Optimizing the lift process in high-rise construction projects

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ABSTRACT: Availability of resources, especially labor and materials, is a critical factor that directly affects the project progress in high-rise construction projects. The project management team is continually seeking to facilitate the supply-chain process to avoid delays caused by labor and construction materials unavailability. This matter is especially of vital significance in high-rise buildings that comprise numerous and repetitive activities.

The challenge that arises in these projects is the optimal vertical transportation of resources, which is possible via special machinery, including tower cranes and lifts. It has been observed in the literature that the optimal planning of construction lifting equipment can lead to significant improvements in reducing The activity delays. This research develops a mathematical model that optimizes the lifts' operational plan in high-rise buildings with multiple lift cars, using integer programming techniques."

1. INTRODUCTION

In a high-rise building construction project, a large number of construction activities are executed in different altitudes and latitudes of the building. Specialty trades, which are activities that require special materials and equipment to be conducted, form a large amount of the mentioned activities. These activities and the labor assigned to them will be idle if the required resources are not delivered to the tasks' locations on time [1, 2]. Lifting equipment is one of the necessary tools for vertical transportation on construction sites. Now the question arises as to how managers should plan vertical transportation of labor and materials in a high-rise building project to minimize costs while meeting all construction activities' requirements?

Most construction projects do not prepare and implement a lifting plan in practice, and expert workers are mainly the decision-makers regarding lift operations. It is obvious that this approach will cause delays and impose costs, especially when a lift becomes the bottleneck of supply chain process in a project [2-4]. This problem can be tackled by employing a precise lifting plan, while not planning the lifting process properly in the early stages of a construction project can cause issues such as having idle lift cars or delayed delivery of materials and resources.

2. METHODOLOGY

The problem of finding the best lifting plan and Vehicle

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Routing Problem (VRP) [5] have similarities in many aspects. The lift car's traveling path can be seen as a VRP, when each roundtrip in the lift planning problem corresponds to a vehicle in the VRP. Also, similar to the lift problem, each vehicle in the VRP must satisfy the demand of many customers.

The main difference between the lift problem and similar shortest path problems [5] is the number of nodes visited on each trip. In contrast with similar problems [6], the lift car does not necessarily visit all of the nodes on one round trip in the problem at hand. Here, the objective is to serve all floors with resource demand, on consecutive roundtrips. Similarly, a cost is associated with each edge (e.g., the distance), and the main goal is to find a tour with the minimum total cost. However, in the lift planning problem, it is not practical if the objective function is only defined by the total cost of the taken tour. In this paper, a comprehensive objective function is introduced that includes all parameters incurring a cost to the lifting process (e.g., the total number of lift stops, the amount of demanded resources and also the type of resources carried to each floor).

$$\text{Minimize } Z = \sum_{i,m,c,l} MD_m \times u_{i,m,c,l} + \sum_{i,j,c,l} [t_{i,j,c} + DL_c] \times x_{i,j,c,l} \quad (1)$$

$$\sum_{i,m} u_{i,m,c,l} \times W_m \leq WC_c \qquad \forall c,l \qquad (2)$$

$$\sum_{i,m} u_{i,m,c,l} \times V_m \leq AC_c \qquad \forall c,l \qquad (3)$$

$$\sum_i x_{i,j,c,l} = \sum_k x_{j,k,c,l} \qquad \forall j,c,l \qquad (4)$$

$$\sum_{i,\, i>j} x_{i,j,c,l} = 0 \qquad \forall j > 1, c, l \qquad (5)$$

$$\sum_m u_{j,m,c,l} \leq N \times \sum_i x_{i,j,c,l} \qquad \forall j,c,l \qquad (6)$$

$$\sum_{c,l} u_{i,m,c,l} \geq D_{i,m} \qquad \forall c,l \qquad (7)$$

$$N \times \sum_{j,i=1} x_{i,j,c,l} \geq \sum_{j,m} u_{j,m,c,l} \qquad \forall c,l \qquad (8)$$

A lift system is expected to transport materials and workforce to the assigned levels on time and with minimum delays, so in this paper, our objective function (Equation 1) is designed to cover delays.

The constant delay itself is affected by the door opening and closing time and acceleration/deceleration delay. In lifting time calculation algorithms presented in the literature, acceleration and deceleration times are precisely calculated. In this study, however, the purpose of the model is not to calculate the exact travel time. Since the main purpose of this model is to find the best travel path, we assume both travel speed and delay at each stop to be constant. Regardless of this issue, implementing the available formula for calculating the dynamic pattern of lift speed will impose an excessive complexity to the formulation, which may reduce the chance of obtaining the optimum solution within polynomial time. However, this does not mean that we have compromised on accuracy to obtain a relaxed optimum solution; the introduced cost function (Equation 1) is a good approximation of the real delay and travel intervals. It also covers all three main delay functions in a typical lift system. In details, the first term ($\sum_i \sum_m \sum_l MD_m \times u_{iml}$), in Equation 1 covers material loading/unloading delay which does not affect the optimization process and has only been included in calculating a good approximation of the total amount of delays. The second term ($\sum_i \sum_m \sum_l U_{iml}$), will not vary since it has to be greater than or equal to the initial demands according to Equation 8 and it is subjected to minimum travel delays. So, if it is not intended to have an approximation of the total delay, then the first summation in the cost function can be eliminated.

Equations 2 and 3 restrict the amount of materials carried on each roundtrip, regarding the weight and area capacity of the lift car. The role of Equation 4 is to prevent more than one entry to each level (node) on each roundtrip. Meaning that it is not optimal for the lift car to make two stops on the same floor on a roundtrip. Equation 5 is also introduced to ensure the lift car is allowed to storage level if and only if it has unloaded all of the materials it has been carrying. The lift visits the storage on the ground floor only after its direction changes to downwards. Equation 6 is introduced to ensure the flow conservation that means the number of arrivals at each floor is equal to the number of departures. Equation 7 forces

Table 1. Notations used in this research

Symbol	Description
i, j, k	Floor number indices
m	Material type index
c	Lift index
l	Round trip number index
$SP(c)$	Movement speed of the lift car (m/s)
$WC(c)$	Weight capacity of the lift car
$AC(c)$	Area capacity of the lift car
$DL(c)$	Average delay caused by each stop (s)
$W(m)$	Unit weight of material type m
$V(m)$	Unit Volume of material type m
$MD(m)$	Load/unload delay for material type m
$H(i)$	Height of level i
$D(i,m)$	The amount of floor i's initial demand of material m
$t(i,j,c)$	Travel time between floor i and j with lift c
$x(i,j,c,l)$	0 If the path from i to j is chosen on roundtrip l 1 Otherwise
$u(i,m,c,l)$	The amount of unloaded materials of type m at floor i in roundtrip l
N	Big Constant
Z	Cost function

the number of unloaded materials at a floor to be zero, if the floor is not chosen to be visited by the lift. Similarly, the total amount of unloaded materials on each floor must be greater than or equal to the total demand of that floor, as restricted by Equation 8.

3. RESULTS AND CONCLUSION

The presented model generates the optimum operational plan in a high-rise construction site with already installed lifting equipment. Unlike most of the models presented in the literature, the platform proposed in this study optimizes the operational process of a lift car in a high-rise construction project. The proposed model can handle lift process planning by considering practical aspects of this problem, and optimizing this process based on a mathematical procedure. Since this optimum finding process is based on a mathematical procedure, the optimal solution is guaranteed to be the global optimum. Optimizing the lifting process not only decreases the construction delays, but also reduces the operational costs of the lift car.

4. REFERENCES

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