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Optimization of lifting time with the help of a linear mathematical model in high-rise construction projects by considering non-demand fines

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ABSTRACT: Timely delivery of materials and equipment to the floors of a high-rise construction project is one of the main challenges for project managers. To solve this challenge, tools such as lifts and cranes are used to transport materials vertically. The way the lift moves between the floors of the building directly affects the completion time of the project. Therefore, providing an optimal schedule for vertical transportation in a high-rise project can lead to saving time and prevent delays in the project. In this paper, a mathematical model with the priority of activity in the day shift and also meeting the maximum amount of demand in two consecutive shifts, to minimize the time of lifting activity is presented. The proposed model tries to meet the demand of the floors as much as possible, and if the demand is so high that it is not possible to meet the demand during two consecutive shifts, considering the fine, it gives the best way to move the lift. Finally, the proposed method is validated on a real data sample related to a high-rise project. The proposed model, in addition to examining the actual sample compared to the models introduced in similar studies, provides an optimal material handling schedule for each work shift.

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1- Introduction

The construction process of high-rise buildings has increased significantly in recent years. However, there are still many problems in planning construction operations. Among the many problems related to high-rise construction, the management of vertical transportation of labor and materials can play an important role in addressing the issue of improving the productivity of construction and reducing the length of project periods, which has been of considerable importance.

With the increase of high-rise constructions and the variety of materials, the movement of required materials in the place of demand has become more complex [1].

In addition, delivering material in high-rise projects gets more complex as vertical distance increases [2]. Many researchers have studied the problems raised by vertical transportation systems in high-rise projects in recent years. e.g.[3-6]. However, few studies have specifically provided an optimal schedule for lifting activity. In high-rise construction projects, to transport labor and materials, lifts and cranes are used. Cranes are commonly used to carry heavy materials but the lift is used to move labor and relatively light materials. Determining optimal scheduling for lift activity is often a complex optimization problem. Another point in choosing the correct tool for the vertical transportation of materials is its availability. Crane access is limited in vertical transport in high-rise buildings, while lifts are more practical tool than cranes. The most critical question for a high-rise construction manager is how to develop a plan for timely supply of materials that meets the demand for floors while also minimizing the time of lifting activity. A more realistic approach to the problem of scheduling lift activity is to consider the type and amount of demand. Jalali Yazdi et al. (3) provided an ideal plan for lifting activity using an integer mathematical model with the goal of minimizing lifting activity time and overall waiting time in each floor while taking into account the type and amount of floor demand. Huang et al. proposed a mixed integer model to handle the problem of lift activity scheduling in order to reduce the cost of transporting lifts between floors [7]. Their model, which assumes a lift and aims to meet the demand of all floors completely, provides the optimal solution. They illustrated that the proposed model can achieve the optimal global solution in a short time by testing it on a sample of 30 floors and comparing the model's results to the results of the genetic algorithm. In this study, we seek to provide an optimal schedule for lift activity by considering two shifts. For this purpose, a linear mathematical model is presented to obtain an accurate timing of the lift activity, which, assuming the amount of materials required for each activity is known, tries to minimize the duration of the lift

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activity in addition to meeting the demand of the floors. In order to meet the maximum demand for floors and due to the limited capacity of the volume and weight of the lift, we have to move the lift from the ground floor to the floors of the building during successive periods. Therefore, it is necessary to determine the optimal number of rounds for the lifting activity. This number of rounds is updated using an iterative algorithm each time the proposed model is executed. To achieve global optimization, algorithms such as branch and branch and branch and cut are used. Therefore, by combining the iterative algorithm and the linear auxiliary model, as well as without reducing the problem answer space, the optimal number of revolutions and the optimal timing of the lift are obtained. The optimal answer obtained from the proposed model determines the exact time of the lift movement and the amount of materials that are moved by the lift in each round. The proposed linear model is tested on a real case study using a CPLEX solver. The optimal global solution obtained from the model, the moment the lift starts to move, the moment the lift reaches each floor, the amount and type of materials loaded in each round by the lift, the stop time in each floor and other parameters are obtained accurately.

2- Methodology

As mentioned earlier, it is important to optimize the lifting activity time. The lift can move between floors to meet the demand for materials. In each round, according to the lift capacity, materials are loaded on the depot and unloaded on the desired floors. This process is repeated until at least one of the following conditions is met:

- The time of two shifts is complete
- The demand for all floors is met

In this article, we seek to provide a mathematical model for scheduling lifting activity which follows the following assumptions:

Delivering materials on the floors is done in two shifts of day and night, assuming that the cost of activity at the night shift is more than the day shift.

The day and night shifts are considered 12 hours each (this number can be changed according to the conditions of each project).

Materials are stocked on the ground floor and then transported by lift to the desired floors.

The proposed model, taking into account the above assumptions, tries to meet the demand of the floors as much as possible. If the demand for floors is so high that it is not possible to meet during the two shifts, considering a penalty is the best possible answer to the problem. In this paper, we present an algorithm to obtain the lower bound ($L_{\min}$) of the number of lifting activity rounds. Then, the proposed model by assuming a certain number of rounds (N_l) for the lifting activity ($N_l = L_{\min}$) is solved precisely. If the mathematical model has an answer for N_l, it is introduced as the optimal number of round, otherwise $L_{\min}$ is updated ($L_{\min} \leftarrow L_{\min+1}$) and the proposed model is returned again for ($N_l = L_{\min}$) is solved. This process continues until the mathematical model has an answer for N_l.

3- Results and Discussion

The proposed model was tested on a real case study and the results were evaluated. For this purpose, the proposed mathematical model was implemented on a 22-story building with commercial and office use located in Mashhad, and a precise schedule was provided for it. The provided model was developed using OPL software, and the optimal solution was obtained using the CPLEX solver.

4- Conclusion

As previously stated, project managers' primary concerns are the timely delivery of materials to the floors of a high-rise construction project and the prevention of project delays. Previous research has mostly focused on meta-heuristic algorithms or simulation methods to answer the challenge of lifting activity planning. Providing a linear mathematical model to solve a problem gives us an optimal global solution, which we obtained in this paper after modeling and solving it with the help of CPLEX[1] solver. In this article, we have investigated two shifts for lift activity, considering the higher cost for the night shift. This causes the mathematical model to become closer to reality. Another issue that has not been addressed in previous research is the consideration of fines for not meeting all or part of the demand for building floors. A noteworthy point in this model is to get the best solution, even for samples whose time required to satisfy their demand is too much. Considering the non-demand penalty in the objective function causes the proposed model to try to satisfy the demand of the floors as much as possible, and if the demand is so high that it is not possible to meet the demand during two consecutive shifts, Fines provide the best way to move the lift. This increases the solution space of the problem and even if it is not possible to meet the demand of the floors, there will still be an optimal solution to the problem. In this paper, by presenting a mixed integer mathematical model, the optimal lift activity scheduling is obtained with the aim of minimizing the lifting activity time. In general, the proposed model can be introduced as a practical tool for planning lifting activities in high-rise projects. In future research, in addition to the vertical transport of materials, the current research can be supplemented by shifting labor between floors and also by considering a combination of lifting and crane activities.

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