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A VALUE STREAM MAPPING-BASED DISCRETE EVENT SIMULATION TEMPLATE FOR LEAN OFF-SITE CONSTRUCTION ACTIVITIES

Prashanth Kumar Sreram
Albert Thomas

Indian Institute of Technology Bombay
Department of Civil Engineering
Powai, Maharashtra,
Mumbai, 400 076, INDIA

ABSTRACT

Lean construction is a promising approach for performance improvement in the construction industry. Value stream mapping (VSM) is an essential lean tool for the process improvement of construction activities. However, VSM, regarded as a static pen-and-paper technique, requires repeating the VSM preparation for every improvement alternative. Therefore, dynamism can be introduced into VSM by developing computer simulation models, which is the study's objective. A VSM-based discrete event simulation (DES) template is presented in this paper for off-site construction activities. The model provides a virtual testing environment for the user to decide upon the potential time reduction in non-value-added (NVA) activities for the process improvement. The development and validation of the model is done based on the actual data from a precast production factory. The DES-VSM simulation model assists plant managers with the best possible NVA reduction strategy and accelerates lean implementation in the construction industry.

1 INTRODUCTION

The foundation for a nation's economic growth, social development, and productivity is the presence of infrastructure. Globally, the need for investment in infrastructure is forecasted to reach 94$ million by 2040. The construction industry contributes to the infrastructure development of a nation by executing these infrastructure projects (Oxford Economics 2017), and a country's economy relies on the performance of the construction industry to remain competitive in the world. Further, on-time completion and execution of the project within budgeted cost determines the success of a construction project. However, delays and cost overruns make construction projects inefficient and wasteful (Azis et al. 2012). In order to overcome these various inefficiencies, lean construction has the potential to challenge the conventional time and cost-driven nature to the flow-oriented perspective (Pan and Pan 2022).

While construction projects are unique, from a macro view through a lean perspective, there are several repetitive processes in every construction project (E.g., road construction, typical floors in building construction, and precast elements for a metro project) (AbouRizk et al. 1992). Even though there are many tools in lean, Value Stream Mapping (VSM) is one of the most widely used lean tools to improve the process flow of inventory and information by highlighting the waste in the construction activity. Further, Value stream mapping offers a thorough understanding of each phase of the material and information flow with the main objective of identifying unnecessary processes and finding strategies to get rid of them (Seth et al. 2017). However, randomness in construction activities needs to be considered for process improvement (Zahraee et al. 2021). In contrast, VSM assumes a deterministic paradigm and cannot represent a system's dynamic behaviors (Jarkko et al. 2013). Therefore, computer simulation can be used to effectively describe

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and analyze lean construction processes from a practical standpoint, including uncertainty. As a result, simulation can be used to test lean ideas before they are put into practice in the field (Halpin and Kueckmann 2002; Mostafa et al. 2016; and Du et al. 2023). Therefore, a VSM-based simulation framework is proposed in this study to practice lean in the construction industry and hollow core slab casting is presented as an example for developing the templates.

The remainder of the paper is organized as follows. Section 2 presents the literature review on the current state of lean construction using simulation and methodology for developing the model. Next, Section 3 introduces a simulation model with case study data and analysis. The paper concludes with a summary of the significant findings and future work.

2 LITERATURE REVIEW

In order to reduce waste in construction, the production process mapping is to be done to gain control of all the activities and resources required to complete the process. Therefore, VSM is the lean tool for improving the production process, representing both material and information flow. Further, VSM helps visualize the process as non-value adding (NVA), necessary but non-value adding and value adding (Singh et al. 2011). Further, VSM is the most widely used tool with more practical use, indicating the success of the tool's application in various industries, manufacturing, construction, healthcare, and precast and off-site construction (Lasa et al. 2008; Forno et al. 2014). VSM is highly useful for workflow identification, improvement, and optimization (Ballard et al. 2003; Simonsson et al. 2012; Yu et al. 2013; Nahmens and Mullens 2011; Heravi and Firoozi 2017; Ahmad et al. 2019; Wang et al. 2020).

While VSM is a simple-to-use pen and paper-based tool, it is also a static tool as the process is depicted as a snapshot of a given production process. Computer simulation, on the other hand, by combining with VSM, helps to create dynamic value stream maps (Solding and Gullander 2009; Paju et al. 2010; Knoll et al. 2019). Goh and Goh (2019) worked on providing and evaluating recommendations to improve modular construction efficiency using VSM and DES. Further, simulation is also used to model the off-site construction process, integrating discrete-event simulation for lean improvements to increase the productivity of the assembly line (Afifi et al. 2022) at an autonomous production tracking to analyze real-time production (Arashpour et al. 2015) for economic comparison of the onsite and off-site fabrication practices of rebar (Polat et al. 2006; Gallardo et al. 2014; Bamana et al. (2019), and Jansson et al. (2016) for simulating an actual construction project to assess the impact of prefabrication and improvements to the design process, respectively.

While efforts to combine simulation with lean concepts were carried out (Nikakhtar et al. 2015; Polat et al. 2007; Bajjou and Chafi 2021; Farrar et al. 2004; Erikshammar et al. 2013), these are confined to activity level and developed as case studies, and pilot studies indicating potential benefits of lean simulation. Further, the researchers have focused on applying lean principles with simulation models in an off-site construction context (Heravi and Firoozi 2017) and also integrating VSM, simulation, and fuzzy logic (Noueihed 2022). Moreover, various software programs are available for building simulation models, including Simio, ProModel, Cyclone, Stroboscope, Arena, Anylogic, Simul8, ExtendSim, SimProcess, AutoMod, JaamSim, EZStrobe, Simscript, SimPy, NS-3. (Hazzar and Abourizk, 2002; Scheidegger et al., 2018).

Computer simulation needs more adoption, especially by the construction industry, both onsite and off-site (AbouRizk, 2010). However, lack of knowledge and skill in developing simulation models among construction practitioners, industry culture and low confidence in simulation models, complexity and high cost of simulation studies, limited multidisciplinary skills, and lack of research cooperation act as barriers to developing site activity level simulation models. Further, the barriers prevent the use of simulation techniques for the practice of lean at the activity level by the frontline engineers (Solding and Gullander, 2009; Leite et al. 2016; Abdelmegid et al. 2020). Therefore, there is a need to research the development and practice of lean-based simulation models as a template for use by the construction industry practitioners at the site and factory level, and research in the direction of lean simulation templates is rarely attempted (Du et al. 2023; Mostafa et al. 2016; Liu and Zhang 2023). Further, the developed simulation model templates can be integrated into the construction management curriculum by which future engineers are equipped with the knowledge of developing and using simulation in construction in the era of digital transformation of the construction industry (Abdelmegid et al. 2020). Therefore, in this study, a VSM-based DES model template is developed for a construction activity from a precast production factory.

3 VSM-BASED DES MODEL

In order to develop a VSM-based simulation model, an actual construction process from a precast production factory is selected. Concrete slabs are one of the most regularly used structural elements in building construction (Al-Shaarbaf et al. 2018). Unlike traditional buildings, using off-site and prefabricated construction increases health and safety, decreases resource waste, improves time management during construction, and improves life-cycle performance (Du et al. 2023). Further, off-site construction provides an avenue for applying lean manufacturing principles to reduce waste and add value to the customer (Pan and Sidwell 2011). A hollow core slab (HCS) casting is a cyclic process involving several interactive activities, resources, and idles for process improvement (Nikakhtar et al. 2015; Al-Sudairi 2007). Therefore, HCS casting, as an off-site construction element, is chosen for the experiment. A semi-automated factory of HCS is approached to observe the activity. The company details are kept confidential as per their request.

The overall methodology for the model development is depicted in Figure 1. The process used for model development is as follows. First, the activity needs to be observed. The factory layout, the resources used, the sequence of activities, and the time taken for each activity are observed during the site visits and by interacting with the engineers. The typical activities of HCS casting are (1) casting bed preparation, (2) prestressing, (3) concreting and curing, (4) cutting, and (5) transfer to the storage yard for stacking. Further, based on the observations, a probability distribution for uncertainty in the process is selected.

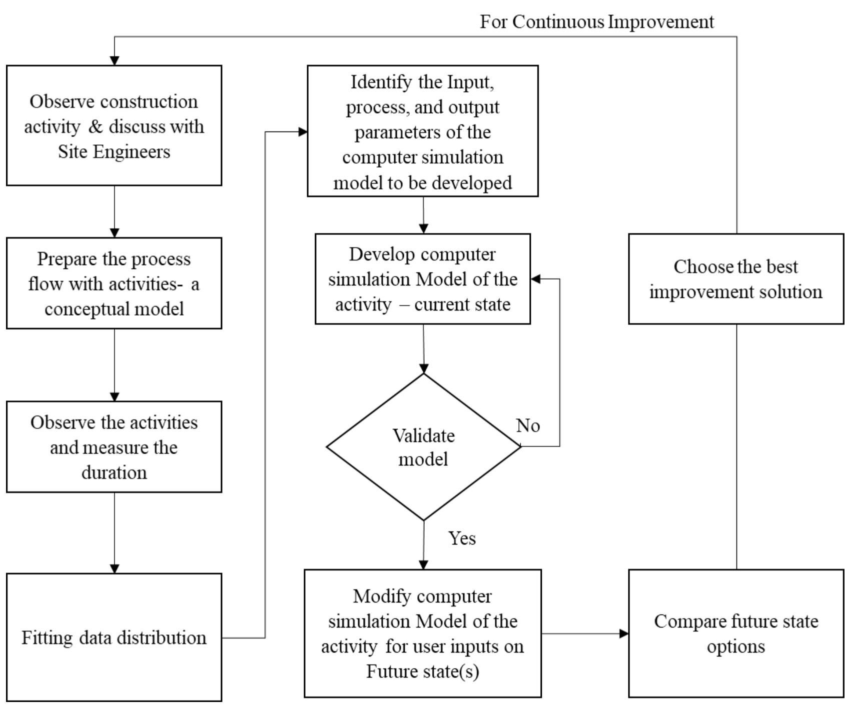

Figure 1: Steps of developing VSM DES simulation template.

The activity durations are indicated in Table 1, based on the activities observed using the work sampling technique (AbouRizk et al. 1992). The beta distribution is suitable for representing the lengths of construction work, according to AbouRizk and Halpin (1992). Further, a triangular distribution is used to approximate the beta distribution; however, this distribution needs three parameters to be defined: the lower or optimistic limit, the mode or most probable value, and the upper or pessimistic limit. Therefore, the triangular distribution is used to simulate the uncertainty in the durations of the HCS casting. Based on identified distributions for each activity, the input and output parameters will be defined as part of the conceptual model, and then the computer simulation model will be developed. To provide the choice of incorporating various simulation modeling types, such as agent-based modeling and system dynamics, as part of additional research on the same study, Anylogic is utilized for this study (Zankoul et al. 2015).

Table 1: Activity durations.

Activity	Duration (in seconds)		
	Pessimistic	Most likely	Optimistic
Preparation of Bed	6691	7096	7523
Pretension	2814	3127	3439
Concreting	23874	23874	23874
Cutting	9783	9783	9783
Stacking	9686	9945	10178

The developed computer simulation model is validated using the face validity method. The face validity technique is used for enquiring with the experts in the activity process regarding the reasonableness of the model's behavior and whether the logic of input-output relationships is correct (Sargent, 2010). The plant manager with ten years of experience in casting HCS has confirmed that the model reflects the current state of the process. Further, the completion time from the simulation runs is in alignment with their actual casting times. Therefore, the model has been considered for developing the improvement scenarios. The snapshot of the simulation model is presented in Figure 2, which shows the process of HCS, the resources utilized, and the use of a bar chart for understanding resource utilization.

Table 2: Activity-wise NVA durations.

Activity	Potential NVA durations (in seconds)
Preparation of bed	2000
Pretension	3000
Concreting	3500
Cutting	1000
Stacking	1500

The NVA durations identified from the site visits were presented to the plant team, as indicated in Table 2. The NVA durations were based on the observed cycle time data, resulting from time spent on shifting materials, waiting times, and equipment breakdowns. Further, Figure 3 indicates the creation of NVA reduction strategies as user inputs in the model beginning. This model acts as a template with the entire VSM process of HCS modeled and ready to use by the off-site construction team for viewing the future state of VSM instantly.

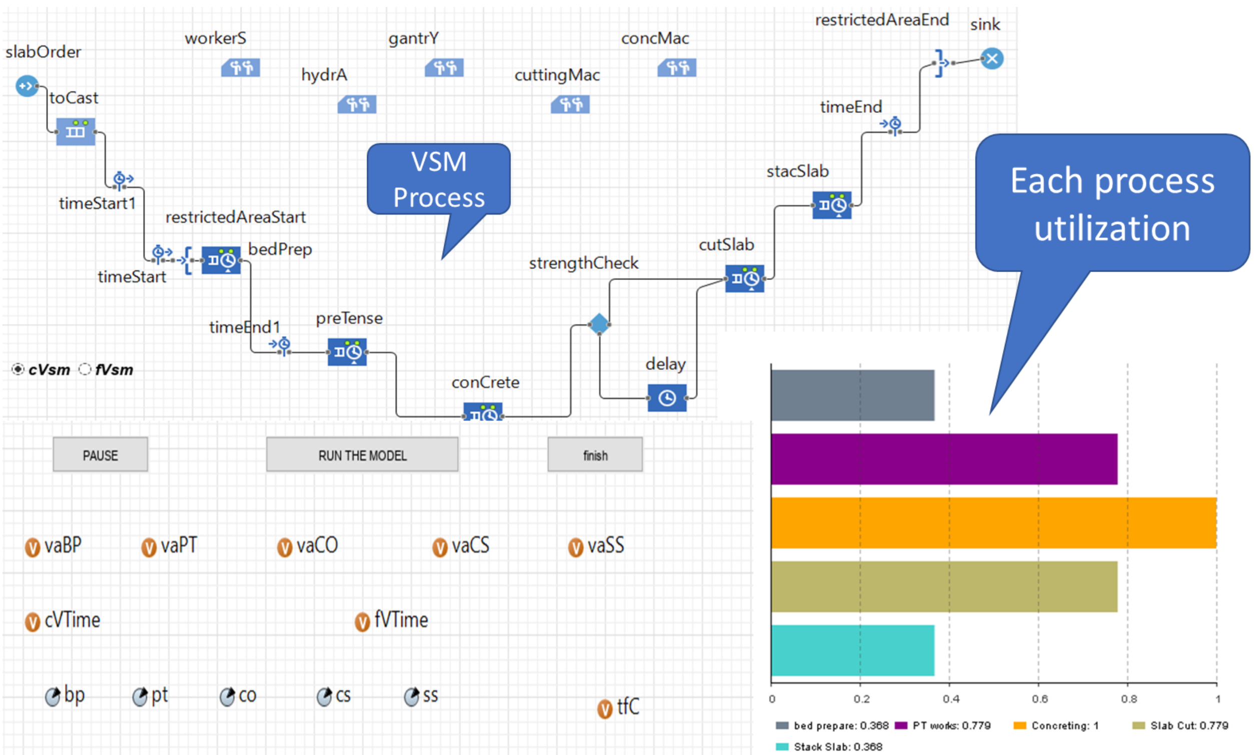

Figure 2: Simulation main window (while running the model).

4 RESULTS, DISCUSSION, AND CONCLUSIONS

The plant team consisting of the plant manager, equipment in charge, and floor in charge was asked to develop a potential reduction strategy for the overall process time reduction. The team has concluded that a possible 50% and 100% reduction strategy is required to understand the effect of reduction strategies like preventive maintenance and training the workers. However, the team has also stated that they need a 0% reduction, as, sometimes, no reduction would be possible despite their efforts. Accordingly, three strategies, namely scenario-1 0% reduction (this is the current state VSM), scenario-2 50% reduction, and scenario-3 100% reduction, are taken up for running the model for future state VSM.

Table 3: Results of the NVA reduction strategies.

NVA reduction strategy	Mean Completion Time (in Minutes)	Improvement From current state (in %)
Scenario- 1 Current state	1084.35	-
Scenario- 2 50% reduction	1000.15	7.77%
Scenario- 3 100% reduction	912.72	15.83%

Table 3 provides the results of the proposed NVA reduction strategies and the potential time-saving compared with the current state of operations. The improvement can be in the range of 7 to 15% depending on the efforts of the team to reduce NVA. Further, the presented model can be used to create more scenarios by varying the NVA reduction in specific activity and see how the results would differ. In this way, future state VSM can be generated instantaneously, and the user (precast industry) gets motivated to implement VSM based DES model as a decision support tool at the off-site construction factory.

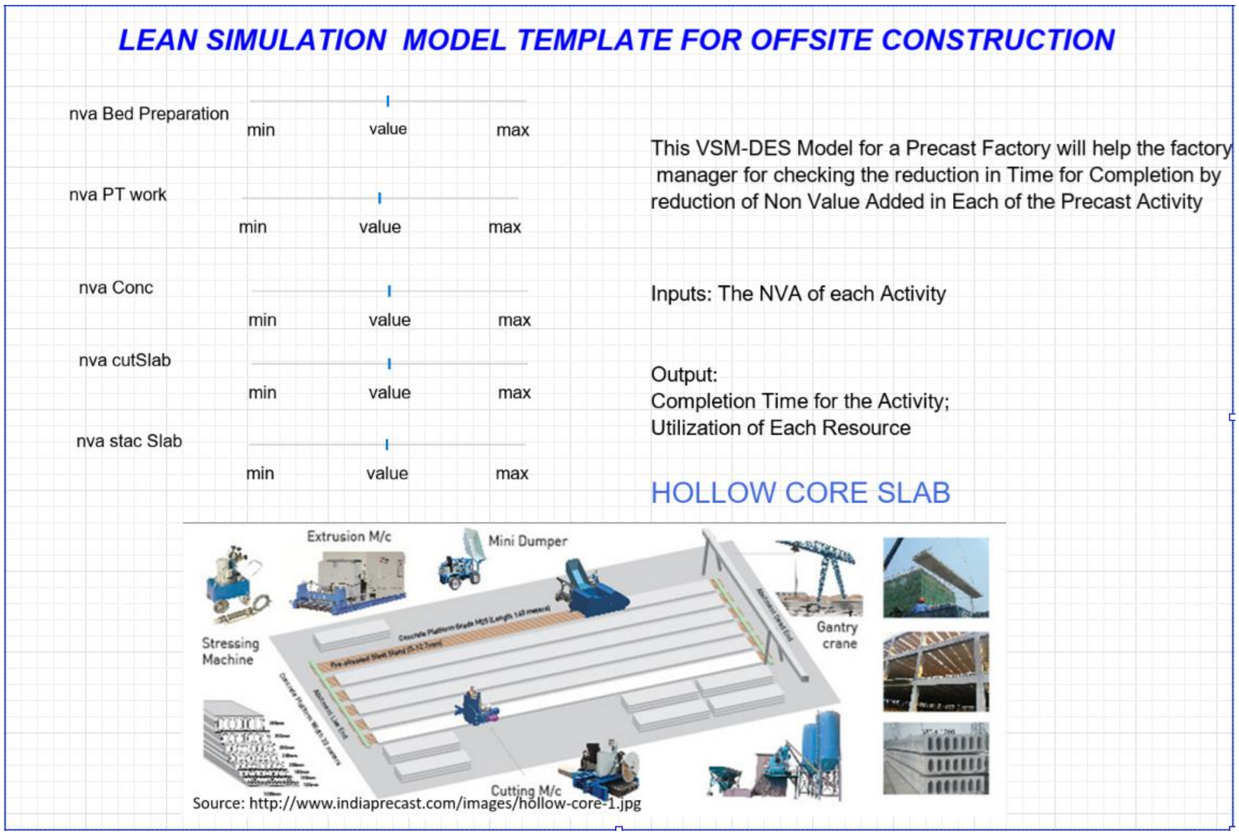

Figure 3: Simulation window seeking user input on NVA strategy at the start of the model.

This research presents a discrete event simulation (DES) based template for off-site building activities. The model offers a virtual testing environment so the user can choose whether to cut down on non-value-added (NVA) tasks to optimize the process. Further, the proposed model improves the efficiency of off-site construction and benefits the factory managers by reducing the waste from the process in their facilities.

Overall, the approach used in this study presents computer simulation model templates as a way forward for accelerating lean implementation at the construction site and off-site construction factory level for facilitating decision-making, considering the limited resources available for a given activity. Further, these model templates could be used for teaching lean at universities for educating construction management students to be ready to work in the era of digital transformation.

5 FUTURE WORK

The presented model is part of an ongoing study, and work is in the process of incorporating cost and environmental calculations for decision-making on the potential savings from the NVA reduction strategies. Further, the model reliability will be refined with more process cycle time data and different factories (automated and manual), and the resource constraints regarding labor shortage, holidays, and risk events also will be incorporated to make the model robust. Moreover, the process durations need to be enriched, with probability distributions based on a goodness-of-fit statistic, to develop the model into a reusable template for other off-site construction activities to accelerate lean implementation in the construction industry for improved efficiency. While the scenarios considered in this study were based on the inputs from the factory personnel, conducting sensitivity analysis would facilitate the interaction between the parameters.

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AUTHOR BIOGRAPHIES

PRASHANTH KUMAR SRERAM is a doctoral research scholar in the Department of Civil Engineering at the Indian Institute of Technology Bombay. His primary research interest is in the area of Computer Simulation, and Lean Construction. He also holds the position of an assistant professor in the School of Construction & Technology at the National Institute of Construction Management and Research, Hyderabad, India. He teaches construction contracts and procurement management. His email address is 194048001@iitb.ac.in, and his homepage is https://www.linkedin.com/in/prashanth-kumar-sreram-pmp%C2%AE-b52a49a1/

ALBERT THOMAS is an Assistant Professor at the Department of Civil Engineering at the Indian Institute of Technology Bombay, India. His research interests include Sustainable Construction, Building Energy Simulation, Life Cycle Analysis, Lean Construction, monte carlo methods, and stochastic optimization, specifically focusing on multi-objective simulation optimization. His email address is albert@iitb.ac.in, and his website is https://www.civil.iitb.ac.in/~albert/index.html.