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An Interactive Database System with Graphical Linkage for Computer Aided Heavy Lift Planning

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Abstract:

Planning heavy lifts is a time consuming and costly activity. Several systems have recently been developed for computer aided heavy lift planning that increase planning productivity and dependability of lift plans. These systems must handle a wide range and growing volume of both graphical and non-graphical data, including information about crane configurations, rigging, lift objects, load tables, and the site of the lift. Methods are needed for handling this data more effectively. This article presents an interactive database graphically linked to a heavy lift planning platform described in an earlier article. A relational database management system, OracleTM, is linked to a computer Aided Design (CAD) and graphical simulation platform, MicroStationTM, to implement dynamic interaction between the database and the elements of the planner hosted by MicroStation. With the interactive database capability, the usefulness of heavy lift planning systems can be greatly enhanced. In this article, related research and developments are briefly reviewed, the implementation and usefulness of the graphical linkage is described, the design of the database is presented, and uses of the interactive database feature are illustrated and then evaluated. Selected implementation details are presented as well.

Introduction

Heavy lifts play an important role in the construction industry. In common industrial construction, such as rehabilitation of power plants and construction of new facilities, utilizing large cranes to install electrical, mechanical, and process equipment is a frequent task. The current surge in modular construction, at grade construction, and industrialized housing technology in developing nations, is also increasing the number and significance of heavy lifts.

Heavy lifts need to be planned thoroughly to ensure lift safety and lift feasibility. Planning involves activities such as rigging design, selection of crane configurations, lift object and crane locating, path planning, access planning, and scheduling. Computer aided lift planning systems also include graphical simulation for interference detection, planner feedback, and plan review. Without proper planning, the execution of a heavy lift can be very dangerous with potential for loss of life and major destruction of property. As well, coordination problems may occur when lift equipment, or large objects being lifted, interfere with their environment (Hornaday 1993). Resolving such coordination problems at the time of the lift usually results in a delay of project and/or rework. By helping to avoid these problems, heavy lift planning becomes one of the keys to project success. Consequently, many owners are beginning to demand detailed rigging designs, lift plans, and graphical simulation of planned lifts.

Most heavy lift planning tasks in small to medium sized companies are still performed manually, despite the advantages of computer aided planning (Hornaday 1993). However, some companies have invested significant resources in the development of computer aided tools for heavy lift planning. For example, a Computer Aided Rigging system (CAR) developed by one EPC contractor (CAR 1990), led to further development of a more comprehensive heavy lift planning system by the same contractor (Alexander 1992). An Automated Lift Planning System, (ALPS), has also been developed, which is claimed to be a comprehensive planning and visualization platform for developing and documenting heavy lift plans (Bennett 1993). Major features of ALPS include crane selection, rigging analysis, and 3-D lift simulation. More general simulation systems can also be used for planning, such as Jacobus Technology's Construction Simulation Toolkit which integrates three dimensional facility drawings and a construction schedule into a simulation environment (TeleMetriX 1993). The schedule is used to run the simulator and construction managers can observe the construction process as the various components of a structure are assembled.

At the University of Texas, research on heavy lift planning includes an implementation of a crane simulation software framework (HeLPS 1991), an industry-wide practice analysis and a planning system design (Hornaday 1993, Hamilton 1992), a path-finding scheme for large cranes and vessels being transported within the jobsite (Varghese 1993), and recent work including that described here (Lin 1993, Wen 1993). Three computerized system platforms resulted. HeLPS (Heavy Lift Planning System) utilized CAD models of site, vessels, and cranes to simulate crane operation on a construction job site. HeLPS employed the 3D graphics display shell WALKTHRU™ to animate crane motion. For site access, a GIS tool, ArcInfo™, and an expert system package, VP Expert™, were used to model construction sites and objects and to resolve the accessibility problem in two dimensions.

None of these existing planning systems are complete. Lift path planning, placement, and multi-lift optimization algorithms remain to be developed (a subject of current research by the authors), and one of the most important and difficult problems has not been adequately addressed. Heavy lift planning requires a very wide range and large volume of data to be accessed, stored, sorted, and manipulated. Graphical representations of lift elements must be related to descriptive data and to non-graphical data including load tables and information about crane configurations, rigging, and lift objects. Handling this data with a Relational DataBase Management System (RDBMS) guarantees data integrity and consistency, reduces redundant storage, facilitates sharing of data, and provides data security. An interactive RDBMS with graphical linkage is described here.

Advantages of a Lift Planning Database with Graphical Linkage

Planning is an iterative process requiring synthesis, mathematical deduction, analysis, data acquisition, communication, coordination, illustration and graphical mapping. For computer aided lift planning, interaction is a key feature, since such planning is an art best performed by humans with the aid of computers. CAD and graphical simulation systems serve well as planning platforms, since they provide planners with powerful computational tools and valuable visual feedback. However, current computer aided lift planning systems rely largely on data stored in computer files. Such data handling methods are unwieldy and inflexible. A relational database has the advantages descibed earlier, and a database with tight graphical linkage to CAD based planning tools introduces many more advantages.

One way to implement such a linkage is to use MicroStation's database interface to Oracle to associate non-graphical data with CAD graphical models and Oracle's database management capability to maintain non-graphical data. Non-graphical data for graphical models is linked to the models with a pointer mechanism which is described later. In addition to advantages inherent in an RDBMS, several advantages for lift planning ensue:

1. Constraint based selection of lift components is made possible, thus saving considerable time otherwise spent for retrieval and review of files.
2. By pointing and clicking on graphical objects, associated information can be retrieved from the database and displayed.
3. By selecting a database record, an associated graphical object can be displayed.
4. Values for parametric graphical models can be organized and stored efficiently.
5. Data entry forms can be created for efficient data entry and for data checking, which is critical in an engineering design and planning system.
6. Records of previous and ongoing lift plans can be efficiently stored and managed.
7. Spatial reasoning algorithms can exploit the database graphical linkage for such functions as establishing safety envelops and checking foundation conditions.

The following sections describe the design, implementation, and uses of an interactive database with graphical linkage.

Lift Planning Database Design

The system described here is implemented on a test bed designed for prototyping computer aided critical lift planning tools called HeLPS2. It is described in an earlier article (Hornaday 1993) which includes descriptions of its system architecture and functional hierarchy. While fundamentally similar to HeLPS2 and each other, proprietary systems such as ALPS and CAR are more powerful in practice. One reason is the immense investment required, for a practically useful system, in non-graphical data acquisition and entry (of, for example, load tables) and in constructing graphical models of the wide variety and large number of commercially available lift components. Amplification of the power of these systems is possible with the tools described here.

In heavy lift planning, major data categories include projects, sites, vessels, cranes, and rigging attachments. Table 1 describes these categories of data as well as subcategories and their related planning functions.

Table 1 Planning Data and its Use in Planning Functions

Data Categories	*Planning Function*
Site	
ownership, site location, site block name, site block type, serial number, bar code, and site layout plan and elevation plan	modeling of the site; important for crane selection, site access analysis, and crane location analysis
ground support capacity	important for crane location planning and crane mat design
construction schedule based on each site block	used in the lift scheduling to avoid conflicts between lifting and other activities
Vessel	
vessel name, ID, fabricator	identification of vessels
Shape, dimensions, center of gravity, and weight	key dimensions describing the uniform envelop around the vessel; important for determine crane configurations and capacity
place location & pick location	definition of the goal and starting points of the lift
rigging requirements	rigging analysis
delivery schedule	scheduling of crane procurement
Rigging attachment	
attachment name, ID, and type	identify of rigging attachments
shape and dimensions, weight, capacity	rigging analysis
Crane	
model name, serial number, bar code, manufacturer	equipment planning management
ownership, available date, location	crane availability checking

key dimensions, and required area for crane rection/operation/ dismantling	crane location analysis, and clearance checking
boom length configuration	capacity evaluation and clearance checking
capacity, weight of each unit, counterweight configuration	capacity evaluation
depreciation/rental,/lease/ overdue, transportation, cost of altering boom length	cost analysis
original purchase data, last maintenance date, replaced part	crane selection, and final evaluation

For preliminary relational database design, formal procedures are followed for establishing tables and the data which is to be included in them (their "attributes"). Relational algebra forms the foundation for "normalization" which is required to achieve the advantages of a relational database. A primary "key" (an unique identifier) is assigned to each table, and then the tables are examined to remove functional dependencies in order to achieve the desired normal form. The final normalized tables are listed in Table 2. All the attributes which currently number 84 are not listed, however they are defined in detail in (Lin 1993). Since the database is implemented using a relational scheme, it is simple to modify the database structure or to create new tables and establish relationships with relevant tables to meet the requirements of different scopes of lift planning activities.

Table 2. List of Database Tables

Table Name	***Description***	***Primary Key***
Table for Project :		
PROJECT_LIST	The list of all the lift projects which planners are in charge of	PROJECT#
Table for Site :		
SITE	General information about the site	SITE#
Tables for Block :		
BLOCK	Information on blocks	BLOCK#
Tables for Vessel :		
VESSEL	General vessel information	VESSEL#
Table for Crane :		
CRANE	The list of available cranes	CRANE#

CRANE_MF	Crane manufacturing data	CRANE_NAME
CRANE_MT	Crane maintenance record	(CRANE#, MAINTENANCE#)
CRANE_COST	The cost of employing the crane in the lift project	(CRANE#, AVAILABLE_TYPE)
CRANE_CA	Crane capacity chart	(CRANE_NAME, BOOM_LENGTH, OPERATING_RADIUS
CRANE_ST	Crane states during simulation sessions	(CRANE#, STATE#)

Table for Rigging Attachments :

RIGGING	The list of available rigging attachments	RIGGING#

Tables for Relationships between Entities :

PROJ_SITE	Denotation of which site belongs to which project	(PROJECT#, SITE#)
PROJ_VESSEL	Denotation of which vessel belongs to which project and specific vessel information for the project	(PROJECT#, VESSEL#)
PROJ_PCRANE	The list of possible cranes for each project	PROJ_PCRANE#
CRANE_RIGGING	Denotation of crane's rigging attachment for the lift	(CRANE#, RIGGING#)
SITE_BLOCK	Denotation of which block belongs to which site	(SITE#, BLOCK#)

After the tables are created, table rows are linked to corresponding graphical elements. Dynamic linkage is implemented using MicroStation Development Language (MDL^{TM}). All these functions operate within the HeLPS2 application.

The HeLPS2 Application

The host environment of the software tools described in this paper is MicroStation. The HeLPS2 shell, model builder, crane simulator, and user interface have been implemented by developing application programs in MDL. The user interface application includes several dialog boxes showing object (project, site, vessel, and crane) information in a lift project, and some menu items for database maintenance and other utilities.

Building user interfaces with MDL can be conceptually described as containing two major parts -- creating dialog boxes and attaching hook functions to dialog boxes and dialog items. A set of dialog boxes used for reviewing database attributes and graphical representations of objects were created. Figure 2 shows the appearance of the developed user interface as it appears during a planning session.

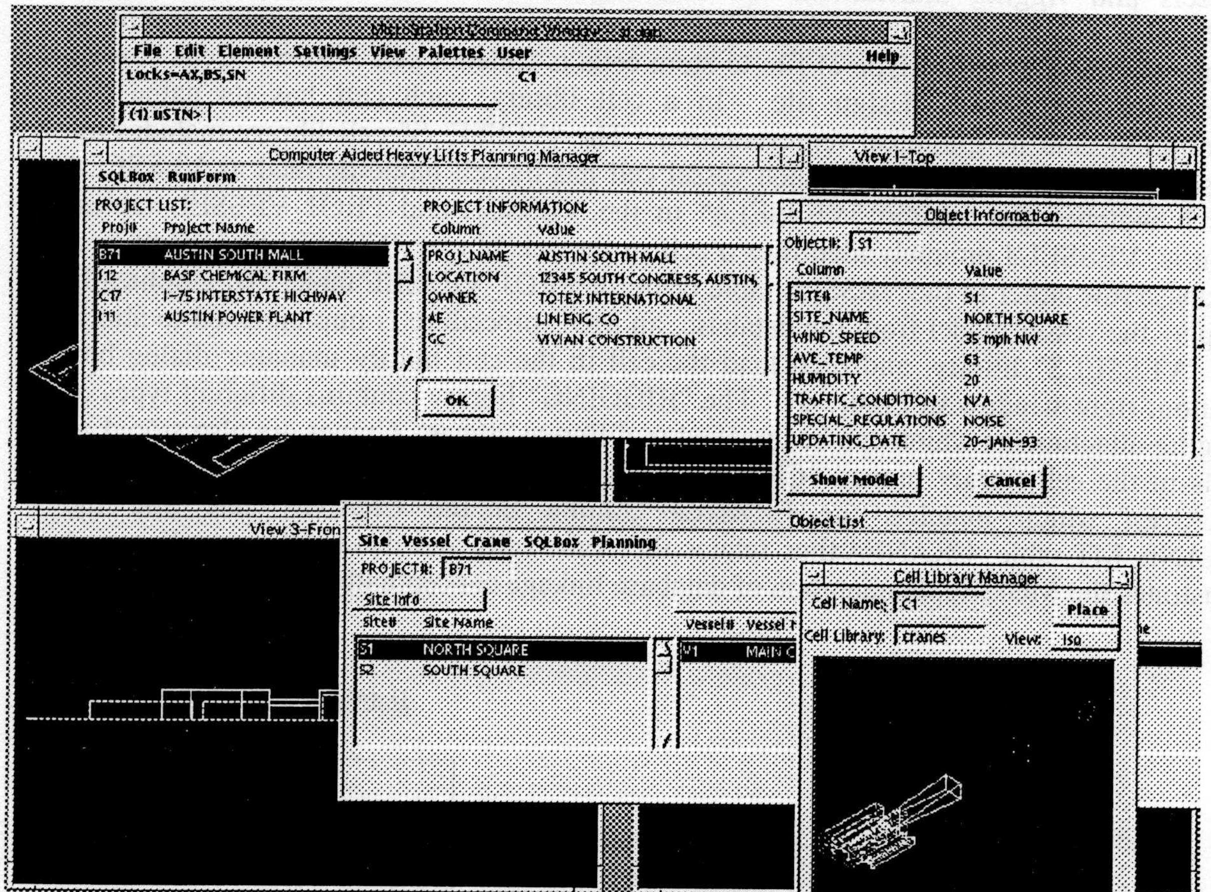

Figure 2. A Planning Session

Implementing Graphical Linkage

In the MicroStation - Oracle environment, graphical representations are stored as standard graphical files, while the attribute non-graphical information is stored in the database. A *database linkage* can be established within MicroStation to relate the database attributes to the design files so that manipulation between graphical and non-graphical data can be made possible. One special requirement needed to enable a data row of a table to be linked to a graphical element is that the table should contain a column named **MSLINK**. When a linkage is established, an integer is written to this column by MicroStation to uniquely identify the linked row.

Site, vessel, rigging, and crane models are represented in different forms in order to implement graphical linkage. Site models are stored as design files. The file name of the design file is assigned as SITE# which is a primary key in the SITE table. The SITE# column uniquely identifies the row in the SITE table as well as the design file for the site. The MDL command "mdlSystem_newDesignFile(SITE#)" is called when calling the site model from the database. Blocks are the geometric components in a site model. They are represented as graphical elements in a SITE design file. An MSLINK column is added to the BLOCK table so that each row can be linked to the appropriate element.

Vessels and rigging attachments are stored as cells in the cell libraries named "CRANES", "VESSELS", and "RIGGING". A *cell* is a group of reusable graphical elements, and the special type of file to store cells is called a *cell library*. Cells can be repeatedly placed in a design file. In a cell library, each cell has its name, its description, and its graphical representation. The "VESSELS" cell library includes all vessels in various lift projects. Each vessel cell has its cell name defined as VESSEL# which matches the column "VESSEL#" in the VESSEL and PROJ_VESSEL tables. That is, VESSEL# uniquely identifies a cell in the cell library "VESSELS" as well as a database row either in the VESSEL table or in the PROJ_VESSEL table. To graphically display the vessel model from the database, an MDL procedure is implemented to attach the "VESSELS" library, and then load the cell in the cell library manager dialog box (bottom right window in Figure 3). The "RIGGING" library contains different types of rigging attachments which can be attached to different cranes. Cranes are also stored as cells in the cell library named "CRANES". Each crane cell's cell name is defined as CRANE# which matches the CRANE# column in the CRANE table and the CRANE_MT table. CRANE# thus relates the crane cells and database rows. Figure 4 illustrates the MDL implementation of database linkage conceptually.

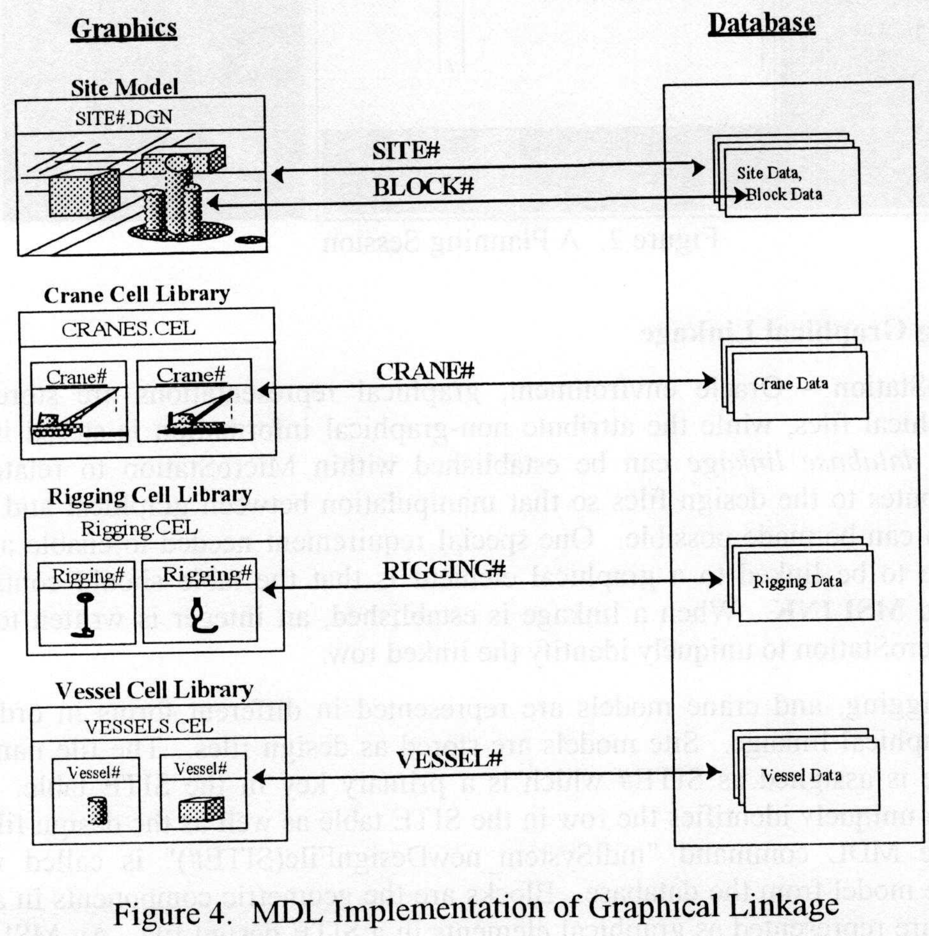

Figure 4. MDL Implementation of Graphical Linkage

For the purpose of crane simulation, the elements which make up a crane, such as boom, cab, base, and rigging, are also stored as cells. Most cells are defined parametrically for efficiency and flexibility, and their parameters are stored in the database. These cells can be selected to make up a parametric crane and can be moved separately enabling the crane simulator to apply master-slave relationships for crane motion simulation.

Using the Database

As described earlier, the database can be utilized in several ways to aid planning tasks . In the following sections, two additional key uses are presented in more detail.

1. Parametric Construction of Model Data

The utilization of database graphical linkage can enhance the construction of graphical models and related data input. An object model builder was implemented that is designed to provide customized tools to create the graphical images of the objects used in heavy lift planning. It includes the crane cell library builder, the vessel cell library builder, and the site model builder.

Parametric modeling is the mechanism used to build object libraries. Crane Cell Library Builder is the module used to create the crane graphic libraries. To simplify the model definition, a crane model is composed of such components as base, cab, boom and rigging equipment. Crane cells are parametrically constructed according to the dimensions given. By specifying the shape and dimensions of the graphical elements, the graphical cell element can be created and attached to the cell library automatically (Figure 6). In this way, elements of a crane (boom, base, and cab) with the same construction rules can be created rapidly. When the model is built, the related dimensional information is input into the database at the same time.

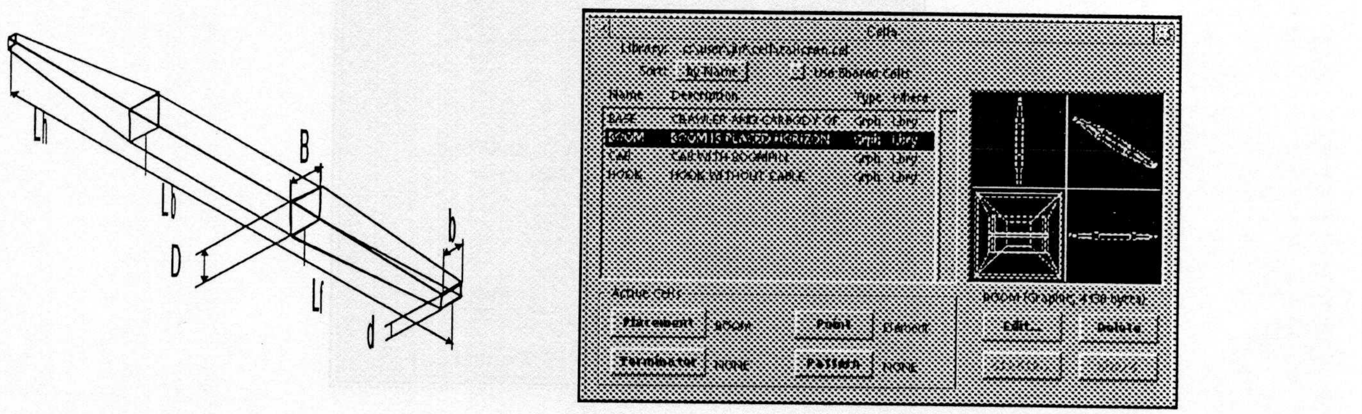

Figure 6. Parametric Construction of Model Data

This intelligent dimension-driven approach is more intuitive, efficient, and productive than the primitive drawing method. A parametric cell approach or dimension-driven design can also be applied in vessel modeling and site modeling where dimensions of the objects are changing during the planning process. Dimension-driven design saves much line-by-line drawing time by simply updating the dimension field of the parametric cell.

2. Crane Selection

A crane selection module was designed to help planners make preliminary feasible crane selections based on selection constraints. The module helps planners determine capable crane class to establish preliminary lift plans during the preliminary planning stage. The crane selection procedure is modeled as two major steps: (1) determination of selection constraints and (2) inquiry of the crane library. The primary constraints include crane capacity, reaching height, operation, cost, schedule, crane weight and crane dimensions. These constraints are further controlled by several factors. In the project, the vessel weight determines the required crane capacity. The spatial relationship of vessel place location, vessel pick location, and crane location constrains the crane's reaching height and operating radius. The construction schedule and local crane availability constrain the determination of crane schedule. When crane accessibility is considered for crane selection, access route clearance and pavement strength also constrain the crane dimensions and weight. Lift budget is another factor to be considered for selecting a crane. Thus, crane selection is not a simple task, since it involves so many project constraints.

The Crane Selection Module provides a dialog box with text input items allowing entry of crane selection constraints (Figure 7). The system suggests default constraints for early stages of planning which the planner can change. A search is then issued of the feasible cranes in the database through the Crane Database Module. A Structured Query Language (SQL) statement according based on the constraints is issued in the background to query the database and return the results.

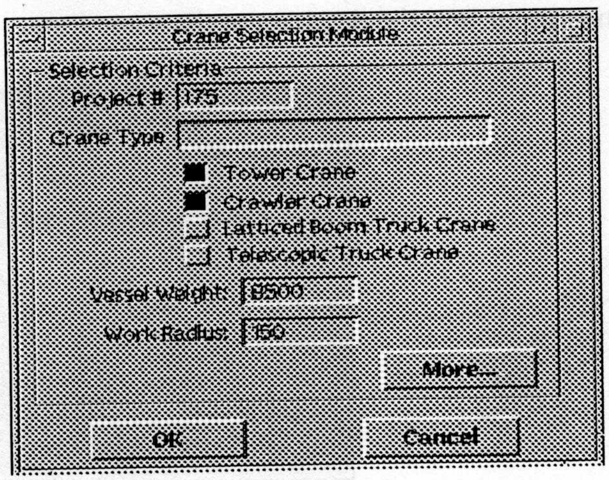

Figure 7. Crane Selection Window

Conclusions, Recommendations, and Ongoing Research

The objective of this research was to investigate ways in which a database management system could be integrated with a CAD and graphical simulation environment to improve heavy lift planning. A functioning prototype has been designed and implemented for experiments and future development. It can be concluded that an interactive database system with graphical linkage can be used effectively for constraint based lift component selection. Graphical linkage also enables display of critical non-graphic data about planning objects that the database organizes and stores efficiently. The database can also be used effectively to manage information on completed lifts, information that can be modified for future lift plans.

Integrating the tools and methods described in this article with existing commercial heavy lift planning systems should amplify their power. These tools are also being used directly or indirectly in the following ongoing research:

1. Computer assisted stationary equipment locating.

An interactive approach for locating large equipment, such as cranes, concrete pumps, and large scale manipulators, is being implemented which also exploits the database capabilities described in this article.

2. Planning approaches for single crane, multiple lifts.

3. Automated path planning algorithms for heavy lifts.

Many path planning algorithms have been developed to control manipulator motion in congested work envelopes. Crane operation in a confined construction site requires finding a collision-free path from the pick location to the place location. Adapting an appropriate path finding algorithm for specific lift preferences can relieve the planners' burden of interactively searchng for a path.

4. Planning approaches for selection and location of multiple crane or derrick lifts.

An approach using inverse crane kinematics slaved to lift object path planning weighted with crane operating preferences is being developed.

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