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Simulation model incorporating genetic algorithms for optimal temporary hoist planning in high-rise building construction

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ABSTRACT

Temporary hoist planning is a key factor for successful project completion in a high-rise building construction. Inadequate plans for hoists in the early stages of a project can cause problems such as failing to hoist resources as required or leaving hoists idle. There are two existing approaches, simple formulas and simulation techniques, for planning temporary hoists. However, simple formulas cannot treat hoist arrangements consisting of different kinds of hoists, while the simulation technique is both time-consuming and tedious when there are many alternatives. In this study, a discrete-event simulation model incorporating genetic algorithms is proposed to support hoist planners while preparing optimal plans with minimal time and effort for high-rise building construction. To verify the applicability of the proposed model, it was applied to a real project and gave better results than a previous approach to temporary hoist planning.

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1. Introduction

Over the past decade, the number of high-rise buildings constructed and their heights have increased. The report of the Council on Tall Buildings and Urban Habitat (CTBUH) by Oldfield and Wood [1] shows that the average height of the ten tallest buildings completed each year in the world has been increasing each decade: from about 150 m in 1960 to about 420 m in 2009. Developments in materials technology and structural engineering, and the necessity for efficient space utilization caused by increasing land prices and the problem of overpopulation in urban areas will maintain this trend until at least 2020.

In high-rise building construction, adequate planning of temporary hoists is a key factor for successful project completion. Hoists, together with cranes, are essential equipment for vertical transportation of construction resources, such as manpower and materials [2]. Too few hoists can cause productivity losses by failing to hoist resources in a timely fashion. On the other hand, too many hoists can incur unnecessary costs when hoists are idle. Higher buildings require more resources and have longer transportation distances. Thus, high-rise building construction has the disadvantage of longer lifting times for workers and materials compared with shorter cycle times in low-story construction. Thus, in high-rise building construction, creating adequate plans for temporary hoists is becoming a more difficult task. Planning for temporary hoists usually depends on heuristic methods, i.e., simple formulas modified by the subjective opinions of experienced practitioners. However, this heuristic method carries the risk of making inappropriate decisions that potentially cause problems such as cost increases and delays.

The simulation technique, especially discrete-event simulation (DES), provides a promising alternative solution to construction system following the criterion of a computer model of the real system based on real life statistics and operations [3]. Ever since the inception of CYCLONE technology [4], simulation models for typical construction systems have been delivered as electronic realistic prototypes for engineers to experiment on, which eventually will lead to productive, efficient, and economical field operations [3]. For the last decade, simulation techniques also have been used to assist in hoist planning handling repetitive activities in a simple way [2,5,6]. Hoist planning is substantially the evaluation of various alternatives to find the best solution. Thus, a planner using simulation has the advantage of saving both construction time and cost by evaluating various scenarios [7]. Despite this advantage, if there are many alternatives, the planner must search for an optimal solution heuristically, by trial and error, which is time-consuming and tedious. Thus, using simulation has problems that make the application of classical optimization methods difficult, or even impossible if possible alternatives increase explosively [8]. Therefore, traditional simulation is not considered as an optimization technique [9].

To alleviate this problem, genetic algorithms (GAs), which are artificial intelligence techniques inspired by the theory of evolution and biogenesis, could be part of the solution. Many hybrid mechanisms that integrate simulation techniques with GAs have been widely applied to different disciplines of research and proved efficient in finding the optimal solution [10]. GAs is relatively more adaptable to the temporary

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hoist planning, whose alternative is a combination of temporary hoists, because it does not operate directly on the variables (phenotype); similar to biology there is an encoded representation (genotype), that allows easy recombination of candidate alternatives [11]. Moreover, one of the most attractive advantages of using GAs as design tools is their ability to find solutions to problems in a way completely free of preconceptions about what is possible and what is not [12]. This is something that human planners find very difficult. Therefore, the purpose of this paper is to propose a simulation model incorporating GAs for supporting hoist planners to create an optimal plan with minimal time and effort for high-rise building construction. This model uses a discrete-event simulation to verify various scenarios for vertical transportation in advance. The GAs assist the planner to search for an optimal solution efficiently in the enormous solution space. In ever-higher building construction environments, the proposed model assists planners to make efficient planning of the temporary hoists at an early stage.

2. Existing hoist planning method

At most general construction companies, planners have in practice used simplistic formulas for planning the number and types of temporary hoists, such as those shown in Table 1. This method is easy to use, and provides intuitive understanding about the decision process. However, it has the limitation for systematic hoist planning that the various alternatives, which consist of different kinds of hoists, are not carefully considered because only a simplistic formula is used. In addition, the calculated transportation frequency per unit area is not guaranteed to be correct for a new project because it is based on historical data from similar projects. Therefore, a significant amount of decision-making in planning for temporary hoists depends on the intuition and rule of thumb experience of the planner. Consequently, this heuristic method carries the risks described previously.

There have been some efforts to apply simulation techniques to temporary hoist planning, because simulation is one of the most useful modeling tools for the design of many types of system. In 1996, Ioannou and Martinez [5] demonstrated the application of DES to vertical transportation modeling. The research presented the mechanisms for preprocessor replacement and automatic code generation that had been designed and implemented to facilitate the STROBOSCOPE (State and ResOurce-Based Simulation of Construction ProcEsses) tool. Although the DES model was only used to solve an elevator problem, the research also showed the potential of DES for temporary hoist planning. In 2004, Ahn [6] presented a process for vertical movement planning for workers using DES. The DES model, which was constructed based on Arena V4.0, helped the planner to find the optimal scenario according to various conditions, such as boarding time, leaving time, and operational efficiency of hoists. Although there was no provision for materials in the application of the model, this was the first research to describe the hoisting process using DES in high-rise building construction. In 2009, Hwang [2] proposed a method for planning temporary hoists for high-rise building construction. The research presented the results of a survey of existing practices, the proposed new approach, and a plan for validation of the proposed approach. This approach showed a framework for applying simulation techniques to the decision-making process for planning hoists.

From the previous research, the advantages of the application of simulation to hoist planning are as follows. First, a simulation allows more actual work process in the model than the simple formula does. Second, the simulation helps the planner to make decisions efficiently and reliably because of its own systematic process. Lastly, the simulation supports interaction between the model and the user in the decision-making process through easy parameter input and modification.

However, these studies have demonstrated not only the superiority of the simulation but also the problems associated with using it for temporary hoist planning. That is, the planner uses a generic simulation model to answer many "what-if" questions by analyzing what happens to the model's behavior when an alternative is changed. Thus, use of a simulation requires some trial and error. Much time and effort must be spent to test many scenarios to search for the best solution [10,13].

Table 1
Example of existing hoist planning using simple formulas.

Phase description	Formula	Remarks
Transportation frequency (Ft)	$a \times b$	a: Transportation frequency per unit area based on historical data of similar project b: Gross areas of actual project
Transportation frequency per day (Fd)	Ft/n	n: Total construction duration, days
Average height of transportation (Ha)	$H \times (1+c)$	H: Height of building c: Charged rate for handicap
Cycle time of transportation (Tc)	$T1+T2+T3+T4$	$T1$: Time of loading $T2$: Time of dumping $T3$ $(=Ha/V)$: Time for lifting up $T4$ $(=Ha/V)$: Time for lifting down V: Speed of hoist
Available transportation frequency per day (Ta)	$(Tw/Tc) \times d$	Tw: Available work time per day d: Operation ratio of temporary hoist
The adequate number of t emporary hoists	Fd/Ta	

3. DES model incorporating genetic algorithms for optimal temporary hoist planning

The kinds of temporary hoist and their performance are quite varied because of the advances in technology and the increase in high-rise building construction. In this environment, planning the optimal temporary hoists based on intuition and experience is becoming more difficult. For instance, to select a temporary hoist from a group having three speed ranges, i.e., low, middle, and high, and three sizes, i.e., small, medium, and large, there will be nine possible temporary hoists. If six temporary hoists are required on a site, the number of possible alternatives will increase exponentially to be nine to the power of six, i.e., 531,441. In actual practice, according to conditions such as installation type, weight capacity, top speed and rental cost, the available kinds of temporary hoist are even greater than this example. Therefore, a search for an optimal solution is time-consuming and tedious work for the planner to simulate the large number of scenarios.

One of the promising methods of optimizing problems where performance can be evaluated by a simulation model is the use of GAs [14]. Parmar et al. [15] proposed a scheme using simulation and GAs to increase farm profit through machinery selection. Azadivar and Wang [14] built a simulation model to serve as a system performance evaluation tool while GAs were used to optimize a manufacturing layout. Some efforts have also been made on optimizing simulations using GAs in the construction domains, such as concrete placement [16], earthmoving [16,17], sewer pipeline installation [10,13,18], and precast concrete production [13]. We examine the applicability of GAs for optimizing alternatives, as evaluated by a DES model, for temporary hoist planning in high-rise building construction. The DES model and GAs incorporated in this study were implemented in Microsoft C# and SQL Server 2005.

3.1. The architecture of the model

The schematic process for temporary hoist planning proposed in this study is illustrated in Fig. 1. This process begins with the preparation of input data about project conditions, which are required

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