Proceedings of the 2022 Winter Simulation Conference
B. Feng, G. Pedrielli, Y. Peng, S. Shashaani, E. Song, C.G. Corlu, L.H. Lee, E.P. Chew, T. Roeder, and P. Lendermann, eds.

REAL-TIME DISCRETE EVENT SIMULATION OF PRODUCTION PROCESSES FOR DATA-BASED CONSTRUCTION MANAGEMENT

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ABSTRACT

The construction industry is characterized by a low level of digitalization and productivity. As construction works are dynamic, unique, and executed outdoors, the management of these processes is complex. Due to advancements in technology, real-time data can be collected during construction execution. These real-time data can be analyzed by machine learning to determine reliable activity durations. Based on the durations, stochastic probability modeling is used to find suitable probability density functions as input parameters for data-driven discrete event simulation. A calibrated discrete event simulation tool is developed for real-time, data-based management of ongoing production processes. The tool estimates the effects of management decisions on key performance indicators and the inclusion of lean construction principles is possible. Additionally, risks, such as weather conditions, can be included in the tool. Hence, it is shown how real-time discrete event simulation enables data-driven decision-making for improved construction management.

1 INTRODUCTION

The construction field is one of the least digitalized sectors with flat or even falling productivity rates, although it is one of the most relevant industries (Patteri and Stolton 2019). As construction works are dynamic, unique, and executed outdoors, the management of these processes is complex. Deviations from the initial schedule occur regularly during construction execution. These deviations are stated delayed by human observation in current practice. Additionally, control actions are performed too late to react appropriately to avoid adverse impacts (Sacks et al. 2020).

Modeling and simulation is deemed an effective method for scheduling construction works as different execution options and their impacts on key performance indicators can be compared in a virtual environment (Leite et al. 2016). Discrete event simulation (DES) is especially suitable for simulating complex construction operations as the focus is on processes and dynamics can be considered by stochastics (Martinez 2010). There are three main causes for not frequently using DES: formalisms are needed (Abbasi et al. 2020), DES is cumbersome to model (Rashid and Louis 2022), and especially reliable input parameters are required (Akhavian and Behzadan 2018). Therefore, research on real-time data collection and processing, DES modeling and simulation, and their links are required (Alvanchi et al. 2021).

In recent years, there have been advancements in the areas of automation and technology. The Internet of Things (IoT) enables the connection and exchange of data between physical devices, such as sensors, and a network via the internet in real-time. The thesis deals with the usage of real-time data for improved construction management by DES according to the digital twin construction paradigm. The digital twin construction paradigm is a mode for holistic management of ongoing construction processes through real-time data considering lean construction principles (Sacks et al. 2020).

The thesis starts with the process of collecting data during construction execution. During concrete pouring operations, sensors were mounted on a crane hook and kinematic data were collected in real time. The data were sent to an IoT platform. Subsequently, ML classifiers are applied to the data for activity recognition. Different algorithms are used to determine classes and to extract the durations of the operations. Within the analysis of the data, experiments are conducted to investigate the effects on the classifiers' performance. The main contributions are the real-time action duration extractions of different executions.

Next, based on the extracted durations, stochastic probability modeling is used to determine suitable probability density functions (PDFs) as input parameters for action durations in a DES. Maximum likelihood estimation is applied to the action durations to identify parameters of different possible distributions. Subsequently, different Goodness-of-Fit statistics are calculated to determine suitable PDFs. The changes of PDFs according to an increasing amount of collected data and their impacts on a DES model are investigated. Finally, the DES model is calibrated to ensure the reliability of the model and to emphasize the need for the use of real-time data. The contributions are the real-time PDF determinations, the investigation of changing PDFs and their impacts on the DES, and the DES model calibration.

For improved construction management, a real-time DES tool is developed. A discrete event simulation system specification (DEVS) formalism is created for a determined work process pattern. Within this formalism, risks such as weather conditions or delivery durations are considered. Derived from the formalism, the DES tool is modeled. The tool can be used to manage ongoing construction works efficiently in consideration of lean construction principles, such as just-in-time delivery. Within the tool, different possible construction options and their impacts on productivity, resource efficiency, and safety-related key performance indicators (KPIs) can be compared. The data-based PDFs are used as input parameters.

The thesis addresses the shortcoming of reliable input parameters by enabling meaningful construction management based on real-time data. Data are collected during construction execution. These data are analyzed by artificial intelligence to gain information about activity durations. The determined activity durations are used for stochastic modeling. Thus, reliable input parameters are defined for a DES model based on current production processes on site. The formalism for a DES is created for explaining the model's semantics and a validated DES tool is developed for simplified application, modification, and reuse during execution. Therefore, the thesis emphasizes the need for and promotes technology usage for real-time, data-based construction management. An efficient and effective approach for improved and more reliable construction management of ongoing production processes based on real-time data is developed.

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