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Schedule risk analysis of infrastructure projects: A hybrid dynamic approach

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ABSTRACT

Schedule risk is a major concern in infrastructure project management. Existing studies have proposed several models for schedule risk analysis, but few efforts have been made on the dynamics and uncertainty of risks and the generality and practicability of the model. To fill the research gaps, this study develops a hybrid dynamic approach for investigating the effect of risks on infrastructure project schedule performance. This approach combines system dynamics (SD) and discrete event simulation (DES) which have mainly been used to analyze the macroscopic and microcosmic construction issues in isolation, respectively. The model is then verified by data which is collected from a bridge construction project. As an application example, the effect of four selected risks on the schedule was explored. The results show that the proposed SD-DES model could be ease of modifying the model to reflect real situation, performing various sensitivity and uncertainty analysis, and showing simulation results more effectively.

1. Introduction

Infrastructure projects, characterized as being large-scale, long duration and high investment [1], are well known for the provision of fundamental facilities for daily living and public transportation [2]. However, different types of risks occur in different stages of infrastructure projects, and these risks may influence schedule, quality, cost, environment, and safety, thereby causing substantial losses or heavy casualties [3]. Therefore, managing the risks in infrastructure project effectively has been an essential part of project management for decades [4].

The schedule is a major concern in infrastructure project management and is always affected by various uncertainties, such as weather, productivity, soil properties, material delivery time, and equipment efficiency [5]. Schedule overrun in infrastructure projects is a global phenomenon and a recurring problem worldwide [6,7]. In Australia, only 1/8 of projects are delivered on time with the average delay time of 40% [8]. In Malaysia, nearly 20% of government contract projects exceed the original schedule [9]. In Saudi Arabia, around 70% of construction projects fail to be completed within the planned schedule [10]. These statistics are common all around the world. Schedule delay can affect not only the infrastructure project itself but also the economy of countries, especially in developing countries where a substantial proportion of economic growth is dependent mainly on the construction industry [11].

Schedule can be affected by numerous risks directly or indirectly [12]. Therefore, construction managers, even experienced ones, can have difficulty anticipating all unforeseen and uncertain events [13]. If schedule risks cannot be identified, then they cannot be effectively managed. Therefore, schedule risk identification is the first step that must be performed prior to risk analysis and risk response. Risk identification has been conducted using questionnaires, interviews, case studies, and long-term follow-up surveys. Table 1 shows all schedule risks identified in infrastructure projects.

According to ISO 31000 (2018), risk identification is the process of finding, recognizing and describing risks, risk analysis is the process to comprehend the nature of risk and to determine the level of risk, and risk assessment is the process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude is acceptable or tolerable. Therefore, risk analysis and risk assessment are analytical works for risk factors and are based on risk identification. Conducting risk analysis and risk assessment is difficult especially with a large number of uncertainties [22]. Many methods for schedule risk analysis have been developed. One of the most important methods is the critical path method (CPM); CPM-based methods for schedule risk analysis have been proposed [12], such as the program evaluation and

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Table 1
Schedule risks in infrastructure projects.

Stakeholder	Schedule risk	References
Client	Clients' variation order, clients' slow decision making, clients' cash flow problem, clients' late contract award, clients' poor management, pressure due to tight project schedule, over high quality requirements	Aibinu and Odeyinka [14]; Assaf and Al-Hejji [10]; El-Sayegh and Mansour [15]; Sun et al. [16]; Zou et al. [3]
Designer	Design variations, incomplete drawing, deficiency in design, inaccurate site investigation information, design drawings are hard to follow	Sarvari et al. [17]; Yuan et al. [18]; Zou et al. [3]; Shen [19]
Contractor	Contractors' financial difficulties, contractors' planning and scheduling problems, contractors' inadequate site inspection, shortage of manpower, material shortages, unforeseen material damages, equipment breakdown and maintenance problem, equipment shortage, equipment delivery problems, lack of skillful labor, lack of safety insurance, failure in applying new technologies, safety accidents, quality problems	Aibinu and Odeyinka [14]; Choudhry et al. [4]; Zou et al. [3]
Subcontractor	Slow mobilization, interference with other trades, financial difficulties, delay in the material provision due to subcontractors' fault	Aibinu and Odeyinka [14]; Ke et al. [20]; Zou et al. [3]
Government	Bureaucracy of the authority, inappropriate interruptions by the authority, complex official approval procedure, unstable government policies	Sarvari et al. [17]; Zou et al. [3]
External environment	Inflation, unsuitable weather conditions, changes in rates of exchange, increase in oil price, contagious diseases	Sarvari et al. [17]; Yoon et al. [21]; Zou et al. [3]

review technique and the probabilistic network evaluation technique. Program evaluation and review technique takes the uncertainty of duration into account, using optimistic duration, pessimistic duration, and most likely duration to describe the duration of the task [23]. Probabilistic network evaluation technique uses mean durations and the correlations among the network paths to generate a set of representative paths from which the probability distribution of duration is attained [24]. Although these methods have made substantial progress, they do not consider the interaction among schedule risks and feedbacks and non-linear relations. Kim et al. [25] considered the relationship among risk factors and applied the Bayesian belief network in quantifying the probability of construction project delays in developing country. Rezaie et al. [26] examined the relationships among uncertainties using an extended Monte Carlo simulation. More recently, system analysis has received increasing attention from researchers. Alvanchi et al. [27] analyzed the plan of assembly construction by discrete event simulation (DES) and evaluated different manufacturing processes of an assembly-type bridge. Li et al. [28] developed a social network analysis model for schedule risk analysis in prefabrication housing production. Han et al. [8] used system dynamics (SD) to develop an assessment method for analyzing the influence of construction project design error. Using this method, they aimed to provide project managers with a better understanding of the effect of design error on schedule. Wang and Yuan [1] also used SD in investigating the risk effects on schedule delay in infrastructure projects. With regard to simulation-based scheduling, Wang et al. [29] integrated building information models with construction process simulations for the generation of a project schedule. Similarly, Liu et al. [30] developed a building information modeling-based scheduling simulation approach to optimize activity-level building construction schedules under resource constraints. Chen et al. [31] proposed an intelligent scheduling system to optimize schedules. This system also integrated cost, manpower, space, equipment and material. Kerkhove and Vanhoucke [32] improved the accuracy of the project schedule simulation by creating a model including both uncertainty and weather conditions. Tang et al. [33] developed an interactive schedule simulation platform to assess and improve alternative decision strategies. The preceding methods for schedule risk analysis enrich the tools for better understanding schedule risk, but they still show some limitations. First, the dynamic changes throughout the construction period have been rarely considered. Second, system theory and methods for schedule risk analysis have been used, but most of the previous studies were conducted only from the macro level or micro level rather than both levels, thereby limiting a comprehensive understanding of schedule risk. In addition, system methods did not integrate well with uncertainty analysis.

To fill this research gap, this study aims to propose a hybrid dynamic model for better schedule risk analysis in infrastructure projects with the aid of system dynamics and discrete event simulation. In the hybrid dynamic model, SD carefully deals with the complex problems of infrastructure project schedule from the perspective of a system, while DES models a system to reveal the micro-level dynamic behavior. SD model will be encapsulated into a discrete event of the DES model to constitute a "task module" so that an activity on node network for other infrastructure projects can be built with the predefined "task module". Compared with traditional schedule risk analysis techniques, this model simultaneously considers micro and macro levels, enabling not only researcher but also project manager to acquire a multidimensional understanding of schedule risks and gain a deeper insight into schedule management. The specific objectives of this study are following: (1) to develop a hybrid dynamics model for analyzing schedule risks of infrastructure project; (2) to validate the proposed hybrid dynamics model for building up confidence prior to simulation analysis; (3) to tentatively explore the impact of single and multiple risks on schedule.

The remainder of this paper is structured into five sections. Pursuant to this introductory section is a detailed description of the research methods. System dynamics and discrete event simulation are utilized to explore the influence of risks on the construction schedule. Interviews site visits were conducted to collect data for model simulation and validation. Section 3 details the process of SD-DES model development. A system dynamics model is encapsulated into a discrete event for constructing a task module, and all the task module are connected according to an activity on node network. Section 4 conducts a case study to test, validate and apply the hybrid model. Conclusion and future research are given in Section 5.

2. Research methods

Construction project management comprises strategic project management and operational project management [34,35]. Strategic project management is centered on system design and provides a basis for determining major targets [36]. Therefore, it is the management actions that are incorporated into a project in order to meet a strategic objective of a project by adjusting time, cost, resources and target [34,37]. In contrast, operational project management is concerned mainly with the steps required to achieve the project objectives, such as the predecessor and successor relationships of network activities and detailed information for execution [38]. Thus, it can be said that strategic project management is macro-level management actions and operational project management is micro-level management actions [35].

SD was introduced by Forrester [39] in the 1960s. This field of science focuses on the structure of complex systems and the relation between function and dynamic behavior based on feedback control theory and computer simulation technology [40]. SD model could solve the problem of causation or simultaneity by updating all variables in