A COMPUTER-AIDED SYSTEM FOR PLANNING AND 3D-VISUALIZATION OF MULTIPLE HEAVY LIFTS OPERATIONS

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ABSTRACT

Planning multiple heavy lifts on heavy industrial projects has a major impact on construction sequencing, scheduling, budgeting and safety. Hence it has to be planned carefully to reduce the risk and to reduce the cost and duration of the projects. Traditional planning techniques are quite unproductive as they use iterative and trail and error techniques. This paper discusses the work done towards development of computer aided multiple heavy lift planning system. The features of the software tool developed on AutoCAD platform includes- selection of cranes, crane location identification, 3D simulation of the multiple lifts and 4D representation of the site. The system developed is evaluated by using a case study. The features of the software like crane location, 3D simulation are evaluated using 25 lifts.

KEYWORDS

Multiple Heavy Lift Planning, 3D Simulation, Cranes, 4D CAD

1. INTRODUCTION

Cranes are commonly used equipment in almost all the industrial construction and maintenance operations. Particularly in erection projects like power plant erection, blast furnace erection projects etc. cranes are the central lifting equipment. With the introduction of heavy lift cranes, it is becoming more common to reduce plant equipment fabrication costs by fabricating larger portions of equipment at specialized off-site fabrication shops. While the fabrication costs and efforts are streamlined, more effort is required to plan and lift these mammoth modules into place.

Large industrial projects involve the erection of many vessels on one project site. The multiple heavy lifting process requires months of planning using traditional methods. Inadequate planning of this activity can sometimes lead to costly damages in terms of lives of construction labour and damage to other operating facilities. This work attempts to develop a computer aided heavy lift planning system, which can improve the productivity and reliability of the multiple lifts planning process.
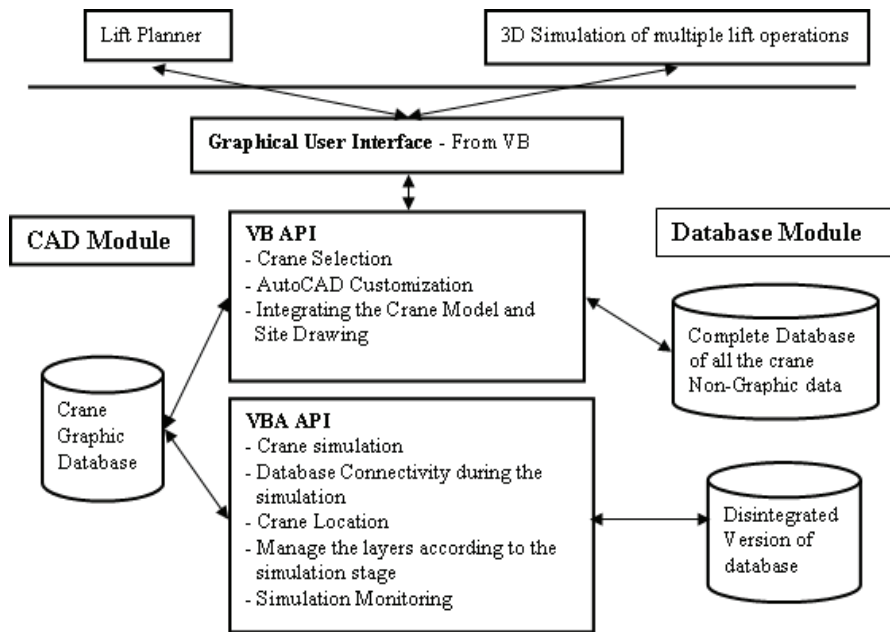
Figure 1 Multiple Lifts Planning System Architecture

2.   BACKGROUND

Previous research on heavy lift planning has focused on single lift simulation, multiple crane locations optimization, crane selection and path planning.

HeLPS (Heavy Lift Planning System) [1] has demonstrated the simulation of single lifts while Lin. K [2] proposed an interactive computer-aided process to optimize crane locations for multiple lift situations. Arriving at an optimal solution using the present studies and tools is not possible as they do not provide a common platform for multiple lift decision-making. Hornaday [3] has presented the detailed analysis of a computer-aided lift planning requirements.   Multi-dimensional   design technologies have been proven to be very helpful to improve the way the planning is done, to communicate the designs and erection sequences. One such successful application is 4D CAD. Though such 4D CAD models are helpful to some extent in visualization, they do not give any information on where the crane needs to be, at what point in the schedule, and should be erecting which vessel. Hence the present work aimed to develop a multiple lifts planning system with the features like 4D CAD, crane selection, crane location for multiple lifts and multiple lift simulation etc.

3.   SYSTEM ARCHITECTURE

AutoCAD® 2007 has been chosen as the application platform. AutoCAD is customized using VBA API to create the multiple lifts planning environment. Fig.1 shows the importance aspects of the system architecture. The interface to select the crane for the given lift parameters like boom length, operating radius and weight of the load is developed in Visual Basic. VB interacts with the database to search the feasible configurations for given parameters and lists the feasible configuration.

The database module consists of two databases-graphic database of crane models and non graphic database containing the load charts. The complete load chart database is disintegrated into the tables of individual crane charts to save time during the search for capacity. The graphic database of cranes consists of CAD models of 10 crane configurations of lattice boom crawler and heavy lift (ringer) cranes drawn to scale. VB builds the custom toolbar and assigns the corresponding modules in the dvb file for manipulating the DoFs of crane, changing the boom length, and crane location

module. The dvb file forms the core of the simulation part. It contains modules of the user defined subroutines and functions to perform the different operations of manipulating the cranes Degrees of Freedom (DoFs) and crane location. VBA interacts with database to identify the minimum and maximum operating radius of each vessel to identify the crane location from the intersecting regions.

Once the crane locatable region is identified; the user can start the simulation starting with the first stage and subsequently can do the other lifts simulation according to the sequence of erection. The VBA module defines the master-slave relationship and loads the selection sets accordingly on which the operations like rotate, move etc. are performed.

4. KEY FEATURES

The present multiple lift planning tool assists the lift planner with the following features:

4.1. Crane Selection

Multiple lift planning system assists the lift planner to select the crane according to the required parameters for the lift. A list of feasible cranes that satisfies the given lift parameters will be listed. The user can check feasible crane for all the lifts and can select a crane based on availability for simulation to check the clearances and capacity.

4.2. 4D Representation of Site

The communication of the design and erection sequence of the plant requires either creation of a prototype of the project layout or development of some kind of graphics animations. The present tool can replace the use of such techniques by the representation of the site as a 4D model. The site details are organized in layers according to the stage of erection. By turning the layers off and on the site can visualized according to the schedule.

4.3. Manipulation of Cranes DoFs

The customized AutoCAD environment provides the toolbar based interface to manipulate the degrees of freedom of crane and to virtually operate the crane on the 3D model of the site.

The crane operation can be simulated to visualize the lift path between the pick and place location. Fig 2 shows the different degrees of freedom of the crane that can be manipulated.
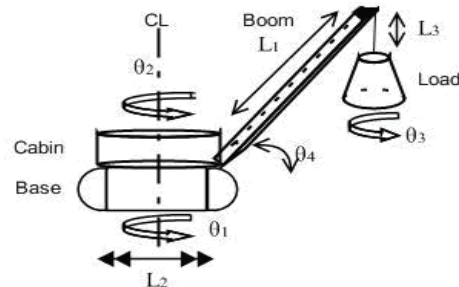

Figure 2 Different Degrees of Freedom of the Crane and the Vessel that can be Manipulated

4.4. Crane Location

One of the key decisions that control the lift planning process of the multiple lifts is the crane location. Work envelope concept proposed by Lin et al. [2] is used to implement the crane location module. Lin has considered the spatial and capacity constraint to identify the interference free work envelope. This method has left the envelope of the crane with interferences unexplored for the possible paths between the pick and place location in the interference region. Hence in this case, the work envelope is drawn for capacity constraint only and the feasibility of the crane location is checked using the 3D Simulation. The user is prompted to enter the details like Vessel ID, Vessel Weight including the weight of the rigging attachments and type of rigging attachment and the stage to which the vessel belongs to. Once the user enters the data, the crane locator module displays the window to select load ID and the choice of boom length for identifying the crane location. This module displays the locatable region for each lift. With a little interpretation using the boolean operation like intersection, the user can identify the crane locatable region for any number of lifts.

The advantage is that it avoids the repetitive task of finding the crane location by conventional multiple lift planning process.

4.5. 3D Simulation of Multiple Lifts

Multiple lifts that are lifted in logical sequence can be simulated to check the lift plan and to visualize the potential hindrances to the lifting activity. The present tool provides the feature to simulate any number of lifts. The user can do it sequentially by organizing the site in different layers according to the erection stage. The capacity is continuously monitored during the lift path planning from the database and the percentage capacity is displayed to check if the capacity is exceeding the certain percentage which can be considered as risk.

5. MULTIPLE LIFT PLANNING PROCESS USING THE SOFTWARE DEVELOPED

The sequence of steps to be followed to plan the multiple lifts is shown in Fig. 3. In the first stage, the lift planner needs to initially identify the erection sequence of the vessels. The list of cranes that can do all the required lifts is displayed based on the capacity constraint. The user can then select the list of cranes for further planning after filtering against the subjective criteria like crane availability and access to the site.

In the stage 2, the lift planner should initially identify the crane configuration for each lift and should minimize the configurations of a crane using his reasoning ability. 3D simulation can be used to provide visualization for the user to identify the different configurations and minimize their number. Once the crane configurations are finalized, in the next stage the user needs to find the crane location for all the lifts using the crane location module.

These locations are based only on the capacity constraint and therefore are needed to be checked for adequate clearances, which can be done using 3D simulation. If the clearances are adequate, the user can perform the simulation of all the lifts to check the feasibility of the overall lift plan.

If the clearances are not adequate, the user can go back to stage 2 where the crane configuration should be reselected and location should be identified for the new configurations. The alternatives for crane locations can be evaluated by the user with cost, safety and project duration as

the criteria. Once the minimum number of crane locations and the configurations are identified, the user can finally check the lift plan for feasibility and plan the path between the initial and final positions for each vessel. The user can record the simulation in a video format and generate the 2D drawings simultaneously during the simulation.
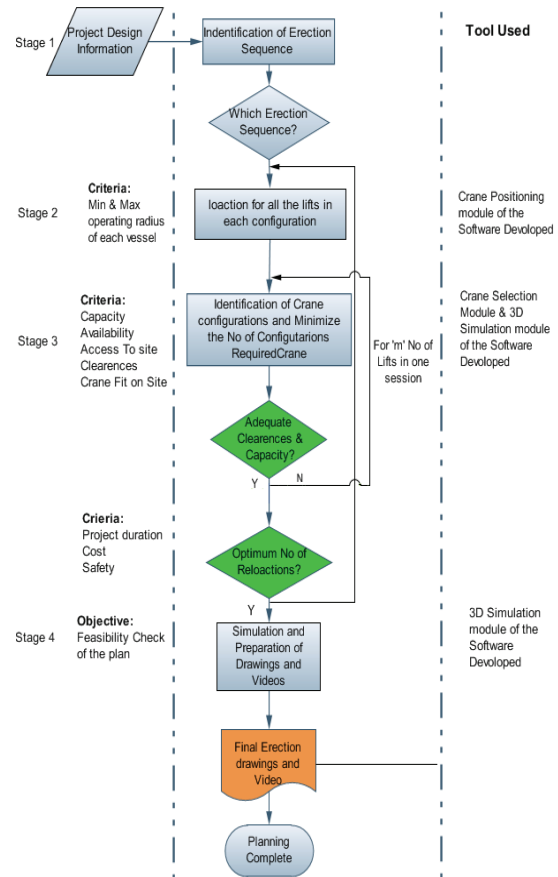

Figure 3 Multiple Lift Planning Process

6. EVALUATION

A case study of Blast furnace erection is used to evaluate the system effectiveness and its value in planning the multiple lifts.

The maximum height up to which the erection was required was 90 m and there was very limited space for assembly of the components. The site congestion was a key constraint for lifting activity and the lifting involved erection of vessels as

heavy as 150 tons in a single lift. So, the lifts can be considered 'Critical'. The project required the erection of 25 such critical lifts in the furnace area. Fig. 4 graphically illustrates the erection sequence of different vessels and the scope of evaluation. Table 1 shows the erection weight of different vessels.
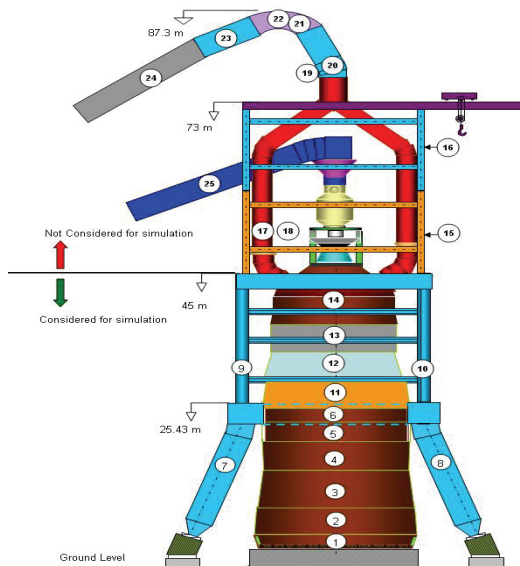

Figure 4 Components of Blast Furnace and Their Erection Sequence

6.1. Preliminary Crane Selection

Initially, the crane selection module has identified two feasible cranes from the database for all the lifts.

Based on the subjective decisions like availability of the crane, access to the site etc., the Link Belt FMC LS1018 ringer crane was not available; hence the further planning was based on the other one, which is the American 9320 ringer crane (A9320).

6.2. Minimize the Crane Configurations

Configuration of a crane includes three important variables- crane model, base type, and boom length. Initially the configurations required for each lift are identified. The cost to be incurred decreases in the order of using more cranes followed by switching the type of base and

Table 1 Erection Sequence and Weight of Different Vessels

Erection Sequence	Vessel	Erection Wt (Kgs)
1	Shell A	86960
2	Shell B	55460
3	Shell C	86180
4	Shell D	90000
5	Shell E	69910
6	Shell F	82070
7	Lower Tower-1(LT-1)	150000
8	Lower Tower-2(LT-2)	150000
9	Middle Tower-1(MT-2)	99000
10	Middle Tower-2(MT-2)	90000
11	Shell G	76320
12	Shell H	72690
13	Shell J	74860
14	Shell K	74860
15	Upper Tower up to 65m	56000
16	Upper Tower up to 73m	30000
17	Offtake-1	55300
18	Offtake-2	55300
19	Uptakes 1	13500
20	Uptakes 2	13500
21	Uptakes 3	14500
22	Uptakes 4	14500
23	Y piece	49000
24	Down comer	35700
25	Charging conveyor	60000

changing the boom length. The first two factors are taken care during the initial crane selection while the third one is minimized in this stage. 3D simulation of the vessels and the lift planners reasoning ability is used to interactively minimize the number of changes to be made in the boom length. In this case, initially the configurations are identified from the elevation required to reach the final location. These are shown in the Table 2.

For example, from the capacity and elevation requirements the shell A to D required a boom length between 42.7 m and 115.8 m while, Shell E and F required a boom length between 54.7 m and 115.8 m. The erection of the lower tower required either 42.7 m or 54.7 m boom length from the capacity constraints. Hence to minimize the configurations the shell A to F and lower tower erection is changed to 54.7 m boom length. The crane locations and the corresponding configurations are finalized for capacity constraint and the clearance is checked during the 3D

simulation. Similarly other configurations are finalized. Table 3 shows the final configuration for the American 9320 ringer crane after the two iterations of simulation. As the simulation module is used for only 14 out of 25 lifts, the vessels 15 to 25 are planned with the maximum boom length so that it will not effect the decision of the crane location due to inadequate clearances, because the clearance between the boom and the vessel increases as the boom length increases. Once the crane configurations are finalized the crane location is found out using the crane location module.

Table 2 Initial Crane Configurations American 9320 Ringer Crane

S. No	Vessel	BL (m)	S. No	Vessel	BL (m)
1	Shell A	42.7	8	LT-2	54.9
2	Shell B	42.7	9	MT-1	67.1
3	Shell C	42.7	10	MT-2	67.1
4	Shell D	42.7	11	Shell G	79.2
5	Shell E	54.9	12	Shell H	79.2
6	Shell F	54.9	13	Shell J	79.2
7	LT-1	54.9	14	Shell K	79.2

Table 3 Final configurations for American 9320 Ringer Crane

S. No	Vessel	BL (m)	S. No	Vessel	BL (m)
1	Shell	54.9	8	LT-2	54.9
2	Shell	54.9	9	MT-1	67.1
3	Shell	54.9	10	MT-2	67.1
4	Shell	54.9	11	Shell G	97.5
5	Shell E	54.9	12	Shell H	97.5
6	Shell F	54.9	13	Shell J	97.5
7	LT-1	54.9	14	Shell K	97.5

6.3.   Crane Location

The objective of the lift plan is to achieve the erection of multiple lifts with minimum number of changes in boom length of a crane at minimum number of locations. In the present case, for the A9320 crane the crane location is done for all the 25 lifts by using the crane location module. The

crane locatable region for all the vessels is shown in Fig. 5. The intersection boolean operation is used to find intersecting regions. The AutoCAD drawing showing the final regions is shown in the Fig. 6. The crane selection module has identified **two** crane locations for the erection of all the 25 lifts. The location 1 has two options on each side of the blast furnace. The option-1 shown in Fig. 6 is chosen because; at this location there is adequate space for the assembly. These crane locations in terms of the relative coordinates are shown in Table 4.
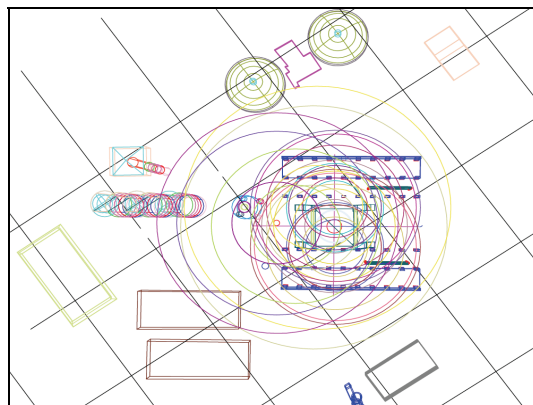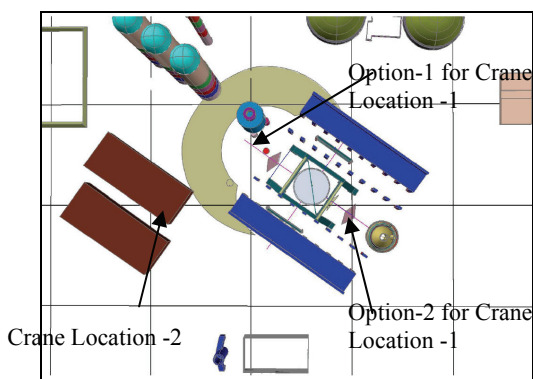

Figure 5 Crane Work Envelopes for All the 25 Vessels

Figure 6 Crane Locations for all the 25 Lifts

6.4.   3D-Simulation to Check the Clearances and Capacity

Once the crane location and the configurations are identified, these should be re-checked for adequate clearances and capacity. The 3D simulation

module demonstrated that the A 9320 ringer crane can adequately perform all the lifts with sufficient clearances and capacity at the locations identified by the crane location module with the configuration identified as shown in Table 3. The simulation was performed for each vessel of the 14 vessels considered. Fig. 7 shows the simulation environment of the software.

Once a stage is simulated, the user can perform the next stage simulation by selecting the stage and the vessel in that stage. Each stage can have as many number of vessel erections as required. The site will be dynamically changed when the simulation is performed between the stages for better visualization of the complete process. The sequence of actions performed by the user during the simulation is recorded in a text file. These can be used during the final erection as a guideline for

Table 4 Crane Locations Identified by Using the Crane Location Module

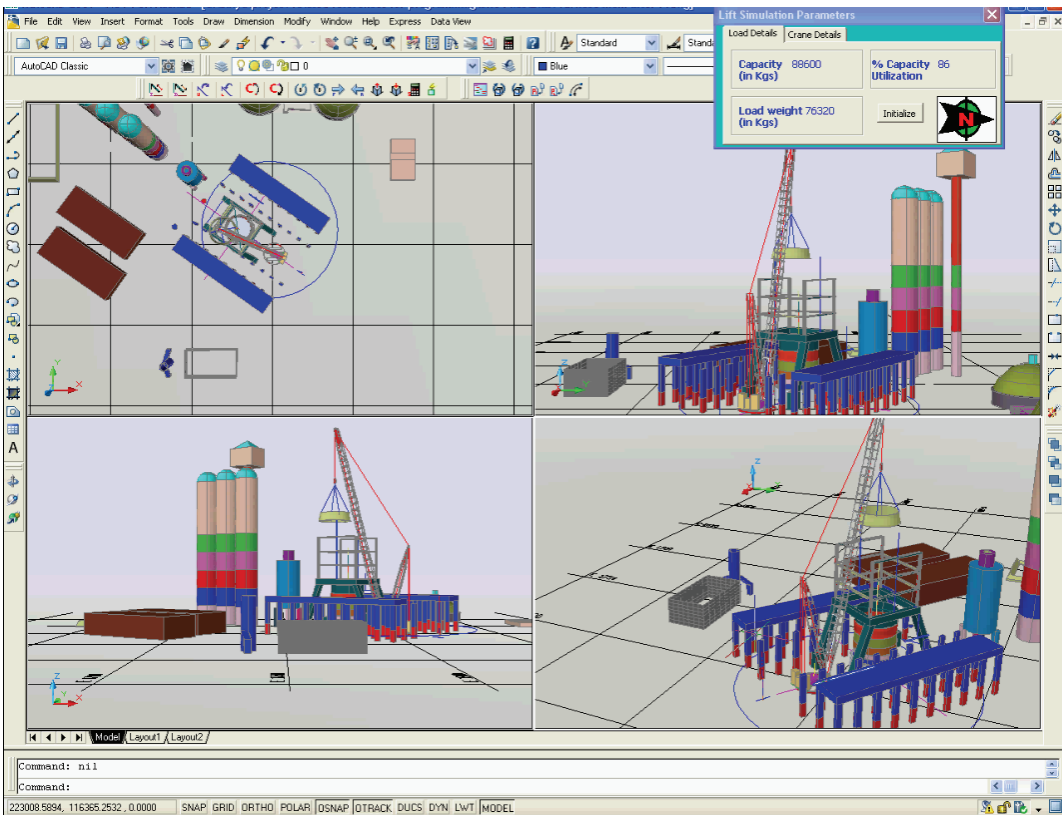| Location No	Crane Location Coordinates		Vessel to be lifted in the location
	X	Y	
1	E- 1801.20	S-605.88	Shell A to G Lower Tower Middle Tower Upper tower Offtakes Uptakes
2	E-1739	S-581.1	Down Comer Y-piece Charging Conveyor

Figure 7 Multiple Lift Planning Software's Simulation Environment with the Monitoring Window

the crane operator or as input to the robotic cranes to automate the crane operations completely on the site. Also the video of the simulation is recorded to communicate the lift plan. The proposed method of lift planning proved to be not only productive and reliable but also the guesswork can be completely eliminated thus saving time and on-site feasibility testing.

7. CONCLUSIONS

Automation of the some of the key decision variables of multiple lift planning like crane selection, crane location can significantly improve the productivity of the multiple lift planning process. The multiple lift planning system developed on AutoCAD platform provided an easy and fast planning interface with the unique features like crane selection, crane location automation for multiple lifts, 3D simulation of multiple lifts and 4D representation of the site.

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