Development of a Computer Aided Critical Lift Planning System Using Parametric Modeling Software

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Abstract

Construction industry has seen a tremendous growth in developing countries in the past few decades. Millions of dollars are annually spent by the industrial owners and the contractors on critical operations in the construction industry. With the intense demand for rapid construction of infrastructure, construction industry faces the challenges of completing projects in a shorter duration. Further, the decreased availability of skilled resources compounds the problem further.

Critical lifts are important but risky activity which has major impact on the construction safety, cost and the schedule. The level of technology that is available in the present construction industry for critical lift planning is limited to 2D drawings and a few Computer aided lift planning software (Hornaday et al. (1997)). The current software tools have many limitations. This paper discusses the work done towards the development of the Computer aided Critical lift planning system using Parametric Modeling software Autodesk Inventor. This platform is used for the first time in developing computer aided lift planning software. The system developed is evaluated using a case study taken from a refinery site, the results obtained are encouraging and demonstrates the potential to improve the overall lift planning process.

Keywords: Autodesk Inventor**,** Critical Lift planning, Cranes, 3D Simulation

Introduction

Critical lift projects involve the erection of equipments at congested locations, within an industrial facility. Planning and lifting such equipment has become difficult due to constraints in space, schedule and dynamic nature of the site. Traditional critical lift planning process requires months of planning. Inadequate planning of these lifts can lead to accidents as well as expenses in the form of damages, schedule delays, and indirect costs incurred due to the accidents.

Cranes are commonly used equipment in almost all the industrial construction operations. The advancements in the cranes have brought a tremendous change in the construction practices. Cranes have increased tremendously in size, capacity and versatility in the last few decades prompting the user to execute increasingly larger, heavier and thus the riskier lifts.

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The current work attempts to develop a computer aided Critical Lift Planning System, which can improve the productivity and the reliability of the overall lift plan. A number of attempts have been made in the past to computerize the heavy lift planning process. These were based on CAD packages or stand-alone software as a result only a few features of the heavy lift plan could be effectively computerized.

The objective of the present work is to develop the lift planning system using the Parametric Modeling software, Autodesk Inventor. In using a parametric model, it is expected that the additional features for an efficient and optimal heavy lift planning can be incorporated.

The paper is organized into six sections. The next section presents a review of the past work in computerized heavy lift planning. The third section discusses the limitations in using CAD platforms and the benefits of the parametric modeling platform. The fourth section presents an overview of the system architecture; this is followed by a detailed description of the unique futures resulting from the current development. The sixth section illustrates the usage of the system and finally the conclusions from the study are presented.

Review of the Research work

The previous works that have been done in the area of heavy lift planning are divided in to two categories. 1. Single Lift Scenario, 2. Multi Lift Scenario (using single crane for multiple lifts) In the area of single lift Scenario Varghese et al. (1997) has developed software called HeLPS (Heavy Lift Planning System) and for critical constructions operations Lin and Haas (1996) has developed software COPE based on interactive approach for optimizing the crane locations.

In the area of multi lift planning Reddy et al. (2007) developed software called MLPS (Multiple Lift Planning System) using the AutoCAD modeling environment. Sainath (2008) has developed software called MHLPS (Multiple Heavy Lift Planning System) using Autodesk Inventor, which has very good crane selection platform but both developments does not have clearance checking, bearing pressure calculations and are limited to single crane lift simulation.

All the computer aided systems developed used the basic CAD platforms like Micro-station and AutoCAD. All these platforms have limited features for the planning process. Further, previous research on Heavy Lift Planning process has concentrated more on the planning of the final erection of equipment and given less priority to areas such as tailing crane modeling, rigging detailing and mat design required for a successful lift.

Hence the present work addresses the aforementioned issues by the integration and automation of the planning processes of heavy lifts using the Parametric modeling platform Autodesk Inventor to develop software called Critical Lift Planning System (CLPS) for multiple lifts.

Need for changing to Autodesk Inventor

The popular CAD package AutoCAD, is based on a geometry driven design where as Inventor is a dimension driven design. The dimension driven approach is very helpful in modeling crane parts like Boom and Mast whose lengths has to be changed frequently. Boom length is

altered by varying the parameters in Inventor where as Dynamic blocks are used to achieve this on AutoCAD.

In AutoCAD every time the design changes, user needs to manually reposition or redraw every affected item, and manually ensure that the design remains within the proper criteria, whereas Inventor retains the intelligence of the design, so that any changes made to the design will always fall within the proper criteria. Equations and interrelationships can be made that actually contain the design criteria necessary for a successful project.

The 3D parts in Inventor such as each extrusion, chamfer, fillet, and so forth, is stored as an independent feature in the browser. This makes it easy to make changes to features whenever the design changes. In AutoCAD, the user has to delete and re-create a specific feature. Such changes in Autodesk Inventor are as easy as changing the dimension value.

Standard Inventor content and models completed by Inventor users are generally much more detailed and consumes less time compared to AutoCAD. AutoCAD solid objects are not very flexible to the user.

The most important feature of the Inventor is Content Center from where we can import the standard parts and the custom created parts by user in to our design without creating from scratch, which saves lot of design time. Rigging attachments like slings, shackles and spreader beams can be stored in the content center and can be imported in to the project.

Autodesk Inventor eliminates the use of complicated layers concept in AutoCAD. Master-Slave relationships in AutoCAD can be replaced by Assemblies in Inventor for controlling crane degrees of freedom.

Interference detection in Inventor calculates the volume of interference of the mating parts which is missing in AutoCAD. In AutoCAD the clearance checking is done for point to point or line to line or a point, where as in Inventor distance can be found from faces, work planes, edges and points which is accurate as we will be drawing exact 3D models.

Customization and programming of Inventor is less difficult compared to AutoCAD. Constraints concepts in Inventor replaced the usage of transformations for boom luffing and cabin slewing.

Rigging attachments which are done by joining lines in AutoCAD can be replaced by exact 3D slings and shackles using Inventor and which gives better results in critical lifts.

System Architecture

The Basic System Architecture is as shown in Figure1. Autodesk Inventor 2010 is chosen as the platform for developing the CLPS, by customizing it through the API (Application Programming interface) using Visual Basic (VB) 2008 as the programming language. Graphic User Interface (GUI) is created in the VB.net and the add-ins for controlling the various degrees of freedom of the crane are created in the assembly environment of the Inventor using VB. Load charts data is stored in Microsoft Access. During the run time Visual basic interacts with both Inventor and Microsoft Access Database.
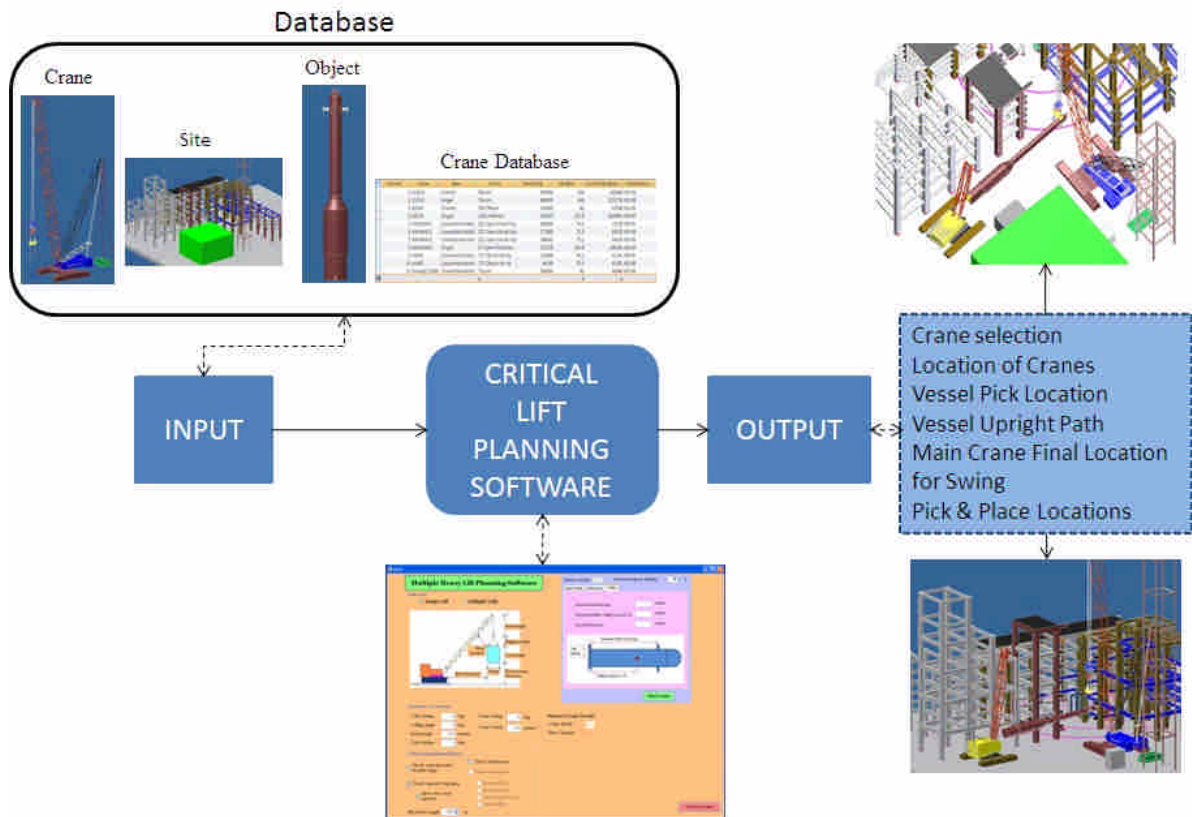
Figure 1. Basic system architecture

The individual parts of the crane are modeled in the part environment and they are assembled in the assembly environment of the Inventor. During the modeling the care should be taken such that the developed models will meet the requirements of the CLPS, like for automatic boom length change, modeling should be done in accordance to coding written for boom length adjust logic, same as for the wire rope length change for hoisting by controlling the rope length parameter.

The inputs to the system includes both Graphic and Non-Graphic data and which upon processing the CLPS will give outputs as crane selection, location of cranes, vessel pick and place locations and the simulation of the lift-path which is as shown in Figure 1.

The basic structure of the system consists of two databases called Graphic and Non-Graphic databases. Graphic database includes 3D models of various cranes models, 3D site layout, Object models and the Rigging attachments like Slings and shackles.

Non-Graphic data like load chart details are developed in the Microsoft Access database for various cranes used in the industry.

The Output parameters and CLPS will be explained in detail in Key Features and Critical Lift Planning Software sections.

Key Features

The key features of the developed software includes Crane Selection, Manipulation of Crane Degrees Of Freedom(DOF), Capacity monitoring, Tailing Loads monitor, Dynamic Clearance & Interference Checking, Sling Load Calculator, Ground Bearing pressure Monitor, Crane Mat design.
    These features are discussed in this section.

Crane Selection

Feasible Cranes and configurations are as shown in the Figure 2. CLPS allows the user to select the right crane based on the user entered crane parameters for a particular lift like physical dimensions of the equipment and the standard clearances required. It then displays the feasible cranes list along with their feasible configurations. Each crane will have at least one feasible configuration for each load to be lifted. The details of the configurations for the highlighted crane, like boom length and the corresponding minimum and maximum operating radius with their capacities are displayed in a separate table as shown in Figure 2. The overall planning logic used is shown in Figure 3, the most appropriate crane that satisfies the criteria will be selected for erection.

	Crane ID	Crane	Base	Boom	Max Capacity (Kg)	Max Boom Length (m)	Counter Weigth (Kg)	Other Details
	4	A9320	Ringer	118S HHBoom	326580	115.8	2630884	NOJIB
	5	M4100WS1	CrawlerExtended	22C Open throat top	181400	79.2	55520	NOJIB
	6	M4100WS1	CrawlerRetracted	22C Open throat top	177800	79.2	55520	NOJIB
	8	M4100WS3	Ringer	27 Open throat top	272100	103.6	180240	NOJIB
▶	11	DemagCC2600	CrawlerRetracted	Tboom	500000	90	50000	NOJIB

Details of : 11DemagCC2600CrawlerRetracted   [Done]

	Load Entity	Boom Length (meters)	Min Op rad / Capacity	Max Op rad / Capacity
▶	Load 1			
		42	8 / 435000	16 / 165000
		48	9 / 395000	16 / 164000
		54	9 / 350000	16 / 174000
		60	9 / 310000	16 / 173000
		66	10 / 285000	16 / 172000
		72	10 / 263000	16 / 171000
		78	12 / 230000	16 / 170000
		84	12 / 203000	16 / 169000
		90	12 / 180000	16 / 168000

Figure 2. Feasible cranes and configurations

Manipulation of crane DOF

Customized panels are created in the Autodesk Inventor assembly environment to control the Crane degrees of freedom which are as shown in Figure 5. By using this add-ins the 3D models of cranes can be virtually moved in the 3D site layout to pick and place the equipment in the final location. The degrees of freedom that are controlled in the system are crane marching, Crane rotation, boom luffing, cabin box swing, hoisting, boom length change and

the load rotation. The crane movement and across the site and the crane placement at the final location for erection can be tested by simulating the crane in the 3D site.
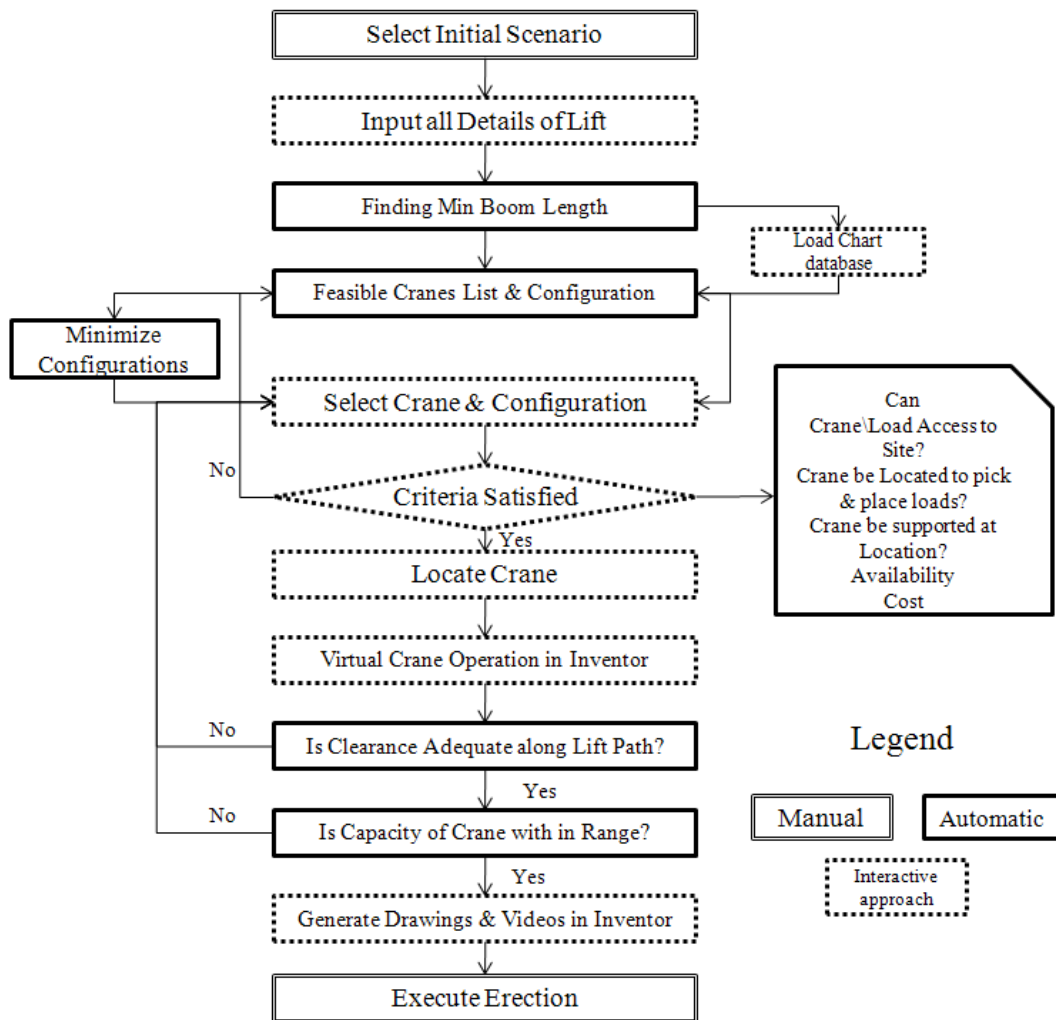

Figure 3. Overall planning logic

Capacity monitoring

The capacity and the operating radius will be monitored in the crane parameters form as shown in Figure 5. Capacity is monitored dynamically throughout the virtual erection. This can be done by connecting the Access database which has the load chart data of the various cranes, to the inventor module. The capacity is calculated based on the operating radius which is measured dynamically and the percentage capacity is displayed to check if the capacity exceeds the allowable limit set by the user.

Tailing Loads Monitor

During the equipment tailing the loads that are coming on to both the cranes are continuously monitored based on the change in the angle of the equipment and will be displayed in the Tailing loads monitor form which is as shown in Figure 5. Vessel angle is the only dynamic variable which needs to be found from the virtual erection scenario for load calculation.

Dynamic Clearance & Interference checking

The clearance monitor form is as shown in Figure 5. For each movement of the crane the clearances are continuously monitored and displayed in the clearance monitoring form. The previous approaches for finding the clearance are quite unproductive because it creates bounding boxes with a specified distance enveloping the part. This doesn't give the exact clearances which are required for critical lifts. Present work addresses this issue by using the concept of work plane at the desired face E.g. Boom front face, and finding the distance between the equipment and the work plane. The parametric modeling features of the software facilitate the work plane creation.

Checking interference

Interference checking is one of the important features of CLPS provided by the parametric modeling software. Assembly environment of Inventor has the advantage of finding interference between two collections of components and also inside a collection of objects. This feature is customized by creating a collection set which has boom and site models as one entity and the other collection set has Object/Vessel as an entity. The interference is found between these two collection sets, and if the interference is detected it will pop up a message box prompting the user to go back to the previous position in the lift.

Sling Load Calculator

The loads that are coming on to the slings are calculated based on the sling angle and the object weight. In addition to sling load, the sling capacity utilization and the minimum sling length needed and the required headroom is calculated.

Ground bearing pressure monitor

This feature provides the option to calculate the soil reactions for 360° swing/Slew of a crane cabin. The pressure exerted by the tracks/outriggers on the supporting surfaces is calculated and displayed. For a crawler crane the pressure diagram based on the length of the track and for a truck crane it is based on the outrigger reactions. It also takes into consideration the change in the allowable boom angle for the particular boom length. Further, it also calculates the maximum and minimum pressures on both the boom side and the counterweight side.

Shafiul Hasan et al.(2010) has developed a model which calculates the Ground bearing reactions and their subsequent mat design, but that is limited to offline monitoring. The present work addresses this issue by monitoring the crane reactions continuously during the virtual lift process.

Crane Mat design or Crane supporting system's design

Based on the reactions obtained from the Ground bearing pressure monitor the crane mat design will be done. Apart from the reactions user has an option to choose the type of timber to be used and the timber dimensions along with the allowable bending and shear stresses. The output form shows the mat design for both Timber and Steel plate and also it displays whether the shear and bending stresses are within the allowable limits.
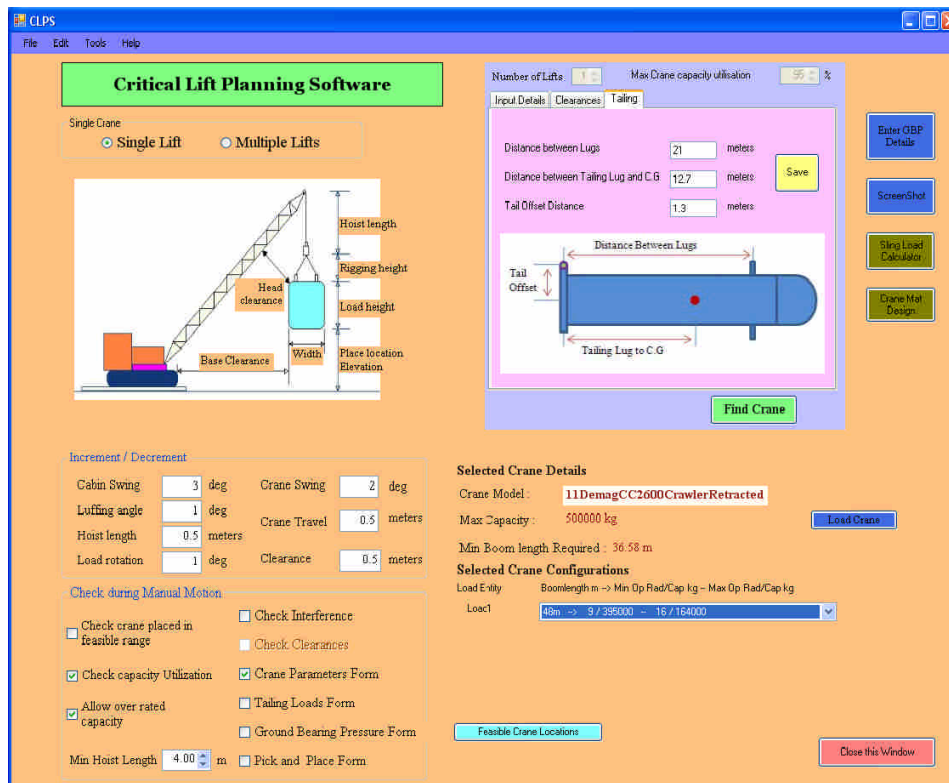

Figure 4. Critical Lift Planning Software Graphic User Interface

Critical Lift Planning Software

The program starts with user entering data in to the Graphic User Interface (GUI) in the respective tabs of Input Details, Clearances & Tailing Details such as Centre of gravity location relative to the lugs which are shown in the Figure 4. Then the user connects the crane load chart database which is an Access database file by clicking on the Find crane button. This results in a display of the feasible cranes with their respective configurations based on the minimum boom length and the load weight which is as shown in Figure 2. From the displayed crane list, the crane which satisfies the criteria mentioned in the overall planning logic will be selected. Based on the selected boom length by the user the boom of the crane will be set.

Then with equipment place location as centre, the system will draw two circles with radii as minimum and maximum radius allowable for a particular boom length as indicated in Figure 5. The crane has to be located in the region between the two circles for placing the equipment safely without exceeding the capacity.

The virtual erection starts with upright/ tailing of the equipment using two cranes, which are the main crane for placing the equipment and tailing crane for making equipment vertical, and the loads that are coming on to the both the cranes are continuously monitored based on the angle of the equipment with the horizontal and the respective loads will be displayed in the tailing loads monitor form as shown in Figure 5.

Once the equipment comes to vertical position the tailing crane will be released and based on the type of the erection either the crane will move with the load or it swings with the load and if necessary it can luff and to place the equipment in its final location.

For each movement of the crane the clearances will be found and will be displayed in the crane parameters monitor form. If the clearance is less than the allowable clearance set by the user in the main form as shown in Figure 4, then the user will be prompted with a messagebox warning the user to go back to the previous position

During the process the capacity will be continuously monitored based on the operating radius. If the capacity exceeds the desired limit the user will be prompted with a messagebox, warning the user that the capacity has exceeded the desired limit. The load pick location and the place location will be stored in the output form.

Capacity of the slings being used will be tested based on the Sling angle and the load weight and the number of slings used, the capacity utilization of the slings and the minimum sling length and the head room required is displayed.

User is provided with a wide variety of options like Clearance finding, Interference detection, Tailing loads monitor, Ground bearing pressure and reactions, crane mat design and sling load calculator as shown in Figure 4. These are as shown in Figure 4 as check boxes, for Critical lifts all these features will be included by clicking all the checkboxes. For non critical lifts some of the features can be unchecked like ground bearing pressure and mat design calculations as it will save the processing time and the memory of the program.
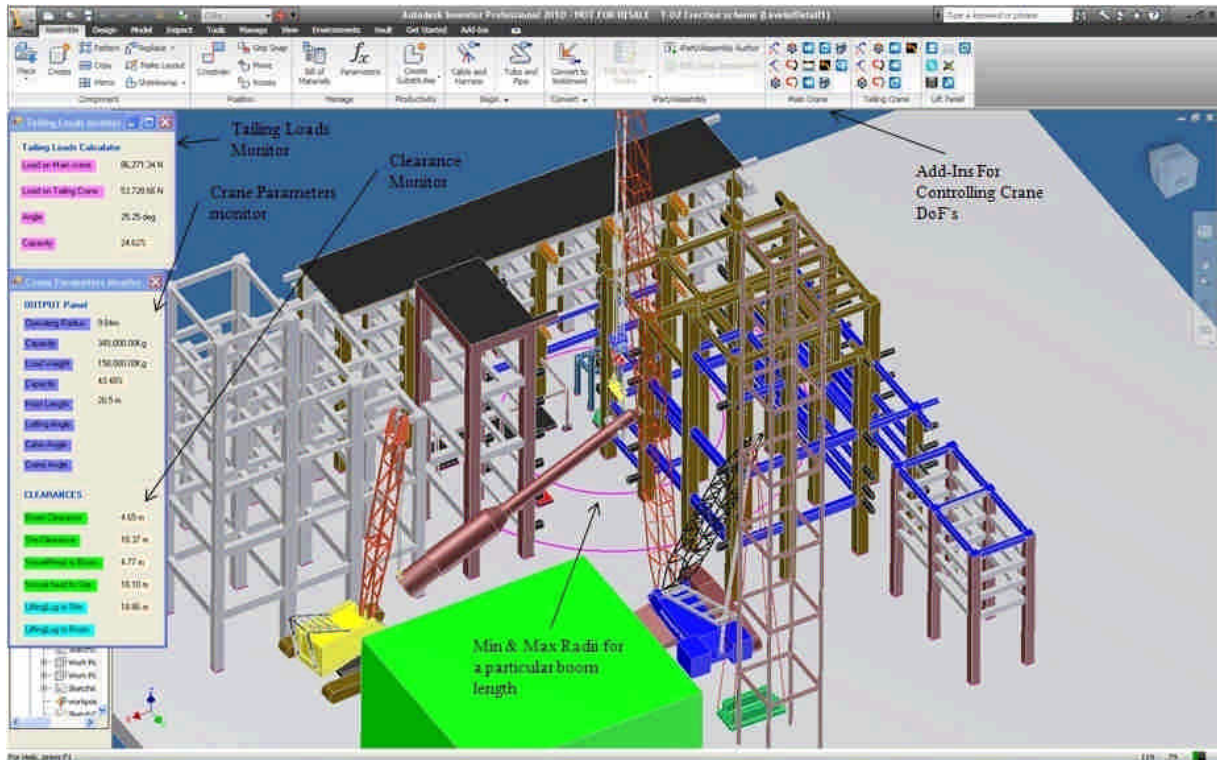
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Figure 5. Critical lift planning software simulation environment with the monitoring window

Conclusions

Automation of the some of the key planning primitives like crane selection, clearance checking, Crane ground bearing pressure reaction calculation and their subsequent mat design has made the Heavy lift planning more reliable and which improves the productivity of the planning process significantly. Visualization is key element in planning critical lifts. It serves as an excellent communication platform.

For developing CLPS Autodesk Inventor proved to be a very efficient tool for modeling and also for customization. Hence 4D representation of the virtual erection along with the aforementioned features with Autodesk Inventor will improve the confidence level of the rigging team and the lift planners to make risk free erection.

This system can be effectively implemented at construction site if Autodesk Inventor is integrated with 3D Plant design system, where exact 3D model of the site will be available for planning critical lifts. However with the limited availability of the lift planners with 3D modeling exposure, for effective integration of CLPS with lift planning system initial training has to be provided for lift planners.

Acknowledgement

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