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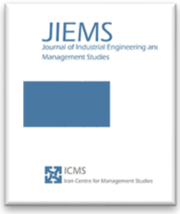

Using VSM Method and DES Modeling for Optimizing Concrete Flooring Process of Industrial Buildings

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Abstract

In recent years, the use of lean construction has been expanded to reduce waste and increase productivity in construction projects. Con-struction managers and engineers try to use innovative methods to reduce waste in construction projects. There are repetitive processes in construction in which waste can be avoided by reducing lag time. This research aims to optimize construction processes using the Value Stream Mapping (VSM) method. For this purpose, the process of Industrial Concrete Flooring (ICF) was selected as one of the sub-constructions of industrial buildings. First, the ICF process was mapped using field observations and recording the time of each activity. Second, the process was modeled using Discrete Event Simulation (DES). The DES model was improved after identifying the process's bottleneck through the analysis of the developed model. The analysis showed that concrete leveling activity acts as a process bottleneck leading to an increase in the duration of the concrete remaining (about 51 min) in the truck mixer and a reduction in the productivity of workers and machinery. Finally, the developed model was modified. As a result, the duration of concrete remaining in the mixer was reduced to 18 minutes, and the utilization of labor and machinery was also improved.

Keywords: Lean Construction, Value Stream Mapping (VSM), Discrete Event Simulation (DES), Optimization, Industrial Concrete Flooring (ICF)

Paper Type: Original Research

1. Introduction

Traditionally, a construction project is normally considered successful if it is completed within its time, budget, and quality goals. Construction managers are always trying to improve the productivity of construction projects by elimi-nating non-value-adding activities. Waste has therefore become one of the critical challenges facing the construction industry. Waste can sometimes be physical and material, and sometimes it can be seen as a waste of time and lost opportunities. For this reason, in recent years, extensive efforts have been made to identify waste in the construction industry, and various methods and tools have been developed. Value stream mapping (VSM) is one of the lean tech-niques for process improvement that is usually used to identify and understand value-added and non-value-added activities from the flow of materials and information in a value stream (Shou et al., 2017). Non-value-added activity may be produced at any stage of a construction project's life cycle, from the design and construction stages to the project maintenance stage (Faniran & Caban, 1998). In other words, any inefficiency that leads to the use of equip-ment, materials, labor, or capital, in quantities greater than what is necessary to produce a building, is considered a type of waste and does not produce added value (Koskela, 1992). Simulation is a powerful tool for supporting deci-sion-making in construction management. It is possible to develop project planning, identify bottlenecks in opera-tions, optimize and improve productivity, and quickly compare alternative construction scenarios by using accurate models of construction processes (Abourizk & Mohamed, 2000). Simulation is the imitation of the performance of a process or system in the real world over time. The simulation model is a logical description of how the components of a system interact. Additionally, the need to construct industrial buildings has grown due to the expansion of various industries. Among the various components of an industrial building, industrial floors form an essential part of the construction process, both in terms of accuracy and cost. Considering that most of the activities related to production happen on the floors, any defect in the floor can prevent the continuation of the factory's production, so moving the production lines and repairing or replacing the floor can be

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very expensive. There are differences between concreting industrial floors and concreting other parts of construction projects. For example, the duration of the activity of level-ing the poured concrete or the duration of the initial setting of the concrete - to perform the final payment operation - is a time-consuming matter. Therefore, a regular schedule is needed for the concrete to enter the site and to carry out each activity. The level of labor productivity and concrete pouring machines' efficiency are affected by this schedule. In fact, this research aims to assist construction project managers in effectively managing time and cost within the context of industrial buildings, particularly through the use of the VSM method and DES modeling to optimize the concrete flooring process. It is hoped that the results of this research will support decision-making for industry profes-sionals and project managers in efficiently managing the construction of industrial projects.

2. Literature Review

2.1 Lean Construction

The construction industry has faced various challenges, one of the most critical being how to manage resources (Zahraee et al., 2013). Projects are temporary production systems. A lean project is a project whose systems are designed to provide a product by maximizing value and minimizing waste (Ballard & Howell, 2003). Researchers try to improve construction processes by minimizing waste. Various tools and methods have been developed to facilitate lean construction, including the "Last Planner System"-which minimizes waste through coordination among project stakeholders (Ballard & Howell, 1994), "Just in Time" -complete elimination of all waste to achieve to the best quality, lowest cost, lowest resource consumption and shortest production and delivery time- (Marchwinski & Shook, 2003), "VSM", etc. VSM facilitates the development of an improvement plan by documenting process steps, the flow of work items, and using a systematic analysis method (Chen & Cox, 2012). By classifying the stages of the processes into two groups, value-added and non-value-added, it is possible to enhance the first group and eliminate the second group. Pasqualini and Zawisla have proposed four stages including 'selection of a construction stage', 'map of the current state', 'analysis of the map of the current state', and 'map of the future state' to implement VSM in construc-tion (Pasqualini & Zawislak, 2005). In this paper, these four steps are used to implement VSM.

2.2 Discrete Event Simulation (DES)

The term discrete event simulation is commonly used for a method of modeling that represents a system as a process, i.e., a sequence of operations performed on agents such as customers, components, documents, etc. These processes usually involve delays, resource usage, and waiting in queues. Discrete event simulation models the performance of a system as a discrete sequence of events in time, where each event occurs at a specific point in time and causes a change of state in the system (Robinson, 2005). Each operation is modeled with its own start event and end event, and no change in the model can occur between any two discrete events. The term discrete has been used for decades to distinguish this modeling method from continuous methods, such as system dynamics (Borshchev, 2013). The liter-ature review revealed that simulation has been used as a suitable tool for modeling and analyzing various construc-tion processes (Al Alawi et al., 2022; Kim et al., 2021; Nasirzadeh et al., 2018). For instance, Du et al. (2016), investi-gated the change order management process via DES. The simulation was also used for the modeling of the bricklay-ing process (Abbasian-Hosseini et al., 2014), concrete delivery, and pouring process (Zahraee, 2013; Zahraee et al., 2021). Due to computer advances and the advantage of using computers, the tendency to use graphic methods for simulation and modeling has increased. Various software has been designed and developed for this purpose, such as SIMPHONY, ARENA, CYCLONE, ANYLOGIC, etc., which are widely used to simulate construction processes. In this paper, due to its high flexibility and unique features, ANYLOGIC software was used for simulation and model development.

2.3 Summary of research background

The summary of the main research background conducted in the subject area of this study is presented in the table below. In general, many studies have been conducted regarding the reasons for cost increases and time delays and also considering different simulation models. However, these topics still require research in the context of industrial construction projects during the execution phase. Therefore, the current research gap and the innovation of this study can be explained.

Table 1. The main Research Background at a Glance

Research Method/Tool	Research Topic/Objective	Source
System Dynamics Model	Providing a system dynamics model for predicting the performance of construction projects based on causal factors	(Ansari et al., 2022)
System Dynamics Model	Development of a sustainable system structure for optimizing the cost of construction waste disposal in line with sustainability goals	(Mak et al., 2019)
System Dynamics Model	Development of a causal loop model for investigating factors related to risk and cost overruns in construction projects	(Asiedu & Ameyaw, 2021).
System Dynamics Model	Analyzing the impact of investment policies on environmental performance indicators in the construction sector	(Marzouk & Fattouh, 2022)
System Dynamics Model	Investigating safety behavior in construction	(Nabi et al., 2020)
Simulation Model	Planning for the production of modular buildings	(Bhatia et al., 2022).
Discrete Event Simulation Model	Maintenance phase simulation for construction projects	(Al Alawi et al., 2022).
Discrete Event Simulation Model	Providing a time-scheduling model for the production of prefabricated walls	(Kim et al., 2021)
Hybrid Simulation Model	Proposing a model for site planning and scheduling of construction projects	(Taghaddos et al., 2021)
Hybrid Simulation Model	Investigating and modeling the safety behavior of construction workers	(Nasirzadeh et al., 2018)

3. Research Methodology

Considering the characteristics of this research (nature, objectives, questions, limitations, etc.) and the literature review, the details of the methodology for this study have been finalized. Accordingly, this research is applied in nature and goal, as it aims to address a real-world issue. In other words, the researcher seeks to make a new discovery relat-ed to a process that occurs in reality. This research falls under the category of mixed-methods research in terms of data collection. Overall, this research embodies a pragmatist philosophy. The approach of this study could be induc-tive and deductive reasoning. The strategy of this research includes mainly case as context study of construction pro-cesses: concrete flooring process of industrial buildings (or ICF - Industrial Concrete Flooring). Additionally, this re-search uses both library and field studies, as well as tools such as observation for data collection. In this regard, this section outlines the steps followed in this research. Fig. 1 demonstrates the research methodology chosen to develop a valid simulation model for the Industrial Concrete Flooring (ICF) process.

3.1 Selection of A Construction Stage

Because large stages in construction occur gradually over a long period, each one could be considered a sub-construction stage inside the construction site (Pasqualini & Zawislak, 2005). In this research, the ICF process is selected as a construction stage.

3.2 Mapping the Current State

First, the actual behaviour of the ICF process must be examined through precise observation to model it. This step is completed through a detailed process mapping and discussions with experts (Figure. 2). After mixing and loading the concrete, it is transported to the project site by a truck mixer. If the queue behind the concrete pump is empty, it moves towards the pump, otherwise, it remains in the waiting queue until its turn arrives. After placing the truck mixer at the pump site, if the concrete already poured has not been leveled, the concrete pumping operation is sus-pended. When the conditions are ready, pumping, and concreting operations are done. The poured concrete, after being leveled and scrutinized by the skilled workers, is left alone for the initial setting to occur. It means that the con-crete is hard enough to walk on. After the initial setting time of the concrete has passed, the top hardening material is poured on the concrete and the surface is ready for the final polishing operation by the power trowel. The finishing of the concrete surface continues until the polished surface is reached.

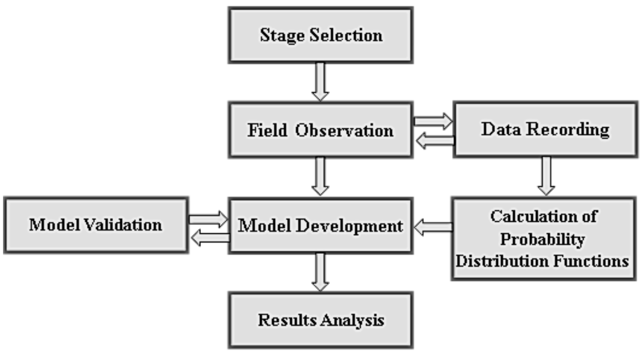

Figure 1. Methodology of DES Model Development

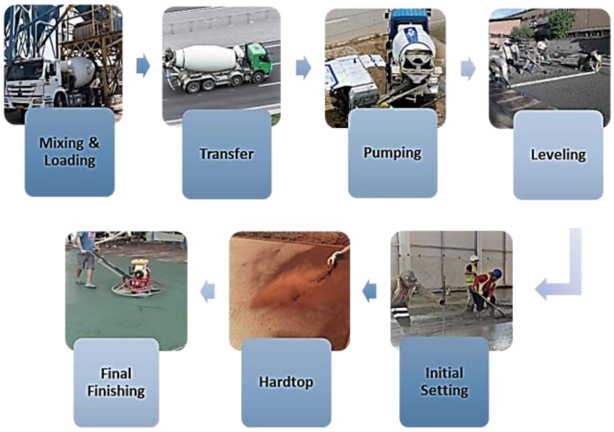

Figure 2. Steps of Conventional ICF Process

Second, numerical data are collected during construction and from historical records. The data collection stage may be repeated several times as needed. This stage happens through the researcher's presence at the project site and re-cording the time of each activity separately. Since in this simulation method, Probability Distribution Functions (PDF) are used instead of fixed numerical values, therefore, the more the number of time measurement repetitions of each activity, the higher the accuracy of the measurement. Then, the collected data was used to define the PDF to estimate the duration of each activity using EasyFit software (Table.2).

Table2. Activity PDF Parameters

Activity	PDF Type	PDF Parameters
Mixing	Weibull	α=5.4379 , β=1.2795
Weighbridge	Beta	α1=0.5078 , α2=0.4802 a=0.9, b=3.7
Delivery	Beta	α1=0.3465 , α2=0.2604 a=12.2 , b=17.7
Pumping	Erlang	β=0.0817 , m=47
Leveling	Uniform	a=4.006 , b=5.993
Initial Setting	Beta	α1=0.7837 , α2=1.0455 a=60.8, b=179.6
HardTop	Beta	α1=0.3803 , α2=0.1789 a=2, b=3
Finishing	Weibull	α=10.92 , β=26.575

Third, the model was developed using ANYLOGIC simulation software according to ICF and PDF of activity duration. As seen in Fig. 3, After the raw materials enter the mixing section, the concrete is loaded by the truck mixer. Loaded truck mixers wait in the exit queue. Once the truck mixer enters the site, if the pump queue is empty, the truck will move directly to the concrete pump, otherwise, it will wait in the pump queue. The duration of concrete pumping depends on the amount of concrete poured on the ground that has not yet been leveled by labor. If all con-ditions are met, the concrete will be pumped, otherwise, the pumping operation will be stopped. The speed of leveling of poured concrete depends on the productivity and number of the workforce. After leveling each concrete unit, a period is required for the initial setting. Once the initial setting time of each concrete unit is over, the hardtop material is spread on the concrete surface in order. If idle labor is available, the hardtop operation will be performed, other-wise, this concrete unit remains in the waiting queue until the labor is freed (The priority of the workforce is to level the concrete). Each concrete unit whose hardtop material has been applied is ready for final finishing. The priority is based on the availability of the required workforce and the order of entering the queue for this activity. In the devel-oped model, two types of human resources (worker and skilled worker) and one machinery resource (concrete pump) are considered (Figure. 4).

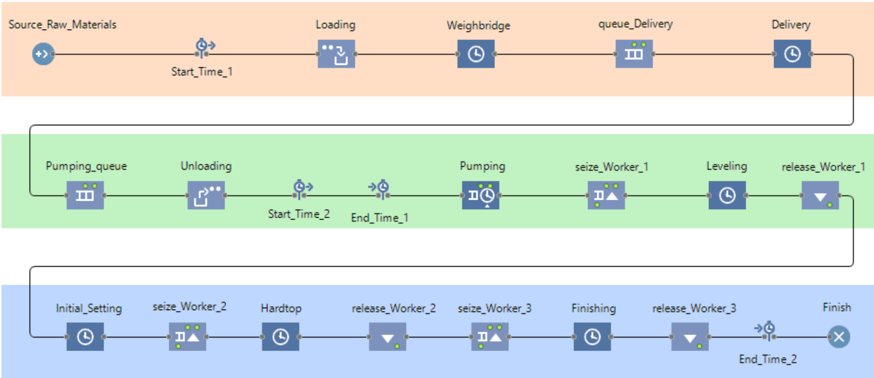

Figure 3. ICF – DES Model

The model can be validated by running it several times and comparing results with a full measured cycle to ensure that the model outputs match reality. By increasing the number of iterations, it can be validated more accurately. Due to some inconsistencies between the developed model and the real world, it may be necessary to make modifications. In this research, the developed model was run 20 times and the results were compared with the actual measured value. Fig. 5 shows that the difference between developed DES model outputs and the actual values is less than ±5%, which is considered acceptable.

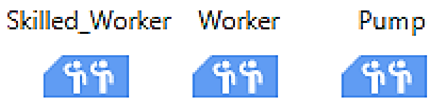

Figure 4. DES Model Resources

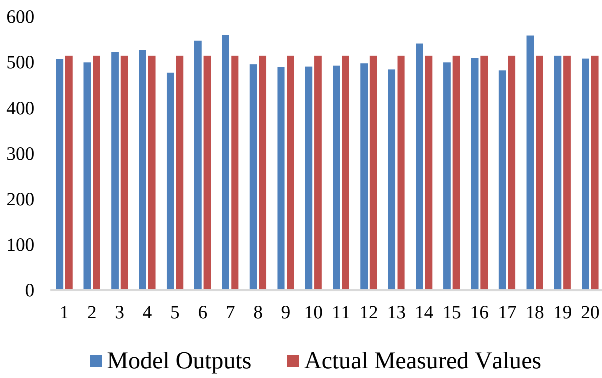

Figure 5. DES Model Validation

3.4 Map of the Future State

After analyzing the current state and identifying the bottlenecks, it is time to remove the bottlenecks. For this purpose, after re-examining the process, by applying modifications in the process, the delay time and the length of queues will be reduced. Finally, the improved modified model will be developed again and the results are analyzed.

4. Results and Discussion

4.1 DES Model Results

In analyzing the current state, it is assumed that 49 cubic meters of concrete are poured and polished daily. Also, the exit rate of the truck mixer from the batching plant is three mixers per hour. Two skilled workers and three workers are available. A ground pump is also used to pump concrete. Table 3 shows the DES model outputs for 20 iterations. Table 3 shows that the concrete is in the mixer for an average of 51 minutes before pouring. Prolonging this time, technically, can reduce the quality of concrete. By inspecting the model during the simulation, the reason for the long waiting period is identified as the delay caused by the leveling of the poured concrete.

Table 3. DES Model Outputs

Num	Before Pumping (min)	Pump to Finish (min)	Skilled Worker Utilization	Worker Utilization	Pump Utilization	Total Time (min)	Productivity
1	54.1	225	82%	63%	41%	459	1.28
2	55.66	229.97	82%	67%	42%	453	1.30
3	55.17	208.67	83%	68%	44%	437	1.35
4	48.59	217.85	76%	67%	41%	461	1.28
5	49.25	229.66	83%	66%	40%	447	1.32
6	46	228.91	84%	65%	39%	445	1.32
7	50.33	218.99	83%	67%	43%	442	1.33
8	46.1	225.74	80%	63%	40%	463	1.27
9	47	224.11	81%	66%	41%	451	1.30
10	52.79	220.62	80%	65%	42%	456	1.29
11	52.26	217.95	84%	67%	42%	439	1.34
12	50.4	223.24	79%	63%	39%	454	1.30
13	49.11	227.67	77%	64%	39%	473	1.24
14	51.94	227.35	78%	66%	40%	461	1.28
15	58.44	220.66	78%	58%	39%	487	1.21
16	53.42	228.06	77%	62%	40%	475	1.24
17	52.6	219.08	83%	68%	41%	438	1.34
18	48.11	228.81	79%	62%	39%	472	1.25
19	50.53	234.47	84%	64%	40%	454	1.30
20	47.14	225.85	82%	66%	41%	445	1.32
Average	50.95	224.13	81%	65%	41%	455	1.29

This delay can be due to limited access to labor, or due to the queue formed for leveling concrete. Since Concrete from the next mixer cannot be pumped until the concrete poured from one mixer is completely leveled, this delay causes mixers to wait longer in the pump queue. On the other hand, utilization of the pump also decreases and as a result, its idle time increases. For further investigation, several scenarios with different numbers of laborers are considered to check whether the delay decreases or increases with the increase or decrease of the number of workers. Tables 4 and Table 5 show different scenarios and their outputs, respectively. Table 5 shows that by reducing/increasing or chang-ing the composition of laborers, there is not much change in the duration of concrete storage in the truck mixer. Therefore, it can be concluded that the reason for the delay in the leveling activity (process bottleneck) is not the number or composition of the laborers, but the reason is the length of the queue formed to perform the leveling. For this purpose, in the next step, with some changes and improvements of the developed model, the impact of this issue will be investigated.

Table 4. Specification of scenarios

Scenario	Skilled Worker	Worker	Pump	Concrete Volume (M3)	Mixer Rate (Mixer/Hour)
0	2	3	1	49	3
1	2	2	1	49	3
2	3	2	1	49	3
3	3	3	1	49	3

Table 5. Model Outputs for Different Scenarios

Scenario	Before Pumping (min)	Pump to Finish (min)	Skilled Worker Utilization	Worker Utilization	Pump Utilization	Total Time (min)	Productivity
0	50.95	224.13	81%	65%	41%	455	1.29
1	51.66	293.34	80%	78%	37%	514	1.43
2	51.87	246.09	63%	79%	39%	472	1.25
3	52.39	206.97	62%	59%	41%	448	1.10

4.2 Improvement of the developed model

As mentioned, the delay is due to the queue formed for unloading and pumping. Therefore, to control the exit rate of the truck mixer, it is necessary to manage the mixing start time and exit of the truck mixer by the batching operator and a coordinating person. Fig. 6 shows the improved model, which includes a coordinator and a batching operator. The current logic in this model is that if there is a truck mixer in the pump queue, the coordinator does not permit the new truck mixer to leave, on the other hand, if more than one truck mixer is waiting to leave the plant, the batching operator will not mix concrete. The improved model is run 20 times and the average results are compared with the original model. Table 6 shows the output of the improved model along with its comparison with the original model.

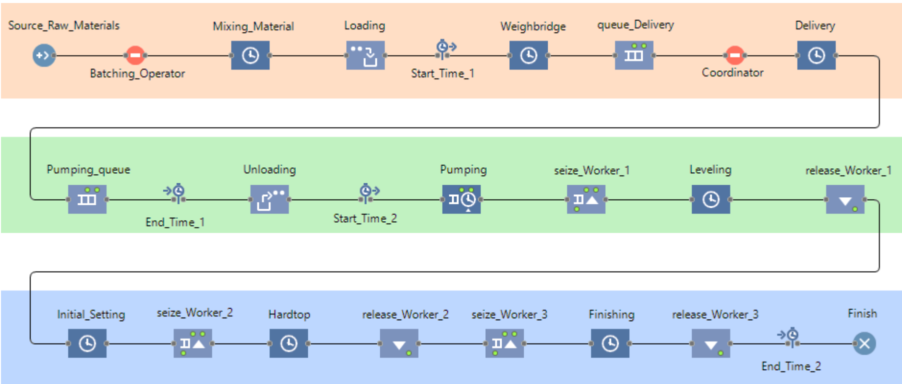

Figure 6. Improved ICF-DES Model

Table 6 shows that the concrete storage time in the truck mixer has decreased from about 51 minutes to about 18 minutes (about a 65% reduction). On the contrary, the total duration has increased by almost 13%. After analyzing the improved model, it can be optimized based on different values of input parameters. This is the fourth step in the VSM. For this purpose, the optimization feature of Anylogic software is used. The model is run as many times as de-sired (1000 times) for different ranges of parameters. The average of these results is displayed as output (Table.7). According to Table 6 if the management decision is based on the use of six human resources according to the condi-tions of the project, it is possible to use a combination of three skilled workers and three workers (with an average time of about 492 minutes) or a combination of two skilled workers and four workers (with an average time of about 491 minutes).

Table 6. Comparing improved and initial models' outputs

Model	Before Pumping (min)	Pump to Finish (min)	Skilled Worker Utilization	Worker Utilization	Pump Utilization	Total Time (min)	Productivity
Improved	18.02	204.05	71%	55%	36%	517	1.14
Original	50.95	224.13	81%	65%	41%	455	1.29

Table7. Optimization Results Based on Different Laborers' Combinations

Laborers		Rep1	Rep2	Rep3	Rep4	Rep5	Rep6	Rep7	Rep8	Rep9	Rep10
6	Total Time (min)	494	492	490	490	491	492	492	495	496	493
	Skilled Worker	3	2	3	3	2	2	2	3	1	3
	Worker	3	4	3	3	4	4	4	3	5	3
5	Total Time (min)	516	516	521	513	519	517	516	520	516	523
	Skilled Worker	1	1	1	1	1	1	1	1	1	1
	Worker	4	4	4	4	4	4	4	4	4	4

5. Conclusions

In this research, the process of Industrial Concrete Flooring (ICF) was investigated by implementing lean construction through the Value Stream Mapping method (VSM). This implementation includes 4 steps. First, after selecting the construction process, the whole process was mapped through detailed field observations and consultation with experts. Second, the current state was modeled using Discrete Event Simulation (DES). Third, the developed model was analyzed after validation. Analyzing the model showed that the leveling activity acts as the bottleneck of the process. Fourth, the model was improved by applying modifications and the concrete stor-age time was reduced from about 51 minutes to about 18 minutes (a 65% reduction). Finally, the model was op-timized for different combinations of laborers. In summary, applying this practical model can reduce delays and prevent cost increases in the industrial context, particularly in the industrial floor concrete pouring system, through the use of lean principles. For any research, even when it has successfully achieved all of its defined objectives, recommendations for improving its findings can still be made. On the other hand, sometimes due to limitations faced by the researcher during the research process, such as time constraints, access issues, and other factors, it is not possible to cover all aspects of the research topic. This study is no exception. Therefore, in this concluding section, several suggestions for future research are presented:

- Exploring the implementation of lean construction principles using other existing methods such as LPS, JIT, VM, and so on.
- Investigating the research topic using other techniques instead of simulation models, such as neural networks, and comparing the results with the findings of this study.
- Using other simulation modeling methods such as agent-based modeling, or researching how different states can be combined, such as system dynamics-agent-based modeling or discrete event-agent-based modeling, and so on.
- Investigating other processes in the construction of industrial projects and studying the impact of fac-tors on these processes, such as the process of manufacturing metal components in factories, transporta-tion, and installa-tion on-site, etc.

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