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Automated Crane Planning and Optimization for modular construction

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ABSTRACT

The majority of industrial projects in Alberta's oil sands are constructed using modular construction. Modules are preassembled components built off-site and transported to the site to be lifted into place with mobile cranes. Heavy lifts include modules as well as major equipment that utilize expensive mobile cranes. Selecting the proper mobile cranes and configurations and finding the best crane position for each lift saves a significant amount of time and cost, while also improving safety. A heavy lift plan facilitates overall site management by reducing extra crane relocations and avoiding dangerous crane clashes. Performing such intensive analysis manually for several hundred lifts and various crane options is a tedious, prolonged exercise. However, no application that carries out such intensive analysis for a number of lifts in modular construction has yet been developed. This paper presents a system, called Automated Crane Planning and Optimization, to automate the above-mentioned analysis for a large-scale project. This system is validated on actual modular projects.

1. Introduction

The heavy lift plan is the backbone of an industrial construction project. Heavy lift mobile cranes on major industrial construction projects are expensive and can run into millions of dollars. Effective management of the mobile cranes is a critical task for safety, cost efficiency and on-time lifting of modules. An effective heavy lift plan results in properly selecting the best types of mobile cranes, crane positions, crane configurations (e.g., boom and jib length, crane counterweight and superlift counterweight, superlift radius), mat configurations underneath cranes, rigging configuration, as well as the appropriate lifting sequence. However, such an intensive analysis on an industrial construction site containing several hundreds of heavy lifts requires the analysis of thousands of variables, including the physical conditions of the site; dimensions, orientations and weights of modules to be lifted; and the lifting schedule, as well as the lift capacities and dimensions of available cranes.

An in-house developed heavy lift software suite, called HeviLift, was developed at PCL Industrial Management Inc. This software analyzes thousands of scenarios in a short time to find a safe, cost-efficient plan for selecting the proper mobile cranes with optimal configuration and positions. This paper reviews the backbone of the HeviLift suite, called Automated Crane Planning and Optimization (ACPO) to automate the process of checking the clearance of crane components with all existing obstructions in a mathematical approach and other lifting objects (e.g. several millions of cranes' lifting options in an actual large-scale project), identifying the potential crane positions (i.e. grid points) and potential logic issues for all lifting objects, clustering lifting options.

This system is developed for analyzing the total lifts of entire project, not only for a single lift. The main inputs of ACPO application include project boundaries, site clearances, objects data, cranes and configurations. Some of input data (e.g. project boundaries, modules location and specifications) can be easily extracted from CAD or BIM models by utilizing a developed Application Programing Interface (API), and stored in a centralized database.

Optimization is not the main objective of this research, but the developed system provides an intensive backbone for optimization purposes. Identifying the feasible cranes, cranes' configurations, cranes' possible locations for lifts, and lifting logic issues is the main goal of this study.

2. Background and state of the art

Modularization of oil and gas and petrochemical industrial plants in the province of Alberta, Canada has become very popular for various reasons, including reducing cost, enhancing safety and quality, easing site congestion, and compressing project schedules [1]. Modularization involves building prefabricated modules off site, transporting to the construction site, and lifting on site [2]. The maximum size of an Alberta-built module is 24 ft (7.3 m) wide, 27.5 ft (8.4 m) high, and 138 ft

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Fig. 1. Modular construction of an industrial plant.

(42 m) long. Such heavy modules may weigh up to 176 Imperial tons (160 metric tons) to be shipped on the road.

Once those modules and other pieces of equipment have been fabricated and built, they are transported to the construction site and lifted into place. In North American industrial construction, such heavy lifts (Fig. 1) are usually performed with mobile cranes on site [3, 4]. Owning a heavy lift crane is rare, and renting a heavy lift crane is expensive, sometimes requiring several months in advance to book the crane. Moreover, heavy lift operations require a heavy lift crew (as many as 10 people) to perform lift-related activities, including preparing the ground, placing mats underneath mobile cranes, assembling rigging, supervising, and securing the module or vessel in lifting operation.

Heavy lift operations are usually part of the critical path of a project and drive many other activities on the site. Thus, an effective heavy lift plan impacts the overall schedule of a modular construction project, saves millions of dollars, and contributes to safety and quality on the job site.

Traditionally, the selection of mobile cranes and the development of engineered lift studies are analyzed individually. In practice, crane selections are usually based on the heaviest lift and/or largest lift radius, not all of the several hundred heavy lifts that occur during a large-scale project. Thus, such analysis requires a very experienced lift engineer to manually determine potential crane positions with great effort and select positions in the project. Typically, 2D plot plans are employed to position the cranes, and to perform boom clearance checks against objects. Spreadsheets are also used as a quick method of determining boom clearances. 3D models have become more prominent recently due to technological advancements, but these require manual user trajectory paths.

The traditional practice of selecting the best configuration and position of the crane, checking all the clearances, and identifying clash detection issues is a very tedious and challenging process. The selected type and configuration of crane(s) do not necessarily provide the optimum solution for an entire project involving hundreds of heavy lifts. Several studies have been performed in the last two decades to examine automating crane selection and crane configurations [5–8], identifying possible crane locations [3, 4, 9–11], optimizing crane locations [12] and planning the lift path [13–18], and recently some studies focus more on single crane behavior [19, 20].

With advancements in computer technology in the 1990s, some researchers at the University of Texas initiated efforts to employ computer technology for heavy lift planning [13, 21, 22]. This work resulted in the development of a Heavy Lift Planning System (HeLPS). The HeLPS assists the lift planners in analyzing appropriate crane locations, checking lift path clearances, accounting for safety factors, as well as calculating ground support during lift. The HeLPS also utilizes CAD models to animate the motions of crane on a structural job site [23]. However, the scope of this analysis is limited to only one single lift.

Several commercial computer applications (e.g., 3D Lift Plan, Compu-Crane, Lift Planner, Cranimation, kranExpert) also exist to assist the lift planner in heavy lift planning. However, there is no academic or industrial application to perform the analysis for several lifts across an entire modular construction project.

Further efforts over ten years have been undertaken to automate planning multiple lifts and optimize the entire lift plan for a modular construction project at PCL Industrial Management Inc. in conjunction with the University of Alberta, and more recently with the University of Tehran. This work has resulted in a software suite, called HeviLift. The main purpose of HeviLift is to perform the intensive analysis of multiple lift planning for the entirety of a modular construction project, containing several hundred lifts, quickly and efficiently. HeviLift include various components including optimization mobile crane selection and location [24, 25], multiple heavy lift planning [26, 27], 3D-model-based crane selection and logistics [28, 29], Mobile Crane Path Planning [30, 31] and creating automated lift studies and 3D lift animation [32, 33]. This paper introduces the backbone of HeviLift, called Automated Crane Planning and Optimization (ACPO), which automates the process of checking the capacity of a crane and checking clearance of various components of cranes (e.g., boom, jib, car body, superlift, and rigging) with other lifting and non-lifting objects. ACPO also tries to find all lift logic and clash detection issues throughout the project. Implementing ACPO for practical case studies proves a number of benefits, including exploring various what-if scenarios in selecting types, configurations and locations of mobile cranes over the entirety of a modular construction project, ultimately reducing cost and enhancing safety.