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Optimization of tower crane and material supply locations in a high-rise building site by mixed-integer linear programming

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ABSTRACT

Facility layout design and planning within construction sites are a common construction management problem and regarded as a complex combinatorial problem. To transport heavy materials, tower cranes are needed and should be well located to reduce operating costs and improve overall efficiency. Quadratic assignment problem (QAP), non-linear in nature, has been developed to simulate the material transportation procedure. Applying linear constraint sets, the quadratic problem can be linearized and the problem could be formulated into a mixed-integer-linear programming (MILP) problem solvable by a standard branch-and-bound technique for true optimal results. Numerical findings show that MILP results outperform those optimized by Genetic Algorithms with almost 7% on improving the objective function values in which facilities and locations can be modeled using integer variables. To demonstrate the design flexibility of using MILP formulation, the problem is also extended to non-homogeneous storages where different materials can be stored at a single supply point.

1. Introduction

Tower cranes are common at construction sites nowadays which are often erected hundreds of feet in height to lift heavy and bulky objects like steel beams, ready mixed concrete, prefabricated elements, large tools such as machinery and equipment, and a wide variety of other building materials within a construction site. They are usually located at a convenient and safe place where most of these heavy and bulky materials can be handled. Ideally, their jib should reach and cover any part of the buildings in a construction site to lift and drop construction materials over various supply and demand points. It is expected that there are many factors to be considered while locating a tower crane to undertake heavy material transportation tasks efficiently in terms of operating costs and transportation distances.

Having a good facility layout including the tower crane and material supply locations is one of the most important parts to increase such production efficiency in construction sites, especially in most metropolitan cities like Hong Kong where the sites are usually confined in nature with a limited area due to the scarcity of land supply. To cope with such construction site conditions, practitioners in the industry relying much on experiences always lack a well-defined approach to come up with an optimal site layout for construction projects [12,28].

Nowadays, building construction projects are highly mechanized employing tower cranes to transport heavy construction materials [24]. As material transportation is one of the major activities in the building construction industry, lifting and hoisting heavy materials by cranes in construction sites are common tasks that require meticulous planning [21]. Construction cranes are classified into tower cranes and mobile cranes. Tower crane, which is suitable for a wide range of work assignments and site conditions, is one of the key facilities for vertical and horizontal transportation of materials, especially for the heavy prefabrication units and large panel formwork in high-rise construction [28]. The demand for tower cranes is rising according to American contractors [24], and crane rental companies have increased the proportion of tower cranes in their equipment fleets [4,5,26]. Locations of tower cranes and surrounding material supply points are critical to the overall efficiency in a construction site. The objective of this paper is to formulate the design problem for a construction site layout involving locating a single tower crane and associated material supply points into a mixed-integer linear program to minimize the total operating cost.

2. Literature review

Two traditional models, Quadratic Assignment Problem (QAP) and Graph-Theoretic, have been developed to mathematically simulate the procedure of material distribution in facility layout problems originally designed for the manufacturing industry [19]. The former one is frequently implemented in layout planning for the construction industry in recent years. It is classified as a difficult problem in the NP-

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