Automation in Construction 61 (2016) 1–15

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Decision support for tower crane selection with building information models and genetic algorithms

Mohamed Marzouk [a,*], Ahmed Abubakr [b]

[a] Construction Engineering and Management, Structural Engineering Department, Faculty of Engineering, Cairo University, Egypt
[b] Structural Engineering Department, Faculty of Engineering, Cairo University, Egypt

ARTICLE INFO

Article history:
Received 10 November 2014
Received in revised form 12 September 2015
Accepted 20 September 2015
Available online 17 October 2015

Keywords:
Decision making
Tower cranes
Building information modeling
Analytical hierarchy process
Genetic algorithms

ABSTRACT

Tower cranes are major construction equipment that is highly demanded in construction projects. The planning process for tower cranes utilization starts in early stages of the construction projects. Poor selection could incur extra costs on the construction projects or cause delays in project duration. The planning procedures for tower cranes include selection, allocation and operation. This paper presents a framework for the selection of tower cranes types and locations at construction sites. The framework considers three main models: 1) decision making model to select the tower crane type, 2) optimization model for the selection of the ideal number and location of tower cranes, and 3) 4D simulation model to simulate tower crane operations. Several clash detection scenarios are presented to assure the safety operation of the tower crane group. A case study is shown herein to demonstrate the capabilities of the developed framework.

1. Introduction

Construction site layout planning is a routine task that needs to be performed at early stages of the construction projects. The location of the permanent and temporary facilities should be determined within the site boundaries. Site layout planning focuses on how to select the efficient space utilization especially in limited workspaces. Careful planning of site layout attributes to the success of construction projects since it influences construction productivity [10]. Several facilities layout should be generated during the planning stage. The optimum layout usually satisfies the site constraints and results in minimum cost. Temporary facilities and equipment (e.g. tower cranes) should be carefully planned throughout the execution of the project [15]. Poor site layout planning could lead to schedule delays, lower productivity rates and increased cost. This highlights the importance of performing careful planning of the different construction operations [13]. Site layout planning includes major items that need detailed study and analysis such as equipment's layout, productivity of resources and associated construction costs [12]. Tower cranes need special consideration when performing site layout planning such as storage places as well as access roads, installation and dismantling spaces, and other criteria need to be considered when planning for crane location.

Understanding the needs and characteristics of tower cranes is crucial during planning phase. Such characteristics include the constraints that limit the selection of cranes, which have a wide variety of types, sizes and capacities. Previous studies have proposed models which attempt to facilitate the problem of both crane selection and location [16,18,19,21]. For example, Shapira and Simcha [24] proposed AHP-based tool to model safety on construction sites with tower cranes. The tool provided the weights of factors without any guidance for the critical factor and how the variance of weight of the critical factor can affect the ranking of the alternatives. This study did not provide any visualization features.

The building information modeling (BIM) was utilized in different applications related to site layout such as geospatial analyses [25], simulating the behavior of all elements on the site [26], and improving visual monitoring of construction supply chain management [27]. Irizarry and Karan [28] presented an integrated GIS–BIM model starts with the identification of feasible locations for defined tower cranes. The model lacks the ability to advice on the type of the cranes after examining the factors that are involved in selection procedure. Furthermore, it does not involve optimization algorithm that can examine several solutions to identify near optimal one.

Al-Hussein et al. [3] demonstrated the use of simulation for depicting the tower crane operation on construction site. Simulation was utilized to assist experts in specific domains to easily build potential scenarios. The model was developed using special purpose simulation (SPS) that supports construction managers with tools to construct simulation models. SPS facilitates simulation modeling through the creation of building environments tailored to the specific requirements of a given construction domain. SPS was utilized in scheduling tower crane operations as the lifted weights were broken down into work packages representing a set of uninterrupted lifts to be performed by the tower

---

* Corresponding author.
E-mail address: mm_marzouk@yahoo.com (M. Marzouk).

http://dx.doi.org/10.1016/j.autcon.2015.09.008

crane. Each work package has different features, including source location, destination location, weight and size, assigned crane for each lifted module, and priority setting of the lift operation.

Mathematical models have different approach, as it tends to maximize or minimize the inputs with respect to clear objective function or with respect to a certain target under a set of defined constraints. Most of the mathematical models used for locating group of tower cranes depend on Zhang model [23]. The location criteria were based on the notion of balancing workloads, minimizing the possibility of conflict and the high efficiency of operation. The proposed mathematical model was based on reconstructing the process of supply and demand of materials handled by a tower crane on a construction site. The proposed model was based on several assumptions;

- The geometric layout of all the supply and demand points are deterministic.
- The crane type is predetermined.
- The hook moves consecutively in the horizontal and vertical plane.

Alkriz and Mangin [4] developed a model for optimizing the location of tower cranes in construction sites using genetic algorithms as an approach to get the optimum results. The model considered balanced workloads between the tower cranes group to minimize the possibility of conflict with each other and maximize the efficiency of operation. The initial location model classified the tasks into groups and identified the feasible location of each crane according to the geometric closeness. Then, the task groups are adjusted to yield smooth workloads and minimal conflicts during crane operation. Finally, the optimization model is applied to optimize the tower crane location and the supply point location for minimizing the material transportation time and cost.

Previous research efforts related to planning of tower crane utilization focused on specific aspects of planning. These aspects included: 1) identifying the critical factor through determining the weights of factors that might influence the selections without performing sensitivity analysis, 2) performing optimization without visualization, and 3) visualizing the process without performing optimization to examine a wide range of feasible solutions to recommend the near-optimum one. This study presents a comprehensive approach that addresses the limitation of previous research efforts and encompasses all required aspects of tower cranes planning. A BIM-based model is introduced to facilitate the lifting operation monitoring, allowing dynamic operation by adding the new site conditions and assessing the lift plan according to the new status. The approach considers three main models related to the planning of tower cranes utilization. First, the decision making model assists in selecting the most suitable tower crane type that matches the requirements of construction projects. Then, analytical hierarchy process (AHP) is used to select the crane type through a series of pair-wise comparisons. Interviews with construction experts were conducted to collect the required knowledge where AHP translates the qualitative knowledge collected from experts into quantitative figures in the pair wise comparison to give reliable results to choose the best tower crane type. The second model performs optimization to minimize the cost of tower cranes in the construction project. Although, analytic hierarchy process is considered a popular tool for the subjective judgment of the qualitative and quantitative data, it has limitations of aggregating the weights of several experts, and having consistent pairwise matrices.

Genetic algorithm (GA) optimization technique is used to identify: 1) optimal tower cranes layout, 2) type of crane base whether fixed tower crane or moving tower crane, 3) shortest rail length that can give higher crane coverage, and 4) optimal lifting assignment plan of the lifted modules. Sensitivity analysis is performed to select the most effective genetic algorithm parameters. The results obtained from the optimization model should satisfy both reach and capacity constraints for all required lifted modules. The third model is used to verify the results by using 4D simulation for the whole system of tower cranes where a 3D model is developed for the construction project and tower cranes. The quantities extracted from the BIM model are inserted in the genetic algorithm model in order to select the crane capacity that is suitable for the required load, after selecting the whole cranes configuration. Finally, 3D clash detection is performed to detect any possible clash(es) during crane operation.

The tower cranes are selected using the AHP model and the results obtained from the genetic algorithms model. The time dimension analysis is considered to visualize construction activities, the sequence of the execution and their interaction among the involved tower cranes. 4D modeling is also used to identify and resolve tower crane conflicts with other working tower cranes, or clashes between the tower crane and the building structure through a series of clash detections scenarios. This gives a better understanding of the project operation conditions and how to mitigate these types of collisions in the early project stages. The proposed model has the following limitations: 1) it cannot take any modification that might take place during construction; 2) it does not model real time visualization with respect to the BIM model, 3) it is unable to provide advanced spatial query functions (e.g., objects-within-specified-distance query), and 4) it doesn't consider the selection of mobile cranes which might be useful for certain situations and can reduce the cost of using tower cranes. A case study of a construction project is presented to demonstrate the use of the developed framework.

2. Tower crane type selection

Analytical hierarchy process (AHP) is utilized as a method for a multi-criteria decision making for crane selection [1,17]. The main goal of the AHP model is to examine the capability of each tower crane alternative against each sub-criterion to select the tower crane type that meets the project needs. Tower cranes are available in a number of forms and characteristics that should be considered in relation to the project needs so as to meet all the requirements of the planned lifts. The selection of a crane for any job should be made after a thorough examination of all the factors involved. These factors comprise the criteria upon which the best alternative is selected; where the main goal is decomposed into a major set of criteria with different weights. Then, these main criteria are decomposed into sub criteria as the level of breakdown extends to the level that affects the alternatives [14]. According to the experts' interviews, it was agreed that the most important criteria that affect the tower crane type selection are the tower crane specification, the project site conditions, the project characteristics and the cost of using the tower crane. Each criterion is broken down into another set of sub-criteria which are used to compare the tower crane alternatives through a set of pairwise comparisons, then selecting the best alternative that suits these sub-criteria. These measures are synthesized to get the most suitable tower crane type that matches project needs. In order to develop the AHP model for selecting the best tower crane type, the following procedure is followed. First, the types of the tower cranes which act as alternatives for the sub-criteria are defined. Second, the main criteria that affect the tower crane selection and categorizing each set of sub-criteria under the main criteria are identified. Third, importance priority for the main criteria with respect to the main goal and for the alternatives with respect to the sub-criteria is obtained. Finally, these results are aggregated to main goal to decide the best alternative for the current situation to be implemented. Each class of cranes possesses certain basic characteristics which will usually guide the selection process to the best alternative.

2.1. Identify alternatives

Tower cranes are available with different configurations. The main differences in tower crane configurations lie in the tower crane jib as there are luffing jib tower cranes and horizontal trolley jib tower cranes.