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HEAVY LIFT ANALYSIS AT FEED STAGE FOR INDUSTRIAL PROJECT

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ABSTRACT

Modular construction has been a widely used method for industrial construction in Alberta. Heavy piperack modules are prefabricated and assembled offsite and transported to site for installation, which minimizes the impact of Alberta's harsh weather and improves efficiency. Such projects are large in scale, ranging from hundreds of modules to thousands; because of this, project planning often requires a relatively long period of time. At the front-end engineering design stage, information is limited, but the planning is critical for determining the appropriate cranes, locations, and lift sequences. To ensure sound planning, information must be extracted from the 3D models, which can be tedious without automation, and engineering analyses are required for crane location selection. This paper introduces a data-driven management system used for project planning. The outputs include selection of crane with locations considering site constraints. Valid automation is implemented in practice to achieve high efficiency.

1 INTRODUCTION

According to Government of Alberta statistics (Alberta Energy 2016), Alberta's oil sands contain the third largest oil reserves in the world, after Venezuela and Saudi Arabia; as of 2014, Alberta's proven oil sands reserves are 166 billion barrels. This lucrative resource has provided countless job opportunities in Alberta; (according to Statistics Canada, in 2014 approximately 133,052 people were employed in Alberta's upstream energy sector). To extract the oil, mega industrial facilities have been constructed, primarily in northern Alberta. As most of the construction sites are isolated geographically from cities and material suppliers, it is more economical to minimize the onsite construction work. Measures to minimize onsite work also serve to reduce the impact on onsite labor personnel of the harsh winter climate in northern Alberta. Modular construction has thus emerged as the preferred approach for constructing these industrial projects. As shown in Figure 1, a typical type of industrial module is a piperack module. These modules, which comprise pipes, cables, and equipment, are prefabricated off site and assembled in module yards, and are then transported by large trucks to the site, where onsite installation is carried out. There are many processes involved in the module supply chain, and one critical process is to use large-capacity mobile cranes to lift and install the assembled modules on site. Due to the important safety and cost aspects of large-capacity mobile crane use, planners must consider how crane re-locations can be minimized, (given that, every time the crane relocates, there are associated costs), and which crane configuration is optimal in terms of cost and schedule. Obtaining the answers to these questions is not easy: the engineering analysis is tedious due to the large number of lifting scenarios that must be analyzed. However, it is possible to find similarities in the engineering analysis process, which makes automation possible. PCL Industrial Management Inc. has collaborated with the University of Alberta to develop an automated decision support system that can reduce the human component involved in the engineering process. In this paper, the developed systems are introduced to showcase how automation can be applied to engineering analysis in the early stages of a project.

Figure 1: Typical industrial module.

Engineering systems for crane automation are not uncommon and have been described in a number of studies in the literature. In general, these studies can be categorized into the following: (i) crane type selection (Hanna and Lotfallah 1999; Al-Hussein et al. 2001; Sawhney and Mund 2002; Wu et al. 2011); (ii) crane location selection and analysis (Tam et al. 2001; Al-Hussein 2005; Huang et al. 2011; Safouhi et al. 2011; Marzouk and Abubakr 2016); (iii) crane lifting sequence and simulation (Al-Hussein et al. 2006; Lin et al. 2012; Taghaddos et al. 2012, 2014); and (iv) crane lifting visualization and path finding/planning (Reddy and Varghese 2002; Sivakumar et al. 2003; Chang et al. 2012; Zhang and Hammad 2012a, b; Lei et al. 2013a, b; Cai et al. 2016). As the capacity of computer calculation has increased over the years, more work has emerged which uses visualization to simulate crane lifting (Lei et al. 2015; Han et al. 2015). Although variations exist among the different systems, the data-driven concept is the foundation for each of these systems. PCL Industrial Management Inc.'s previous work with the University of Alberta is based on a server database which stores all crane and project information. As more 3D models are provided in the project, the conversion from data to 3D model, and vice versa, becomes important. Through the research collaborations mentioned above, PCL Industrial Management Inc. has achieved automated data exchange among various types of design software and the existing internal database. In this paper, an approach for analyzing the onsite crane utilization at the project's front-end engineering design (FEED) stage is introduced which includes crane configuration determination, crane location analysis, and crane lifting sequence using visualization tools. Many parts of this approach have been successfully automated.

2 FRONT-END ENGINEERING (FEED) CRANE ANALYSIS

2.1 Data Extraction from 3D Models

In the FEED stage, the objective for onsite crane lift analysis is to *identify possible crane configurations that can be used for the project and, based on these, to select corresponding crane locations to perform the lifts with determined sequence*. 3D models (conceptual and detailed models) are usually provided by the client complete with pertinent module specifications. For onsite crane lift analysis, the initial task is to extract the location and dimension information from these models. For example, piperack modules are limited by their building envelopes. (Figure 2 shows a Navisworks piperack model provided by the client.) There is a large volume of essential information for analyzing the lifts, and, at the FEED stage, module dimensions and weights are critical. The provided 3D model contains the coordinates of the module location, which can be extracted either manually or through automation. The automation requires programming using Navisworks Application Programming Interface (API) (see Autodesk Navisworks Developer Network for details). All the extracted information is stored in an in-house database developed by PCL Industrial Management Inc. This database also contains crane information necessary for analysis, such as the crane's geometric information (e.g., boom length/depth, tailswing length, lifting capacity chart provided by manufacturer, etc.). Figure 3 shows the user interface from PCL's database, which contains all the extracted information of the modules to be lifted. In addition to the module information, the site boundaries must be defined in order to identify the possible crane accessible areas. Areas that require site preparation or foundations are excluded from this stage of analysis. The method used to identify the boundaries is documented in previously published papers (Hermann et al. 2010; Safouhi et al. 2011).

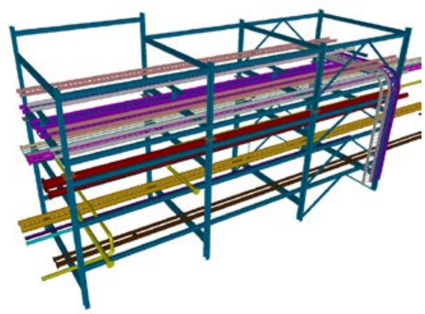


Figure 2: A piperack module sample from Navisworks model.

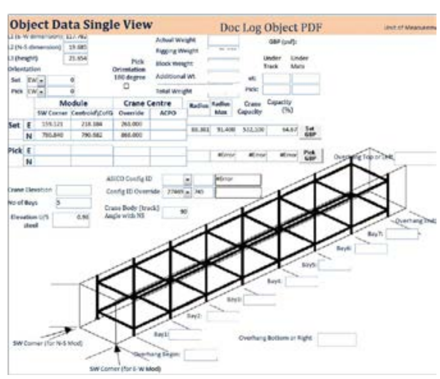


Figure 3: User interface for extracted information.

2.2 Crane Selection and Location Determination

Crane selection is based on various factors, but primarily the following: (i) whether or not the crane configuration has sufficient capacity to perform the lifts (determined by the heaviest module of the project); and (ii) whether or not the crane configuration allows sufficient clearance (boom/jib clearance and crane body clearance). Other factors may also affect the crane selection, such as the availability of cranes, and so on. Once potential crane configuration candidates are selected, all the lifted modules must be analyzed to ensure that the selected crane configurations are qualified for the job. When analyzing each lifting scenario, the crane's capacity must be checked by Equation (1), Equation (2), and Equation (3).

$$C_{Crane} \geq W_{Module} + W_{LoadBlock} + W_{Rigging} + W_{AdditionalWeight} \quad (1)$$

$$C_{Reeveing} \geq W_{Module} + W_{LoadBlock} + W_{Rigging} \quad (2)$$

$$C_{Rigging} \geq W_{Module} \quad (3)$$

where C_{Crane} = crane lifting capacity based on the given lifting radius (provided by crane's manufacturer); $C_{Reeveing}$ = reeving capacity, determined by the hoist line; $C_{Rigging}$ = rigging capacity, calculated separately based on the capacities of the components; W_{Module} = lifted module weight (in the FEED stage, since the module design has not been determined, the W_{Module} is determined by historical data; later, the estimated weight can be replaced with actual lifting weight); $W_{LoadBlock}$ = weight of the lifting hook block; $W_{Rigging}$ = rigging weight used for lifting; and $W_{AdditionalWeight}$ = auxiliary ball and runner weight. In a previously developed system, PCL Industrial Management Inc. has co-developed with University of Alberta an analysis system that includes the checking equations (Hermann et al. 2010). This system is capable of automatically finding all the crane locations based on the selected crane configuration. In the case study presented below, the outputs of this system are discussed.

2.3 Lifting Sequence and 4D Simulation

The lifting sequence depends on various site constraints, some of which are unavoidable: e.g., the upper modules must be installed after the installation of the bottom modules, and the connected modules (pipes running through both modules) must be installed in sequence. Also, different priorities are given to different locations, and the plot plan is divided into independent/dependent areas. The goal is to minimize the number of crane relocations on site and to reduce the size of crane mats needed; (crane mat analysis/optimization is beyond the scope of the research presented in this paper). In current practice, the sequence is determined based on the experience of crane planners; however, the challenge is to check the selected locations and sequence between the database and the 3D model. This is a laborious process due to the large number of lifts and the manual nature of the drafting process. An AutoCAD plug-in is developed in order to link the in-house crane database to the AutoCAD system so that the 3D lifting scenario can be generated automatically, which reduces markedly the human component in the process. The generated CAD model can be appended to the existing Navisworks models provided by the client, such that the sequence can be applied for 4D animation generation. Navisworks requires specific input formats for sequencing (e.g., CSV file, MS project file, etc.). Figure 4 shows a typical sample of the sequence that can be input into the Navisworks model and can be matched to items in the model.

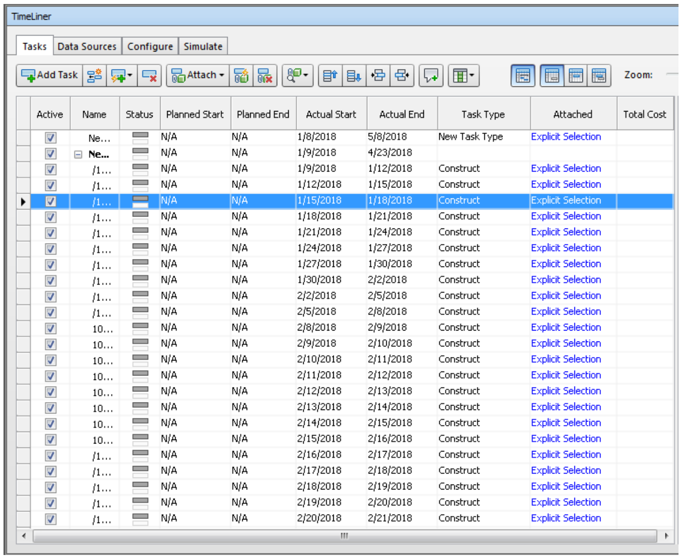


Figure 4: Sequencing using TimeLiner in Navisworks.

3 CASE STUDY AND DEMONSTRATION

In this section, the case of an industrial project is presented to demonstrate how the above described information technology is implemented. The project is at the FEED stage, and some information is missing due to the fact that the design has not been fixed. Module weights from previous projects are used as a benchmark for analysis based on the number of module bays. At the FEED stage, the maximum estimated weight (rather than average weight) is used so that constructability is always ensured. The planning process is a data digging and reflection process, where the raw data, such as dimensions and coordinates, is extracted from the 3D model. For the selected project, a total of 233 modules are identified, and all information is stored in the database as shown in Figure 5; (some information has been redacted in the interest of confidentiality). This information is further analyzed using the developed advanced crane planning and optimization (ACPO) system in order to identify potential crane configuration candidates. Figure 6 is an output screenshot from the ACPO system with possible crane locations (brown dots), where the green boxes are the lifted modules at their set locations. The crane locations are further analyzed and plotted in AutoCAD using the developed automatic plug-in system and are linked to the Navisworks model for the purpose of 4D animation. Figure 7 depicts the 3D model development from (i) the original 3D model to (vi) the model with selected cranes at its lifting location.

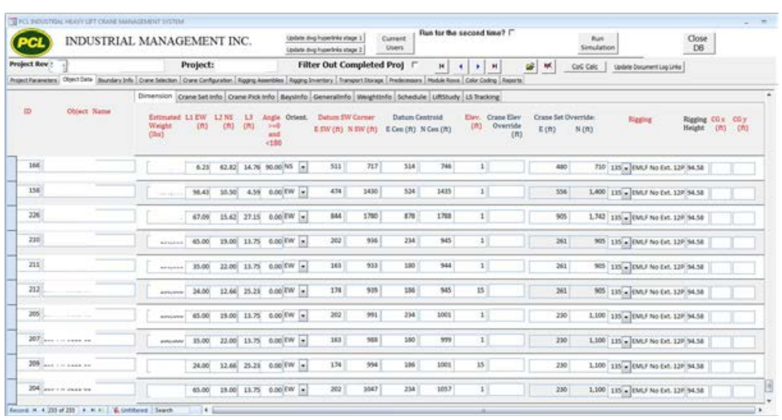


Figure 5: Module information storage in database.

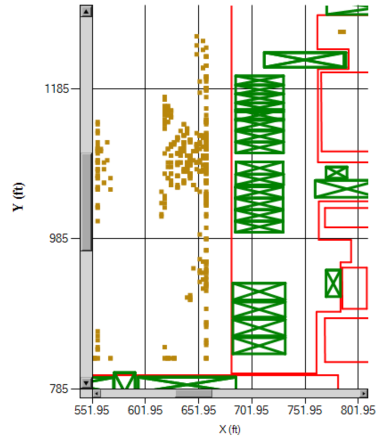


Figure 6: Crane locations and modules at set locations from ACPO system.

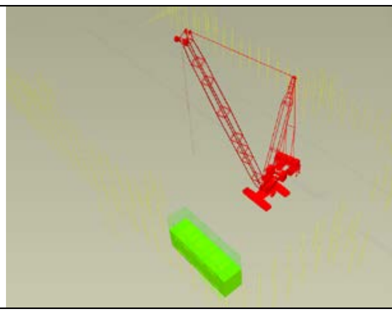
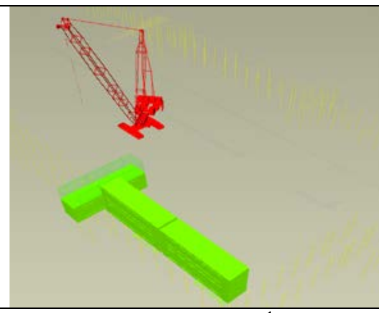
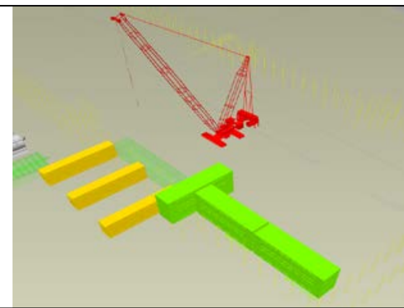
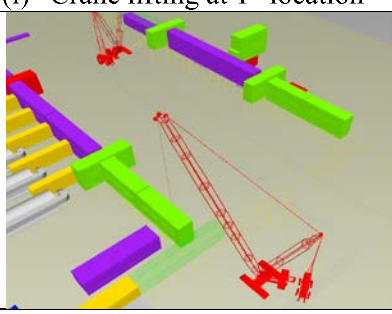
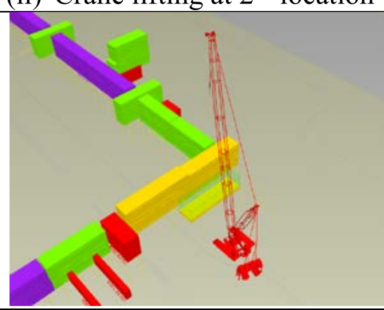
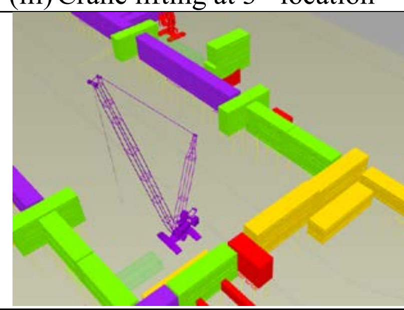
		
(i) Crane lifting at 1st location	(ii) Crane lifting at 2nd location	(iii) Crane lifting at 3rd location
		
(iv) Screenshot4	(v) Screenshot5	(vi) Screenshot6

Figure 7: 4D animation screenshots.

4 CONCLUSIONS AND FUTURE WORKS

This paper introduced the practice of data extraction from Navisworks model at the project's FEED stage and use of the data for analysis and for formulating plans for onsite lifting. The main extracted data from the model are the dimensions of lifted modules, which are entered into a server database. Other database information needed for engineering analysis includes crane geometric information and lifting capacity data. Potential crane configurations are then selected for analysis through an automated crane location selection system, and, based on the selected crane configuration, locations are determined. An AutoCAD plug-in is developed in order to automatically plot crane models in a 3D environment, which is eventually linked with the Navisworks model. A .csv file is used to create a lifting schedule in Navisworks. In future, there is a research opportunity to automate the crane lifting sequencing process using mathematical algorithms and tools. In this case, the cost of different crane operations will be considered (e.g., a penalty needs to be applied to cases of crane movement from one location to the other in order to minimize onsite crane movement).

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