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GA optimization model for solving tower crane location problem in construction sites

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Abstract Tower crane is increasingly becoming one of the key components of temporary site layout facilities in most construction projects. Determining the location of tower crane is an essential task of layout planning, which is also the central focus of this study. The optimization of tower crane location depends on many interrelated factors, including site constraints, shape and size of the buildings, type and quantity of required materials, crane configurations, crane type, and construction site layout. These factors vary from one project to another, resulting to complicated site layout strategies and approaches. This fact makes the crane location problem impractical to be solved depending on experience of practitioners only which was gained by assuming and through trial and error.

This paper aimed at developing an optimization model to solve tower crane location problem in construction sites. The objective was to minimize the total transportation time. Genetic Algorithms (GA) optimization technique is utilized to solve the problem. A numerical example is presented to test and validate the results obtained by the model.

1. Introduction

Tower crane is a basic machine for lifting and transporting material and devices. The construction process for buildings and many engineering fields requires transporting different materials and equipment in a short period, which creates the importance of tower crane presence in most construction sites. Selection of location for tower cranes to be used in constructing a building is among the most important issues in planning the construction operations.

Tower crane location must be selected to suit the requirements of the job. If the crane's basic characteristics do not match the job's requirements then it may lead to significant effects in terms of high cost, possible delays, and unsafe work

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Abbreviations

X_{si}, Y_{si}, Z_{si}	coordinates of supply points (m)	T_a	time for trolley radial movement (min)
X_{dj}, Y_{dj}, Z_{dj}	coordinates of demand points (m)	T_w	time for trolley tangent movement (min)
X_c, Y_c	coordinates of tower crane (m)	V_a	radial velocity of trolley (m/min)
L_{ij}	distance between supply (i) and demand (j) (m)	ω	slewing velocity of crane jib (r.p.m)
L_i	distance between crane point and supply point (m)	TL_{vij}	vertical hoisting time when the hook is loaded (min)
L_j	distance between crane point and demand point (m)	TU_{vij}	vertical hoisting time when the hook is unloaded (min)
Z_{ij}	vertical distance between demand point and supply point (m)	V_{vl}	vertical hoisting velocity of loaded hook (m/min)
θ_{ij}	angle between L_i and L_j (rad)	V_{vu}	vertical hoisting velocity of unloaded hook (m/min)
α	jib simultaneous movement parameter		
β	hook simultaneous movement parameter	T_{ij}	cycle time between supply (i) and demand (j) (min)
Q_{ij}	quantity of material to be handled from supply (i) to demand (j) (ton)	L_{xc}, L_{yc}	dimensions of crane base area (m)
C_{ij}	capacity of tower crane for the cycle of loading between supply (i) and demand (j) (ton)	L_{xs}, L_{ys}	dimensions of supply area (m)
		L_{xd}, L_{yd}	dimensions of demand area (m)

conditions. The use of any type of crane requires planning but tower cranes require more than usual because their structures, foundations, and presence on the site are generally for as long as the heavy construction phases continue. In selecting the most suitable location of tower crane, the characteristics of various machines available must be considered against the requirements imposed by the loads to be handled and the surroundings in which the crane will operate. Other factors such as weights, dimensions and lift radius of the heaviest and largest loads must also be considered, which necessitate the use of an optimization technique such as GA to solve such problem.

Many studies have been developed to optimize the location of tower crane, based on lifting time and cost. A mathematical model was developed by Rodriguez-Ramos and Francis [1] to find optimum location of a crane in a construction site. The technique considers radial and angular crane movement of construction materials. The objective of the model is the minimization of the total crane transportation cost between crane and the construction supportive facilities that are serviced by the crane. This model is actually locating the position of the crane hook when waiting between movements. At the same time, the calculation of lifting time does not take into consideration the vertical motion of tower crane hook and the simultaneous movement between the angular and radial hook movement as reported by Abouel-Magd [2].

This model was then adopted by Choi and Harris [3] to develop a mathematical model for optimizing tower crane location. However, they considered that the angular and radial movements were carried out simultaneously with the hoisting movement. Instead of locating the optimal hook waiting position for a crane, they suggested to locate the optimal location of a tower crane to serve the predetermined supportive facilities (Leung and Tam [4]).

On the other hand, a graphical model was developed to help user to select the location of tower crane by Cooper [5], and its methodology was by examining user suggested locations to meet a number of technical requirements while considering available machine. Shapira and Goldenberg [6] criticized that this system anyhow provides guidance, and all decisions are left to the user's discretion.

One major important model is developed by Zhang et al. [7] as it was a major key step for all following studies. A mathematical model is developed for location optimization for a group of tower cranes using Monte Carlo simulation approach. This mathematical model involves three steps, such as initial location generation model, task assignment model and single tower crane location optimization.

Tam et al. [8] used the main function that was developed by Zhang et al. [7] to develop a GA model to optimize supply locations around tower crane based on least cost. However, the optimization was focused on supply locations not the crane. Son [9] developed a GA model to optimize the location of tower crane using Zhang et al. [7] model for computing hook travel time. The study was restricted only for precast construction projects. Alkriz and Mangin [10] developed a GA model for optimizing the location of tower crane and construction facilities. In this study, the loading and unloading time modeled by Zhang et al. [7] was neglected because they do not vary when the crane and facilities location changes within site from one place to another.

One modern application for the model is the one introduced by Huang et al. [11]; this model applied the mixed-integer linear programming technique to solve the problem of locating tower crane and facilities. Another application is the GIS-BIM model that has been developed by Irizarry and Karan [12] for optimizing a group of tower cranes. The main objective of the model is to locate a group of tower cranes to reach minimal amount of conflicts. Lien and Cheng [13] proposed a new model for optimizing tower crane location and the quantity of materials to be transported from supply to demand areas using particle bee algorithm (PBE). The technique is applied on former models by Tam et al. [8] and Huang et al. [11] and the results show that PBA has better performance than particle swarm optimization (PSO) and bee algorithm (BA). However, the selection of tower crane location is limited to predetermined locations.