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An integrated decision support model for selecting the most feasible crane at heavy construction sites

SangHyeok Han[a,*], Shafiul Hasan[b], Ahmed Bouferguene[c], Mohamed Al-Hussein[d], Joe Kosa[e]

[a] *Department of Civil, Building and Environmental Engineering, Concordia University, Montréal, Québec H3G 1M8, Canada*
[b] *Mammoet Canada, Edmonton, Alberta T6S 1H6, Canada*
[c] *Campus Saint-Jean, University of Alberta, Edmonton, Alberta T6C 4G9, Canada*
[d] *Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta T6G 1H9, Canada*
[e] *NCSG Engineering Ltd., 28765 Acheson Road, Acheson, Alberta T7X 6A8, Canada*

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ABSTRACT

Heavy industrial projects, especially oil refinery facilities, consist of numerous components such as modules and vessels, which are large, heavy, and long objects. The successful completion of these projects requires precise planning and selection of safe and efficient single- and/or tandem crane lifts, which are strongly influenced by the crane types and models used. Thus, selecting not only the best crane type and model, but also the most efficient crane operation among alternatives, can result in productivity and safety improvements. In this respect, this paper proposes an integrated decision support model which designs, simulates, and evaluates potential crane operations in accordance with feasible crane types and models based on equipment, cost, site, and environmental aspects of the project. The proposed methodology consists of two components: (1) 3D-based crane selection simulation, which enhances the process of crane selection by not only accurately verifying and identifying engineering factors, but also analyzing feasibility (procedures) of tandem and single-crane operations, from crane installation to lift completion and disassembly of the crane configuration, in a 3D environment; and (2) a crane selection matrix which calculates the crane evaluation scores by measuring various factors of each feasible crane against the project criteria and constraints. The methodology is tested in a case study in order to illustrate its effectiveness.

1. Introduction

Heavy industrial projects, especially oil refinery facilities, consist of a large number of components such as modules and vessels. These projects can be divided into two types: (1) new construction and (2) shutdown construction for facility maintenance. Although both types of projects heavily rely on cranes to remove and/or install components, safety and efficiency are of particular importance for shutdown construction projects, given the complexity and congestion on site and the scheduling and other criteria to which the project is subject. Without proper planning for safe and efficient crane operations, cost overruns and schedule delay can occur and profits from the oil refinery facility can dramatically decrease. Most of the components in heavy industrial projects are lifted by single-crane operations, but the two-crane lift, referred to as a tandem lift in this paper, has become crucial for installation of large vessels or reactors raised to a vertical orientation at the final destination. Since operating two or more cranes to lift a single object involves a higher risk than does single-crane operation due to an increase in disproportionality, intelligent and formal tandem crane lift analysis is an essential component of risk mitigation from the planning phase of a project. However, in current practice the scope of planning and risk mitigation is typically determine based on the lift engineer's judgement and experience depending on the circumstances of crane operation [1]. In particular, the selection of crane types, locations, and operation among several alternatives is carried out based on lift engineers' judgement even though many factors, including space, crane availability, and assembly and disassembly crane configurations, must be taken into consideration to ensure selection of the most suitable and reasonable crane equipment and operation. It should be noted that this research primarily focuses on measuring project criteria and constraints to assist lift engineers/project managers in selecting the most suitable crane types and models for single- and/or tandem lifts among feasible alternatives.

Since the crane selection process is a critical yet time-consuming

* Corresponding author.
E-mail addresses: sanghyeok.han@concordia.ca (S. Han), shafiul.hasan@mammoet.com (S. Hasan), ahmed.bouferguene@ualberta.ca (A. Bouferguene), malhussein@ualberta.ca (M. Al-Hussein), joe.kosa@ncsg.com (J. Kosa).

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task in crane lift planning, researchers and engineers have attempted to develop applications and methodologies using various algorithms in order to select cranes efficiently and effectively. Appropriate crane type and model selection contributes to the efficiency, timeliness, and profitability of projects. Based on previous studies, crane selection algorithms are categorized as follows: (1) project factor-based algorithms; and (2) scenario-based algorithms. In developing project factor-based algorithms, previous researchers have identified the crane-related factors in projects—which are site conditions and layouts, building design, and economy of crane use—by investigating the different types of work involved, crane capability, and safety aspects of actual projects. Aggregating these factors by importance, fuzzy logic and neural networks have been adopted in order to realize the highest expected overall efficiency of crane type selection [2,3]. In scenario-based algorithms, the selection of crane type is affected by the heaviest lift and/or the largest lift radius (capacity) determined by the distances from crane locations to pick and set positions of lifted objects on site. For this reason, the notion of a relational database management system (DBMS), which is a tabulated system including crane type, geometric lifting configuration specifications, and lifting capacity, has been introduced for effective and efficient mobile crane type selection [4]. From this work, many researchers have integrated the tabulated system with three-dimensional graphics and simulation techniques in order to facilitate the selection of crane types and models [5–9]. Since the selection of crane types and models is strongly affected by potential crane locations, combined systems in terms of the selection of crane locations and types have been developed for better efficiency and safety of construction sites [5,6]. More recently, Wu et al. [12] have developed an algorithm for selecting mobile cranes on construction sites that takes into account the lifting capacity, the geometrical characteristics of the crane, the dimensions of equipment and rigging, and the ground bearing pressure. This algorithm has been integrated into a 3D computer-aided system that performs the following functions: (1) crane selection, (2) crane modelling, (3) 3D-simulation, (4) 3D computer-aided design modelling, (5) rigging calculation, and (6) data management.

While for most projects a single crane is sufficient to perform the required lifts, in some instances a lift may require tandem cranes. One such example is the lifting of heavy-pressure vessels which needs to be rotated from a horizontal to a vertical position prior to being set at their final position. This type of operation requires planning and arranging of adequate crane support, as well as preparation of collision-free rotation of the vessel from a horizontal position to a vertical position. To satisfy these requirements, two cranes are selected based on their respective lift capacities, and the lifts of each crane are analysed individually for potential crane locations associated with pick positions determined based on expert knowledge. Since this method of crane selection is time-consuming in practice, Hermann et al. [13] have proposed a crane selection methodology to lift long vessels in industrial projects. Although tremendous progress has been made in the crane selection phase, the current static-based procedures in practice still have deficiencies due to the uncertainty of crane operations. In this regard, advances in information technology have led to 3D CAD systems that can be used to simulate crane operations based on selecting the feasible crane locations, types, and models before determining a specific crane type and model for a given lift.

Crane operations are generally defined as one of two types: pick from fixed position (PFP), in which the location of the crane is fixed during the lifting operation, and pick and walking operation (PWO), in which the crane is required to walk while the load is being lifted. Previous studies have evaluated path feasibility for heavy objects, such as columns and large vessels, based on the framework of the PFP method [14–18]. According to the site environment, where, for instance, site congestion may have a significant bearing on crane trajectory, the PWO method is the only solution for successfully transferring the objects to their set positions. For such cases, 3D visualization-based motion planning is developed [19]. Since large-scale industrial construction projects involve heavy and long loads, tandem crane operations have been designed using heuristic search, genetic algorithm (GA), and multiagent-based and incremental coordination methods [7,18,20–22]. Furthermore, utilization of 3D visualization of mobile crane operation is proposed for crane lift planning. This visualization encompasses crane location, crane selection, crane support system, and crane motion planning [23]. Although alternative crane operations have been previously proposed in the literature, these studies have not addressed the need to consider the cycle time of each crane operation in order to select the best scenario in the design phase of the project. To overcome this limitation, a 3D-based crane evaluation system is introduced as a platform where safety identification and productivity aspects are integrated for the purpose of selecting the most suitable mobile crane operation (i.e., the crane lift with the shortest cycle time) among several alternatives [24]. At this juncture, it is important to note that this work falls within the set of procedures known as “off-line” since they are run before the lift begins. In order to complete this picture, it is worth noting that recent advances in computer technologies have allowed researchers to explore on-line solutions for real-time monitoring of crane operations and, more importantly, to analyse their effectiveness for the purpose of proactive safety assistance. These real-time processes have been integrated into a paradigm referred to as smart workspace for crane lifts and use the hybrid visualization approach, which integrates 2D images or sensors with 3D models, point cloud data, and linear-regression models [25–29]. The purpose of these studies is to efficiently and effectively identify and/or design real-time anti-collision workspaces for improved safety of crane operations.

Although many researchers and practitioners have contributed to this field through the development of crane selection frameworks and motion planning algorithms, additional research is still required due to the following reasons: (1) available frameworks for feasible crane model and type selection do not provide a decision support model by which to select the most feasible crane type and model (e.g., lattice boom crawler crane versus telescope boom truck-mounted crane) for single and/or tandem crane operation in heavy industrial projects; and (2) current crane selection algorithms have mainly focused on safety for lifts, whereas a variety of other project factors must be considered in order to improve both project safety and productivity. Furthermore, in practice the selection of crane types and models heavily relies on the lift engineer's experience. To overcome these limitations, this paper proposes a framework, which consists of a crane selection matrix as a crane decision support measurement tool, 3D-based crane selection simulation involving load distribution analysis, 3D crane simulation and preliminary crane selection, based on cost, site, and environmental aspects (factors) of projects. In other words, this framework measures, calculates, and compares various factors of the project in accordance with each of the different crane types and models, and types of crane operations. This framework results in the selection not only of the most suitable crane type and model, but also of the most efficient and safe tandem and/or single-crane operation, thereby ensuring successful delivery of the large, custom-designed objects required in heavy industrial projects. Furthermore, this paper describes the benefits of the proposed 3D-based crane selection simulation, which can reduce uncertainties and/or guesswork encountered by lift engineers and/or project managers (e.g., boom angles to ground for the calculation of the required crane capacity, lifting heights, and clearances) during tandem and single-crane operation in the design stage of crane lift analysis.

2. Methodology

The crane information used as inputs includes configurations, geometry, capacity chart, and rigging system, including slings, shackles, and spreader beams. In addition, the load information, such as weight, center of gravity, and dimensions (width, length, and height), is important input data. The methodology presented in Fig. 1 describes the