	Φ12	12/11/2009	20	A1, A2	10							
	Φ20	12/11/2009	1.5	A1, A2	0.6							
	Φ22	12/11/2009	72	A1, A2	36							
	Φ25	12/11/2009	5	A1, A2	2.5							
						10	Φ12	15/11	3.44	16.56	3.44	
						0.6	Φ20	15/11	0.2	1.3	0.2	
						36	Φ22	15/11	12.63	59.37	12.63	
						2.5	Φ25	15/11	0.89	4.11	0.89	
						10	Φ12	16/11	3.44	13.12	6.88	
						0.6	Φ20	16/11	0.2	1.1	0.4	
						36	Φ22	16/11	12.63	46.74	25.26	
						2.5	Φ25	16/11	0.89	3.22	1.78	
						10	Φ12	17/11	3.44	9.68	10.32	Needing replenishing
						0.6	Φ20	17/11	0.2	0.9	0.6	
					36	Φ22	17/11	12.63	34.11	37.89	Needing replenishing	
					2.5	Φ25	17/11	0.89	2.33	2.67	Needing replenishing	



- 1: Site office
- 2: Temporary store
- 3: Bentonite liquid system
- A1: Rebar production place
- A2: Rebar production place
- M1: Drilling machine
- M2: Drilling machine
- M3: Drilling machine
- M4: Drilling machine

Fig. 6. Site layout plan.

Table 5. Comparison of costs after using LPPM.

Work item	Original project cost (VND)	Project cost with using LPPM (VND)	Potential cost reduction (VND)	% cost reduced
Concrete	\$21,372,307,866	\$19,380,287,300	\$1,992,020,566	9.32
Rebar $\Phi \leq 18$ mm	\$2,890,338,623	\$2,814,898,229	\$75,440,394	2.61
Rebar $\Phi > 18$ mm	\$11,804,424,486	\$11,804,424,486	0	0
Bentonite liquid	\$5,578,097,118	\$5,418,968,112	\$159,129,006	2.85
Drilling work, soil moving work, and other types of work	\$26,538,501,230	\$22,557,726,055	\$3,980,775,185	15
Total	\$68,183,669,323	\$61,976,304,182	\$6,207,365,151	9.1

V. CASE STUDY RESULTS AND ANALYSIS

After implementing the seven arrangement steps in the HUDC-HOL project, the following were generated: a progress schedule regarding the bored pile execution work items, a diagram of bored pile execution, the material requirement plan, the types and quantities of steel at all the piles, the manpower, a machine and equipment requirement plan, and the moving path of machines. With the LPPM, the total costs of the project were reduced by 9.1%, as reported in Table 5, and the bored pile project progress was shortened by 37 days, although the Long Giang contractor is experienced in this field in Vietnam. In this project, the waste from concrete, machines, and manpower was large. The wasted work related to drilling and moving is highest and accounts for 15% of the total waste. This waste results in ineffective use of machines, equipment, and manpower. The paths for moving drilling machines and trucks were not planned effectively. The materials in the construction site were not stored in the most efficient locations. The second largest waste was concrete, with a waste rate of 9.32% due to the following reasons. The amount of concrete that was disposed of without use was high. A large amount of concrete was used due to the larger range of dimensions for bored piles caused by inadequate drilling technology (unqualified drilling machines) and unqualified workers. The waste of steel corresponds to $\Phi > 18$ mm was the lowest with the rate of 0%. The waste of steel corresponds to $\Phi \leq 18$ mm was the second lowest with the rate of 2.61%. These steel rates are due to the simple nature of the rebar structures of the bored piles, which are almost entirely constructed from original steel bars. The bentonite liquid was recycled by the contractor using effective solutions, which were offered in this research, so the bentonite liquid waste rate may be reduced by an additional 2.85%. Based on the results of this study, contractors can increase their benefits if all contractors incorporate and use the LPPM together.

VI. CONCLUSIONS

Seven major types of waste in construction projects were systematically generalized by definitions, causes, results, and examples. A new model for planning prebid for construction

contractors based on the construction lean theory has been presented. An LPPM has been proposed. The LPPM includes seven arrangement steps corresponding to the seven major types of waste in construction projects. As a result, the LPPM combines all three important concepts transformation, workflow, and value generation to make a lean prebid planning process for construction contractors. Moreover, the seven arrangement steps are defined clearly (definition, principle, methods or tools, and results) and arranged in series. Thus, the LPPM can efficiently eliminate or reduce these types of waste in construction projects. This study used a case study project in Vietnam and proved that the LPPM can help the construction contractor to obtain a lower project cost and a shortened project duration while maintaining the quality criterion. Additionally, the contractor can easily understand and apply the proposed model in the real world.

Nonetheless, the research findings are limited by the numbers and types of the projects. Thus, more real projects should be used as case studies to achieve more robust results. Additionally, it is important to address the effect level of each type of waste as well as each arrangement step in the LPPM, which represents another valuable direction for future research.

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