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Construction worker hoisting simulation for sky-lobby lifting system

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A B S T R A C T

Effectively transporting construction workers to their workspaces located at height is crucial in high-rise building constructions because excessive hoisting time can lead to productivity loss and schedule delay. High-rise building constructions are characterized by a small number of hoisting equipment and a large amount of construction resources to be hoisted. Accordingly, a sky lobby system has been applied in high-rise building construction sites to increase the performance of lift systems. However, the performance of sky lobby systems can be significantly changed according to the configuration factors, such as the number of shuttle and local lift cars and the sky lobby floor location. Nevertheless, previous studies did not yet focus on the relationship between these factors and the performance of sky lobby systems. Therefore, we examined herein that relationship by using a discrete event simulation method. Through the simulation experiment, we found that the configuration parameters could have a significant influence on the system performance. The configuration parameters showed non-linear and complex patterns in the lifting performance, thereby making it difficult to find an effective configuration method to increase the performance of lift systems and even deteriorating the performance of lift systems in the commonly used range of configuration parameters. Therefore, the configuration parameters of the sky lobby system should be more carefully planned with quantitative methods before being applied to high-rise building constructions.

1. Introduction

Supplying the right quantity of construction resources at the right time to workspaces located at heights is crucial in building construction projects [1]. Transporting construction workers, one of the most important resources for construction, to their workspaces particularly has a possibility to affect the construction schedule [2]. The hoisting time of workers is included in the working hours. Hence, construction workers, who spend much time on moving, obtain less working time, which can negatively affect the construction productivity [2]. Furthermore, the construction lift cars used for hoisting workers are also used for hoisting other types of construction resources, such as construction materials and equipment, during the working time. Therefore, excessive time allocation for hoisting workers can interrupt other types of resources to secure the availability of lift chairs. Consequently, construction tasks can be delayed in the form of material shortage. The daily manpower in high-rise building constructions is relatively larger than that in other types of constructions. Meanwhile, increasing the number of construction lift is limited because of the insufficiency of equipment installation space and the additional installation cost. Accordingly, the construction schedule in high-rise building constructions tends to be easily affected by the hoisting of workers.

Many previous studies were conducted to improve the performance of lift systems in a manner of controlling the range of service floors of lift cars. One of the most well-known types of lift systems is the sky lobby system [3]. This system comprises shuttle lift cars that travel between lobby floors and local lift cars that serve the floors in a local zone. This system in high-rise buildings poses a bigger possibility to shorten the cycle time of lift cars compared to other lift systems (e.g., zoning lift system) [3,4]. In addition, this system is possible to efficiently utilize a space for installation of lift cars because two or more lift cars that serve in different local zones are able to share one hoistway [5]. This system is increasingly being applied to high-rise buildings because of such advantages [6].

Previous studies on the lift system agreed with the effectiveness of the sky lobby system [3,4,6]. However, some configuration factors of a sky lobby system (e.g., service range of lift cars, sky lobby floor location, and number of local and shuttle lift cars), have a possibility to influence the travel paths of individual workers inside buildings. The performance of the sky lobby systems can be changed according to these configuration factors. However, little information is known with regard to how and the extent to which these configuration factors influence the

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performance. In addition, how a lift system has to be configured to obtain more effective performance in building construction is not yet provided.

Therefore, we aim to examine the relationship between the performance and the configuration of components (e.g., lift cars and lobby floors) of sky lobby systems in hoisting construction workers. First, previous literatures are reviewed to understand the components of the sky lobby systems and identify significant parameters regarding the configuration of lift system components that influences the performance of lift systems. Second, a simulation model is developed using a discrete event simulation (DES) method to evaluate the performance of various alternatives of lift system configurations. Third, a simulation experiment is conducted based on data from a real high-rise building construction project in order to validate a simulation model and examine the relationships between the performance and configuration parameters of sky lobby systems.

2. Preliminary study

2.1. Sky lobby systems in high-rise building constructions

The lift systems of building constructions have distinct characteristics from the elevator systems after construction. First, the lift demands in building elevator systems are unpredictable before operation, and, hence, are assumed to stochastically occur with the specified distributions. On the contrary, those in the lift systems during construction can be estimated from construction data, such as daily schedule, quantity of works, and work productivity. Second, passengers, who make lift demands in lift systems of building constructions are construction workers, who can be controlled by construction managers. Therefore, controlling the lift traffic on the workers (e.g., order for passengers to board lift cars) is possible. Among the various types of building constructions, the lift systems of high-rise building constructions tend to suffer from a large amount of lift demands. The construction activities are simultaneously conducted because of a tight construction duration. Therefore, a daily lift demand becomes significantly large compared to that in other types of building construction projects. In addition, the large height of high-rise buildings requires more time for lift cars even when transporting the same number of passengers. Thus, high-rise building constructions are more likely that an excessive hoisting time is required and productivity loss and schedule delay are caused.

The low performance of lift systems in a high-rise building is caused by the increase in stop floors and lifting distance during a round trip of lift cars [6]. For example, the time loss caused by loading and unloading passengers increase as the number of stop floor increases. In addition, the lifting time and chance to be stopped also increase as the lifting distance increases. Therefore, controlling those factors to increase the performance of lift systems is important. One of the most significant methods of controlling those factors is to restrict the range of service floors of individual lift cars, and a zoning system is one of the representative examples for this. The floors of buildings in a zoning system (Fig. 1A) are grouped into two or more local zones. Moreover, lift cars serve the main lobby floor and one local zone to which the lift car is assigned [6]. The passengers in the main lobby can possibly arrive at their destination floors by taking the lift cars whose zones include their destination floors. The service range of lift cars is restricted by zones. Hence, the number of stop floors and lifting distance can be effectively reduced in this type of lift systems. However, previous literature on lift systems [4,6,7] discussed that the performance of this lift system can significantly decrease in high-rise buildings with more than 40–60 stories. As an alternative of zoning systems, a sky lobby system is used for high-rise buildings [8].

The sky lobby system is composed of local lift cars, which only serve floors within a local zone, and shuttle lift cars, which connect zones to each other through the sky lobby (Fig. 1B). The passengers, whose destination floors are not served by the local lift cars of the lower zone, have

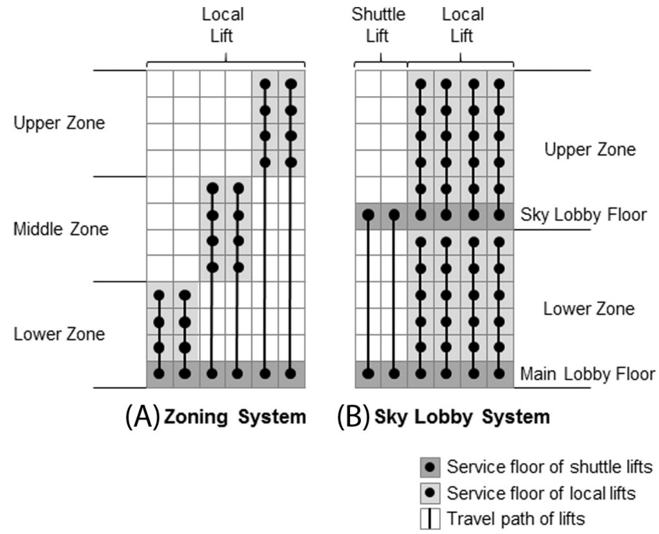

Fig. 1. Zoning (A) and sky lobby (B) lift systems.

to use the shuttle lift cars when starting travels on the main lobby floor to reach the upper zone that includes their destination floor. Accordingly, the passengers are required to transfer lift cars on the sky lobby floors. The cycle time of the lift cars in this type of lift system can be shorter than that in the zoning lift systems because the local lift cars in an upper zone do not have to move to the main lobby floor and can reduce the lifting distance. Moreover, the number of stop floors, which also has a negative effect on the cycle time, decreases as the service floor of lift cars is reduced. On the contrary, previous studies pointed out that the traveling time of passengers has a possibility to increase even though this system can reduce the cycle time of lift cars because transferring lift cars on the sky lobby floor takes additional time [6]. The waiting time for transferring lift cars can be affected by various factors with regard to the configuration of the system components. Thus, examining what type of and to what extent configuration factors can affect the performance of sky lobby systems in high-rise building constructions is essential.

2.2. Performance measures of lift system and configuration parameters

Defining the performance measures of lift systems first is essential in examining the relationship between the performance and the influence factors of the sky lobby system. Traditionally, three performance measures (i.e., round trip time (*RTT*), handling capacity (*HC*), and interval (*Int*)) are used to evaluate the performance of lift systems [6]. *RTT* is the average time required for a single lift car to perform lifting operations and return to the main lobby floor. *HC* represents the average number of passengers that can be transported in 5 min. *Int* is defined as the average time between elevator departures. The equations for these performance measures were defined by Barney [6] as follows:

$$RTT = 2Ht_v + (S+1)t_s + 2Pt_p, \quad (1)$$

$$HC = 300C \cdot RTT^{-1}, \quad (2)$$

$$Int = RTT \cdot L^{-1}, \quad (3)$$

where H is the average of the highest floors at which the lift car arrives; S and P are the average number of stop floors and passengers, respectively; t_v and t_p are the average time to move between two adjacent floors and for a single passenger to enter or leave a car, respectively; t_s is a composite time concerning each stop of lift cars; C is the average number of passengers per trip; and L is the number of lift cars in the same group. These performance measures provide useful insights for

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