INTEGRATING MOBILE CRANE LIFT PATH CHECKS INTO AN INDUSTRIAL CRANE MANAGEMENT SYSTEM

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ABSTRACT

In Alberta, Canada, heavy industrial projects are constructed using a prefabrication approach: spools and pipes are produced in the factory, and are assembled into modules that are transported to the industrial plants for installation by mobile cranes. Planning the onsite mobile crane operations is critical to the project budget and schedule. However, due to the large magnitude of industrial projects, manual heavy lift planning is tedious, and the results are not particularly responsive to site changes. This paper introduces an integrated mobile crane management system developed by PCL Industrial Management Inc., in collaboration with the University of Alberta, which investigates crane location selection and path checking for field module assembly. The project information is stored in a database, and the proposed system retrieves data, performs the calculations, and records the results back to the database; the calculations involve automatically selecting locations for the mobile crane, considering the crane capacity, lifting range and utilization. Lift paths for modules are checked for feasibility based on selected locations, satisfying the site and crane configuration constraints, and crane walking paths are planned if needed. The designed system is tested in an industrial project to validate the effectiveness of the system.

KEYWORDS

Industrial projects, heavy lifts, mobile crane, path checking, location selection

INTRODUCTION

Modularization has been widely adopted in Alberta, Canada for constructing industrial projects. The project structures are built by the stacked modules, which have been prefabricated off-site with various components, such as spools and pipes. The completed modules are transported to the site and erected using mobile cranes. The management of field crane operations is closely related to the project budget and schedule, where incomplete planning can result in project cost increases and schedule delays while deliberate planning can improve productivity and enhance safety. Traditionally, heavy lifts are planned by engineers based on their experience and intuition. However, the nature of industrial projects makes heavy lift planning challenging for the following reasons: (1) industrial projects consist of a large number of lifts, and the manual-based planning procedure is lengthy and the planned results are difficult to update; and (2) compared with typical building construction sites, industrial project sites are usually highly complex and congested. Thus, integrated and automated systems are required for efficient planning and management of industrial projects. A considerable body of research exists which investigates the efficient management of crane operations: crane type and location selection (Hanna & Lotfallah, 1999; Al-Hussein et al., 2001; Sawhney & Mund, 2002; Wu et al., 2011); crane path planning (Sivakumar et al., 2003; Chang et al., 2012; Olearczyk et al., 2012; Zhang & Hammad, 2012a; Zhang & Hammad, 2012b; Lei et al., 2013); and lift supply location optimization and lift sequencing (Huang et al., 2011; Lin et al., 2012; Taghaddos et al., 2012). Furthermore, 3D and 4D tools have been utilized to support visualization of crane operations and detection of potential conflicts (Kang & Miranda, 2006; Kang et al., 2009; AlBahnassi & Hammad, 2012;

Wu et al., 2011). In Alberta, Canada, PCL Industrial Management Inc. has been collaborating with the University of Alberta on the development of computer applications to assist with heavy lift planning for industrial projects. An original system prototype, an Advanced Crane Planning and Optimization (ACPO) program, has been proposed by Hermann et al. (2010) which focuses on automating the process of selecting a suitable mobile crane, positioning it, and simulating the operation processes. Automation has been achieved by implementing the designed algorithms in the programming environment, which links to the company's central database where the project and crane information is stored. Based on this prototype, efforts have been made to extend the system's functions: Taghaddos et al. (2012) have presented a simulation agent which is applied to industrial projects to track the availability of resources; Lei et al. (2013) have introduced an algorithm for checking mobile lift paths. All of these developed programs communicate with one another on a regular basis. This paper introduces the most recently developed system, which focuses on crane selection and path planning.

SYSTEM OVERVIEW

The core of the crane management system is a company's central database, which stores the crane and project information and the computed results. Currently, the database stores 300 cranes, 26,000 crane configurations, and 394,000 capacity entries. All the information is entered manually or through a customized AutoCAD interface that retrieves the data from the electronic drawings automatically. Other than the database, the entire system consists of four main components: (1) Advanced Crane Planning and Optimization (ACPO) program: calculates the crane position work area, considering the crane's tail-swing and site boundaries; (2) Advanced Simulation in Industrial Crane Operations (ASICO) program: determines the lifting sequence according to pre-defined lift logic constraints; (3) Crane Path Checking and Planning (CPCP) program: checks whether or not the crane has a feasible lift path for the selected crane locations, and, if not, plans the crane walking with loads; and (4) 4D animation: presents snapshots of crane operations at different time phases. The system performs the calculations following the sequence presented in Figure 1. The sequence begins with recording the inputs to the company's central database. The inputs include the site boundaries, and lifted module information (weights, dimensions, etc.). Once all the inputs have been stored in the database, the ACPO reads the data and performs calculations to select the potential crane locations, considering the crane's configuration and the site boundaries. Meanwhile, the ASICO takes the module's spatial logic constraints into consideration in generating the lifting sequence. The CPCP then uses the results generated by the ACPO and ASICO to determine whether or not the crane has a feasible lift path at the selected locations; in the case where the crane does not have feasible lift paths, the CPCP subsequently calculates a crane walking path that will allow the crane to pick the lifted module from an open area and then walk to its set location. In the end, the 4D animation module allows for visualization of the calculated results. Meanwhile, all the developed systems communicate with and provide feedback to one another. In the following sections, the different system components will be discussed individually.

Crane Location Selection

Crane location selection involves analyses of several factors, such as the crane's geometry and site constraints. On industrial sites, an area where the crane can be settled to perform the lifts without any conflict with the surroundings is called the mobile crane position work area. In defining the crane position work area, two site constraints are considered: (1) the Inside Boundary Limit (ISBL); and (2) the Outside Boundary Limit (OSBL). An ISBL is a set of 2D points that defines an area onsite which is unavailable for crane positioning; the OSBL defines the outer limits of the project site (see Figure 2a for a typical industrial project site represented by the ISBLs and OSBL). Based on the ISBL and OSBL, the crane's tail-swing geometry is used to create the crane position work area (A detailed algorithm for cranes without tail-swing has been presented by Safouhi et al. (2011)). Meanwhile, the entire site is gridded (Figure 2b) and the grid points located in the crane position work area are obtained (Figure 2c). Based on these obtained grid points, the points where the crane has sufficient capacity and boom clearance to lift the modules are selected as possible crane locations (Figure 2d). However, these locations may not be applicable for performing the lifts, and thus need to be passed to the Crane Path Checking and Planning (CPCP) program for further checking.

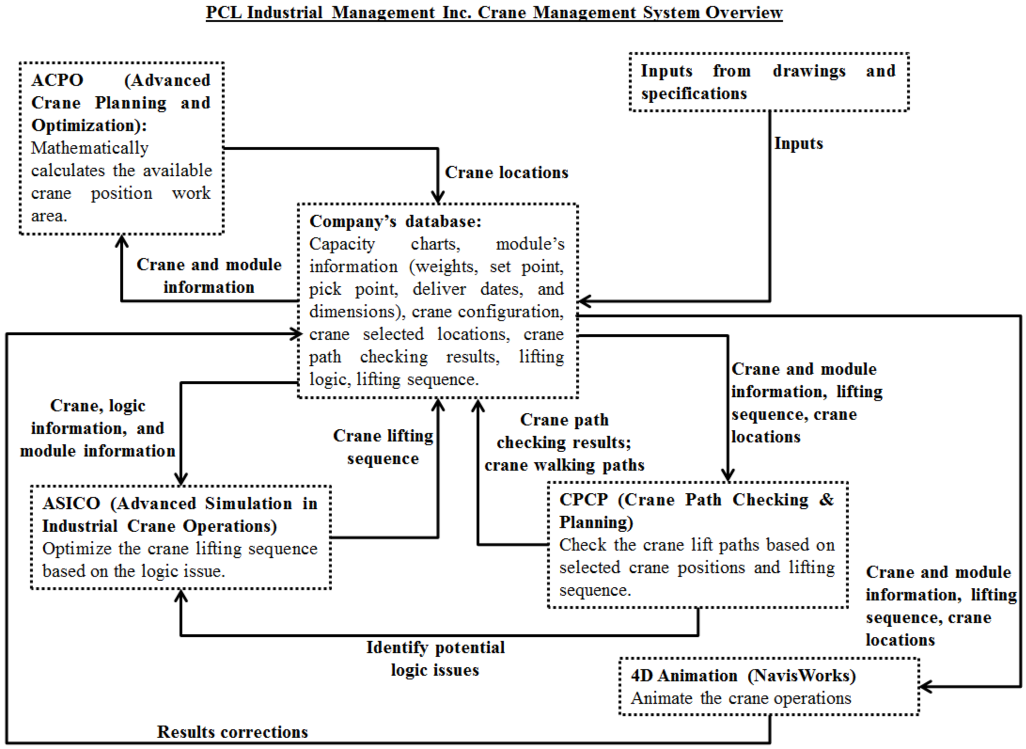


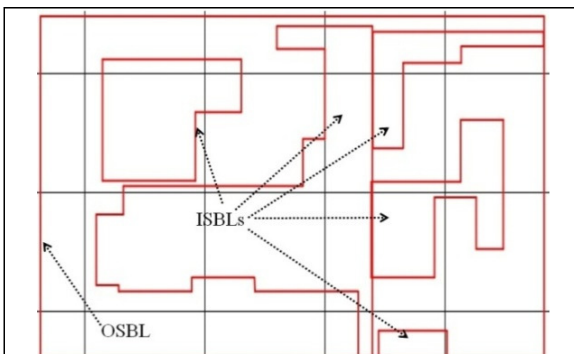
Figure 1 – PCL Industrial Management Inc. crane management system overview

Crane Lift Sequencing

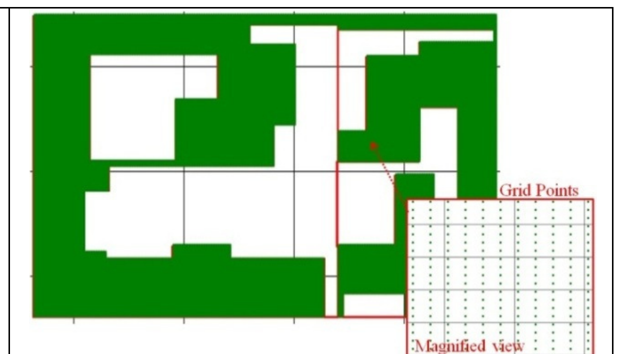
Field construction of the assembled modular is the last step in industrial project construction. The sequence of lifting these modules has a significant impact on project cost and schedule. The process of planning the lift sequence is quite complex and must accommodate several logical considerations (Taghaddos et al. 2010), outlined as follows: (1) it is efficient to erect the modules in sequence rather than randomly placing them on the site; (2) it is technically challenging to place a module between two adjacent modules; (3) the module at the bottom position should precede the above modules on the lift sequence; (4) for some predefined areas, cranes are only available for a limited period of time; and (5) once a given module is installed on site, the occupied area is no longer available, such that the newly installed module becomes a site constraint. Based on these constraints, Taghaddos et al. (2010) have proposed a computer-aided system, ASICO (mentioned above), to be used in arranging the field construction lift sequence. A case of implementation of this system has been presented by Taghaddos et al. (2012). The outputs of the system include: (1) selection of suitable mobile cranes for all lifts during the project period; and (2) a lifting schedule satisfying the availability and accessibility of the cranes, which considers crane mobilization and demobilization time, initial locations, configurations, and riggings. The generated outputs are visualized in a 4D animation module, and the produced lifting sequence is used for the CPCP as one of the inputs. One limitation of the current system is that once the CPCP identifies the crane locations that do not have lift paths, the results must be fed back into the ASICO for re-planning of the sequence. Research efforts are ongoing to solve this problem, with two alternative strategies currently underway: (1) establish a loop mechanism between ASICO and CPCP to optimize the lifting sequence; and (2) integrate the CPCP algorithms into the current ASICO system in order to identify the logical constraint once and thus generate a more reasonable sequence without any loop calculation.

Crane Path Checking and Planning

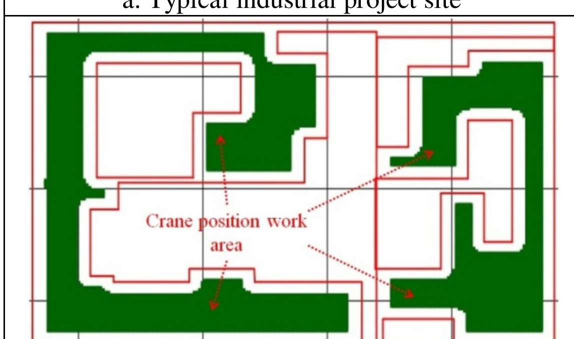
CPCP comprises (1) lift path checking; and (2) crane walking path planning. The detailed algorithm for the lift path checking has been proposed by Lei et al. (2013). The lift path checking is performed based on the results of ACPO and ASICO; (ACPO generates all the possible crane locations, and ASICO calculates the lift sequence). A crane's maximum and minimum lift radii (R_{max} and R_{min}) are calculated based on the crane capacity and configuration, which are modified based on the given site constraints. A configuration space approach is used to simplify the work space. Figure 3a presents an industrial project site with all the lifted modules at their set positions, with all the potential crane locations calculated using ACPO (shown as dots in Figure 3b). The lift path checking is carried out for each of the selected crane locations. Figures 3c to 3h show an example of lift path checking for one selected crane location (the lifted module is Module 141). Figure 3c presents the case scenario, where several modules have been installed. The crane's R_{min} and R_{max} are calculated based on crane capacity, module weight, rigging requirement, and boom clearance (Figure 3d). However, due to other site constraints, the calculated R_{min} and R_{max} cannot represent the crane's actual feasible operation area. The crane feasible operation area and pick area are calculated considering crane configuration and module geometry (Figures 3e and 3f). Figures 3g and 3h present the side view and perspective view of the case scenario, where the crane boom is at the module's set position and sufficient boom clearance is provided for the lift. By merging the crane feasible operation area and the pick area, the lift path for Module 141 can be arranged (Figure 4). However, in some congested areas, the mobile crane is unable to place modules from a stationary position, and instead the crane needs to walk with the load. In Figure 5, the process of planning crane walking paths is presented. For each lifted module, each crane location that has failed the path check is entered for walking path planning. The crane collision-free operation area is determined based on the length of the mobile crane's tail-swing, and the pick area for the module is calculated considering the module's geometric size and layout. Based on the crane collision free operation area and the pick area, the crane's walking path is planned. The algorithm for crane walking path planning is currently under development, and will be implemented in the near future.



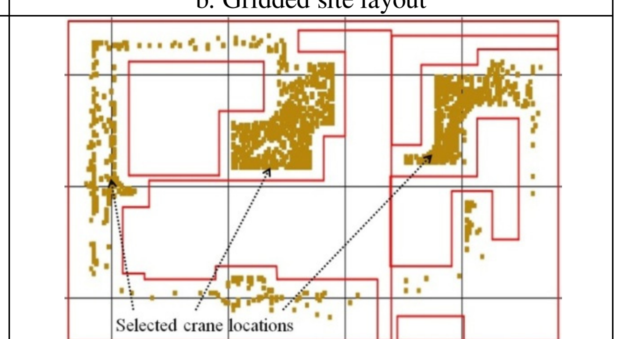
a. Typical industrial project site



b. Gridded site layout

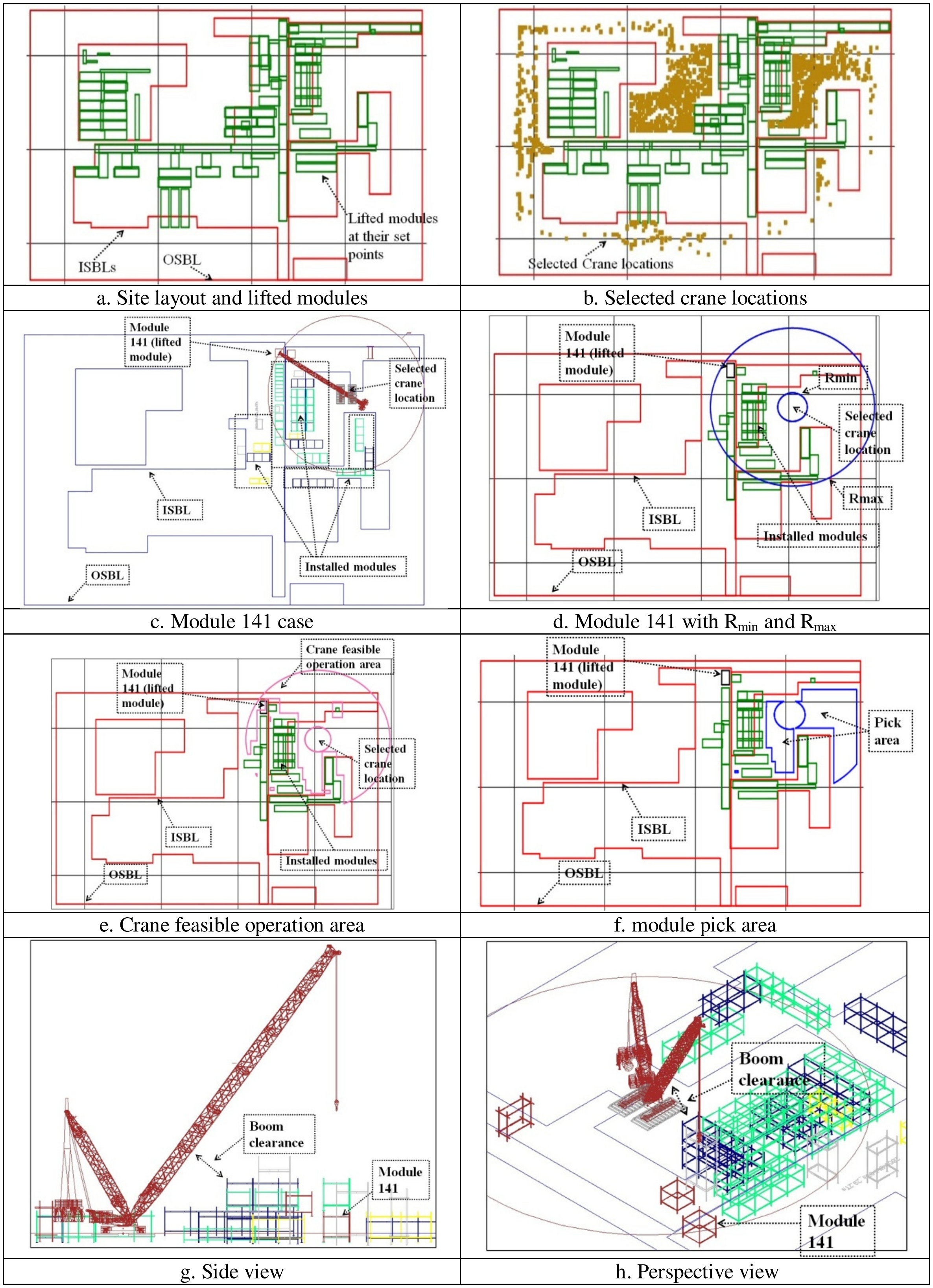


c. Crane position work area



d. Selected crane locations

Figure 2 – Crane location selection



a. Site layout and lifted modules

b. Selected crane locations

c. Module 141 case

d. Module 141 with R_{min} and R_{max}

e. Crane feasible operation area

f. module pick area

g. Side view

h. Perspective view

Figure 3 – Crane lift path planning case

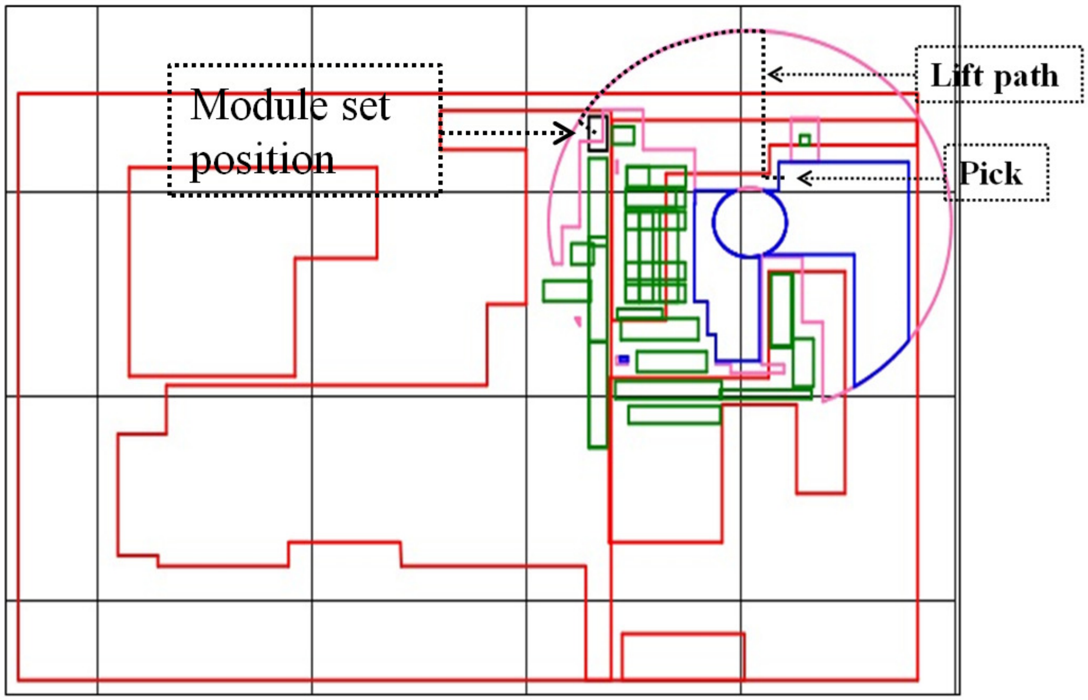


Figure 4 – Lift path solution

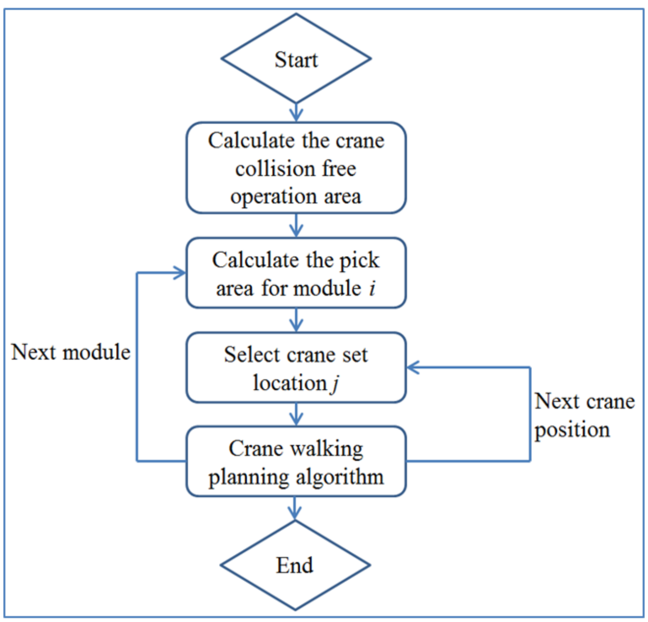


Figure 5 – Crane walking path planning process

IMPLEMENTATION

The developed system has been applied and tested as part of an ongoing industrial project by PCL Industrial Management Inc. This project features the onsite installation of 170 modules in a relatively congested scenario. The mobile crane used for the analysis is Demag CC 2800 with a superlift equipment.

The system is implemented within a Visual Studio 2010 (VB.Net) environment. Based on the layout and module information, a total of 17,619 crane locations have been selected, 13,739 of which have satisfied the constraints for lift path checking. Thus, 78% of all the selected crane locations have lift paths without the necessity for crane walking. Implementation of the system has proven the effectiveness and efficiency of the developed system. However, the application has also exposed some shortcomings of the current system. For instance, the schedule used for CPCP is based on the results from ASICO. After running the CPCP, there are still some crane locations that do not have lift paths and for which crane walking is not possible. Alternatives need to be provided for these points by adjusting the lift sequences. This requires repetitive calculations among different components of the system. In order to avoid this, further integration of the developed system needs to be achieved in future research.

CONCLUSIONS AND FUTURE WORK

This paper has introduced an integrated crane management system for industrial projects. The sub-system, ACPO, selects the possible crane locations based on the site layout (ISBL and OSBL), and the configuration of the mobile crane. The entire site layout is gridded, with the points that satisfy the crane capacity and boom clearance requirements recorded as possible crane locations for lifted modules. Meanwhile, another sub-system, ASICO, performs the schedule calculations based on the lift logical constraints. The CPCP then takes the results from ACPO (crane locations) and the lift schedule from ASICO, and conducts the path checking for each selected crane location. The failed locations are further checked if crane walking is possible. Throughout the calculation process, input data and final results are stored in the company's central database. Each sub-system can perform the calculations independently as well as integrate with other systems. The developed system involves originally developed algorithms as well as adoptions from other domains, such as robotics. Also, this system contributes by greatly reducing the human effort involved in the heavy lift planning process. Based on their current progress, the authors plan to explore other possibilities in the future: (1) since the lift sequence determination precedes the path checking, the lift sequence may be adjusted following utilization of the CPCP. The authors plan to integrate parts of the CPCP algorithms into ASICO such that the lift sequence can be determined and loop calculations avoided; (2) crane walking path planning is currently under development, and is expected to be implemented soon; and (3) 4D animation of the detailed crane operations will be developed to assist practitioners in visualizing site layout and detecting potential conflicts.

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