An Integrated Information System for Crane Selection and Utilisation

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ABSTRACT

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This thesis presents a methodology for crane selection, location, and utilization on construction sites. It first describes the current practices and discusses the factors that are considered in the selection process, then it introduces a crane selection methodology. This methodology was used in the development of a computer-integrated system, designed to support users in the selection and location of appropriate cranes for their construction projects. The system integrates a relational database, a selection module, an optimization routine, and 3D-graphics and animation module. The developed system provides its users with powerful graphics capabilities, featuring a multimedia environment and a practical user-friendly interface. The system offers the flexibility in using metric and empirical units and can be run in a network environment. Its database system can accommodate different types of commercially available cranes, and powerful storage, sorting, and query routines. The system was implemented using MS-Visual Basic, MS-Access DBMS, AutoCAD, and 3D-Stodio. Numerical examples are presented to demonstrate the use and capabilities of the developed system.

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Chapter 1 INTRODUCTION

1.1 RESEARCH MOTIVATION

Construction efficiency has been steadily improving through the years due, in part, to more effective use of cranes. The increasing lifting capacities of the new cranes has allowed contractors and planners to perform heavy and large prefabricated lifts (building elements joined together, which can collectively weigh hundreds of tons). This result in increasing quality (i.e. material prefabricated at a remote site) and reducing the overall construction costs. Executing these lifts using cranes needs careful planning to ensure safety and economy. This involves the selection of technically feasible and cost effective crane configurations for any given lift condition and site constraint.

Construction sites are normally congested with nearby facilities or by a complicated network of overhead power lines, all of which create a difficult environment for the selection of appropriate crane and its location on site. The traditional way of selecting a crane is a manual-based and time consuming process, which approach problem solving mainly based on experience. During various stages of the lift planning process, information collected about lifts and sites is retrieved several times, examined, analysed, modified and updated. The conventional approach to the collection of information about the lift and the site is inadequate and is based on many assumptions, all of which make it an expensive process. For example, the cost of employment and deployment (i.e. haling, transporting, permits, erection, and dismantling) of a large crane could be hundreds of thousands of dollars. Failure to select the most suitable crane may results in unnecessary extra cost, should the selected crane be replaced with another one without advanced notice. In addition, a number of on-site preparations need to be addressed prior to the crane's employment to prevent crane accident and to reduce lift execution costs by avoiding the crane's idle time while these preparation take place. The risks involved in the traditional crane selection methods are increased by these factors, which are often not taken into consideration or difficult to analyse.

To improve the quality and reduce the cost of engineering planning, and in response to the increasing need for the use of computers, the construction industry has addressed the need for utilisation of advanced computer techniques. Despite the usefulness of these advanced computer techniques, the construction industry remains slow in adapting, even well established computer systems. Although, graphics using CAD systems and 3D are capable of representing the physical objects of the site and the crane to facilitate efficient planning environment, they are not amongst the premiere tools used in crane selection and cranes operation domain. Except in some limited cases, 3D are not used, at least to their full scale. In addition, lifts planning is a data-intensive process; it requires the search and evaluation of a large number of crane configurations, a process that is time consuming and can often lead to costly mistakes. The need to develop an efficient system capable of processing data associated with crane configurations, lift capacity settings, and rigging equipment is evident and cannot be ignored. The primary advantage of such a system lies essentially in the speed with which search through and evaluation of large amounts of data can be done. Several systems have been developed to assist in selecting cranes and in planning their lifts. These systems lack the support of a comprehensive database to provide information about crane configurations, their lift capacity settings, and rigging equipment. Although crane manufacturers provide data about their cranes, this data is not consistent and do not follow standard format. This creates frequent problems for crane users, especially when interpolating the load charts. This requires the users to make decisions based on job conditions and crane categories that can lead to costly mistakes.

This research presents a methodology for crane selection location and on-site utilization for construction projects. The proposed methodology incorporates an integrated computer system capable of advising the users on the selection of appropriate crane(s) for their construction projects. The methodology integrates procedural algorithms for performing routine calculations and graphics to support the crane selection process, in four different modules: crane selection module, optimization module, 2D and 3D graphical module, and 3D-Animation. All the modules share a global database system involving four databases (cranes database dedicated to crane geometry and capacity load charts, rigging database stores rigging equipment and lift attachments, 3D-CAD library dedicated for storing 3D drawings of cranes and rigging components, and projects database, which stores the project's information). Visual Basic is the programming language used for the design of the user interface and the system file sharing and integration. Six case examples are presented to demonstrate the effectiveness of the various components of the methodology.

1.2 Research Objectives

In crane selection and lift planning, the construction industry remains experience-based approaching problem solving primarily through trail and error. The objective of this research is to establish a methodology for crane selection location and on site utilization and to implement its methodology into an integrated computer crane selection system. The goals of the proposed system are to meet the industry needs referred to improve ***performance, information flow of data, economics*** (i.e. control costs, or increase profits), ***efficiency, service*** to customers and suppliers, and ***safety.***

1.3 RESEARCH PLAN

This research aims at developing an automated systematic approach to the crane selection process. The nature of this research, because it is carried out in collaboration with an industry-partner, this requires the development of a workable system. Two main phases were established for this research work, the ***analysis*** and the ***implementation*** phases.

1.3.1 The analysis phase

The analysis phase involved the following steps:

1) **Literature Review:** A review of the state-of-the-art literature in the area of crane selection was carried out and an up to date relevant to the subject literature is presented.

2) **Site visits (construction sites and equipment rental companies)**: Site visits were conducted to meet with practitioners and discuss the current practices used in crane selection.

3) **Working with the expert:** Full-time work with the sponsoring company's experts and participation with the company's daily experience in equipment management and crane selection, and on-site utilization. Site visits and discussion on issues that could improve productivity and safety.

4) **Knowledge Acquisition:** Experts in the domain of crane selection were identified, their knowledge was acquired and incorporated in the methodology.

1.3.2 The implementation phase

The implementation process of the methodology of this research involves eight steps as shown in Figure 1-1. these steps are described in this section.

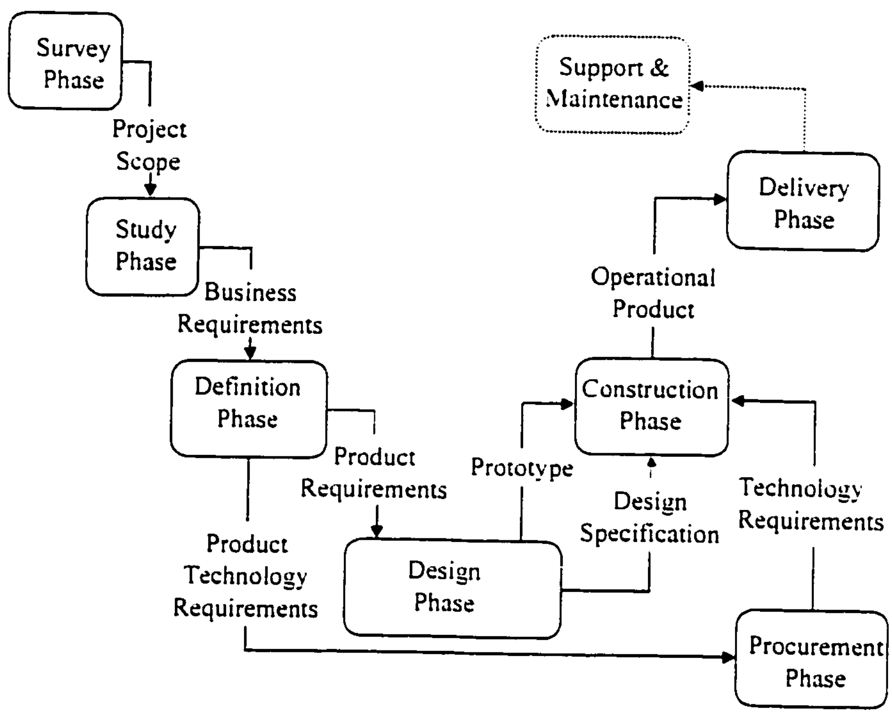


Figure 1-1 Research Plan

Figure 1-1 depicts how the project is sequenced throughout the system implementation phases. Based on the structured methodology, the following seven phases were defined including their purposes, main activities, deliverable, and participants:

1) **The Survey Phase**

Purposes: To define the scope of the project and to establish the project team, participants, budget, and schedule.

Participants: This phase describes the system and the project from the perspective of system owners.

Prerequisites: The key inputs to this phase were the ***planned system initiative***.

Deliverables: The key deliverable for this phase was the ***project charter,*** which presented the findings, recommendations, and plans of the project team to the executives.

2) **The Study Phase**

Purposes: involves understanding the business problem domain. establishing the problems (opportunities, and directives) solving values, and establishing the system development values.

Participants: This phase described the system from the perspective of the system users (sales representatives and companies executives).

Prerequisites: Two key inputs were needed to this phase: 1) the statement of project and system scope from the *survey phase,* 2) the results of the study of the existing system and the collected information from the system users concerning ***the business*** and the perceived ***problems, causes, and effects.***

Deliverables: Detailed study report. in a formal presentation. which included an updated feasibility assessment and the proposed system objectives.

3) **The Definition Phase**

Purpose: To identify the data, process, and the system's user interface requirements.

Participants: System users played essential role in specifying, clarifying, and documenting the business requirements.

Prerequisites: This phase was proceeded by the approval of the **system objectives** and the collection and discussion of the ***requirements and priorities*** from the system users.

Deliverables: The final model and prototypes were organized to reflect the **business requirements**.

4) **The Configuration Phase**

Purposes: To recommend the target design and implementation of the system.

Participants: All members of the project team including system owners, system users, and system designers were involved in this key decision-making phase.

Prerequisites: Complete specification of **business requirements**, and **ideas and opinions** from all system users.

Deliverables: Identifying the technological standards and the evaluation of the proposed system by the following criteria and fusibilities: 1) Technical. 2) Operational, 3) Economic, and 4) Schedule feasibility.

5) **The Procurement (Purchase) Phase**

Purpose: To research the information technology marketplace and propose one that best fulfills the business and technology requirements.

6) **The Design Phase**

Purpose: To transform the business requirements from the *definition phase* into a workable model.

Participants: Database operators and system users to evaluate the new system's ease-of-learning, ease-of-use, and compatibility with the stated **business requirements**.

Prerequisites: The **business requirements** from the definition phase. **design requirements** from the configuration phase, **technology integration requirements** from the purchasing phase, and system users ***ideas and opinions*** about the system's design.

Activities:

- **Step 1:** Defined the base-level scope of the system.
- **Step 2:** Defined, designed, constructed, and loaded the database.
- **Step 3:** Defined, designed, and constructed the inputs. Demonstrated a prototype to the system users. *(Milestone)*
- **Step 4:** Defined, designed, and constructed the outputs. Demonstrated a prototype to the system users. *(Milestone)*
- **Step 5:** Defined, designed, and constructed the interface. Demonstrated a prototype to the system users.*(Milestone)*
- **Step 6:** Implemented the first version of the system.

Deliverables: A technical set of **design specifications** using modeling. This design model depicted the following: 1) the structure of the database; 2) the structure of the overall application; 3) the overall 'look and feel' of the user interface.

7) **The Construction Phase**

Purpose: To build and test a functional system that fulfills business and design requirements and to implement the final interfaces of the systems.

Participants: System users to provide feedback on the system functionality, ease-of-learning, and ease-of-use.

Prerequisites: The **design specifications** were the key input to the construction phase.

Activities: System testing, data verification, algorithmic validation, and system performance.

Deliverables: The final deliverable of the construction phase is the **functional system.**

8) **The Delivery Phase**

Purpose: To install, deploy, and place the new system into operation.

Participants: The entire project team was active in this phase. In this phase: system users communicated implementation and operational problems.

Prerequisites: The key input in the delivery phase, was the functional system and the system users' continuous feedback to address new problems and issues.

Activities: Training of system users, writing manuals, and the loading of databases and system files.

Deliverables: The ***production system*** and ***training and support*** for system users.

Postrequisites: Once the system was loaded in the user's computers, the research objectives changed to include system support. **System support** involves the ongoing maintenance of the system after it was placed into operation. This includes program maintenance and system improvements (i.e. fixing software "bugs", recovering the system, assisting users, and adapting the system to new requirements).

1.4 THESIS ORGANIZATION

Chapter 1 (Introduction) introduces the thesis by describing its general context (crane selection) and the problem addressed (selection, location and on site utilization). The chapter also discusses the objectives of this research, namely the development of a methodology for crane selection and on-site utilization and its implementation. Finally, the chapter addresses the research plan, which followed the approach of the analysis of a problem-solving type of research.

Chapter 2 (Literature Review) includes a summary of the review of the state-of-the-art literature. A description of the techniques used in an attempt to automate the crane selection process, with emphasis on knowledge-based expert systems, case-based reasoning and object-oriented programming. In addition, the chapter shades light on the use of spreadsheet and graphic software applications for equipment selection in the construction industry. The applications of database management systems in the construction field are also described. Finally, the chapter discusses the current practice and the factors considered in crane selection.

Chapter 3 (Methodology) discusses the proposed methodology for crane selection. A description of the conceptual design of the system components, which includes the following: 1) the conceptual design of the database; 2) the algorithm used in the database; 3) the methodology and the algorithm used in the selection module; 4) the methodology and the algorithm used in the optimization module.

Chapter 4 (Implementation) discusses the development of the integrated-computer system. A description of the methodology used in the development of the system's components including the database, the 3D module, the optimization module, the crane selection module, and the 3D-animation module.

Chapter 5 (System Performance) presents the methodology used for populating the database, data verification, algorithmic validations, and the performance and the challenges of the system. The chapter also evaluates the theories of the methodology using numerical examples (case studies).

Chapter 6 (Conclusion and recommendations remarks) contains generalizations concerning the value of the proposed structure for crane selection. based on the findings and the deliverablès of this research. The chapter also formulates the research contributions and proposes some recommendations for practical applications and future research.

Chapter 2 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a review of the applications of knowledge-based expert systems (KBES), object-oriented programming (OOP), case-based reasoning (CBR) methodology, computer aided design (CAD) systems, spreadsheet applications, and database management systems in the construction industry in general, and those applied to crane selection in particular. This chapter focuses on the application of crane selection location and those utilised for heavy and critical lifts.

2.2 REVIEW OF APPLICATIONS USED FOR CRANE SELECTION

2.2.1 Application of KBES

Knowledge-based expert systems (KBES) and their various applications in the construction industry have been extensively described in the literature, (Mohan 1990, Moselhi et al. 1990, Alkass et. al. 1988, Levitt 1987). They have been used for equipment selection (Al-Hussein 1995, Al-Hussein et. al. 1997, Alkass et. al. 1993, Amirkhanian et al. 1992, Moselhi and Ghazal 1992, Alkass and Aronion 1990. Alkass 1989. Christian et al. 1987. Bernel 1986, and James 1989).

Very few attempts at developing computer modules for crane selection and their use have been reported in the literature. **CRANE ADVISOR** (Al-Hussein et. al. 1995-A) is a decision support system (DSS) for crane selection, it integrate a knowledge-base and algorithmic programs to assist in the crane selection for high-rise building projects, and has been developed in an object oriented programming (OOP) environment using Level 5 expert system shell. Vargheses 1992 combined an expert system NEXPERT and geographical information system (GIS) to develop a route access planning model to optimise the route selection when moving large objects from their storage location to their site placement. Varhheses in his research addresses the accessibility problems in heavy lift planning in 2D. **PRECISE** (Karl & Gary 1993) is a computerised analysis method to minimise the number of moves required by a mobile crane to erect steel structures. The system selects the optimum path for the crane and determines the steel erection sequence. The system uses artificial intelligence (AI) techniques to solve the problem. It is limited to a single story steel structure.

CRANES (Cooper C., 1987) is a rule-based expert system for the selection of tower cranes for the construction of multi-story buildings. It requires the user to input the crane's location in addition to the building dimensions and the load distributions. The system is also limited to the selection of tower cranes only.

LOCRANE (Warszawski 1990) has been developed as a test case for the application of the expert system methodology to construction planning tasks.

Earlier models such as **COCO,** developed by the "Department of the Environment. London" (DoE, 1972), as described by Gray and Little 1985. The model requires the identification of the load and crane position, assuming limited types of cranes. Similar approach has been developed, but considering the building as a regular shape to optimise the crane's locations (Furusaka and Gray. 1984).

2.2.2 *Application of OOP*

Object-oriented programming (OOP) provides a highly flexible and modular programming environment for the analysis and design of computer systems that are capable of solving complex engineering problems. OOP paradigm and characteristics of abstraction, inheritance, modularity, and encapsulation of data (see Booch 1991) have received considerable attention among professional and academic groups. OOP techniques have been successfully used for analysing and designing of computer systems for crane selection. Al-Hussein et. al (1995-A) utilises OOP techniques in designing a computer module for crane selection for high-rise building construction. Cranes and buildings have been classified into classes and sub-classes, inheritance and encapsulation of data have been used to formulate the problem.

2.2.3 *Application of CBR*

The use of case-base reasoning (CBR) approach in construction has mainly been limited to solving design problems. **CADRE** (Bailey and Smith 1994) is an approach, which focuses on dimensional and topological adaptation of geometric models of existing buildings to find a solution to new design problems. **CADSYN** (Zhang and Maher 1993) is a case-based building design system based on the consideration of architectural space planning, structural design, and services design.

Little attempt however, to use case-based reasoning for equipment selection has been reported in the literature. Al-Hussein et. al. 1995-B uses CBR technique in a module that resinous from previous cases to assist in the crane selection process. In this approach data on existing cases (i.e. cases involving buildings that has already been constructed and the crane selection problem has been solved), has been gathered and stored in a database. along with description of the decision making process and procedures used in their construction. Associated problems raised from wrong decisions made during the planning process have also been stored in the database. This data is used to avoid potential problems that might occur during the decision-making process for new projects.

2.2.4 Application of DBMS

Database Management Systems are having a major impact on the growing use of computers. It is fair to say that databases will play a critical role in almost all areas where computers are used including engineering and construction. Large systems need to store permanent information to be shared by the systems' different modules. this is done through a database management systems (DBMS). Different database structures are available. such as, hierarchical and networked DBMS which represent data and data interrelation using predefined structures and which are, therefore, difficult to modify. In this context. relational DBMS are widely used. they allow data modelling using simple structures (tables) without having to predefine the data interrelations. Relational database management systems and CAD have been used for planning lift scenario modeling. crane selection, and crane placement (Haas and Lin 1995). Al-Hussein et. al. 1995 developed a database system, capable of storing, indexing and retrieving information on constructed projects cases and information on commercial cranes to perform communication between all the crane selection system's components. This information includes: shape of the building site constraints, terrain condition, design drawing specifications, crane types, crane sizes, material handling specifications, material storage, etc., which can be stored in such a global database that can be updated with new information as it becomes available.

Al-Hussein et. al. (1998), developed a Decision Support System for crane selection and location on construction sites. The integrated crane selection module and three databases, dedicated respectively, for cranes, rigging equipment, and projects' information. D-Crane (Al-Hussein, 1999-A) is a comprehensive database for cranes load charts and geometry, designed to be used by crane selection module to assist users in the selection and location of the most suitable crane for a construction project.

2.2.5 Spreadsheet Applications

Large number of cost components such as owning and operating costs are associated with the use of cranes on a construction sites. Their calculations require mathematical procedures using computerised spreadsheet to assist in estimating equipment costs (Harris and Macffer 1983; Roberts, 1987; Alkass et. al. 1994). Spreadsheets have effectively been linked to expert systems (Alkass et al 1992; Alkass et. al.1990). Al-Hussein et al (1996) developed a spreadsheet application in QuatroPro capable of handling algorithm calculation to perform equipment cost calculations in a model called Equipment Cost Estimation and Analyser (ECSA). Al-Hussein et al (1999-B) have used MS-Excel to developed an optimisation module to optimise the on site location of cranes and to validate the algorithm used by the crane selection system.

2.2.6 Heavy Lifts Planning and 3D-CAD Applications

Many computer programs have been developed to automate planning heavy lifts. **Cope** (Lin et al 1996-A, Lin et al 1996-B) is a system that assists in determining the minimal number of equipment relocation based on an integer-programming model. Heavy lift planning system (HeLPS) have been developed by (Dharwadkar 1991 and Wolfhope 1991), which utilized CAD models of sites, vessels and cranes to simulate crane operation on a construction job site. HeLPS employed the 3D graphics display shell WALKTHROUGH to animate crane motion. A crane library which consists of a standard 3D model of components which make up the crane has been developed by the authors along with a monitoring window showing the crane components (i.e. crane position, boom length and crane lifting capacities). A similar study was reported **HeLPS1** and **HeLPS2** (Hornaday et al 1993) involving an integrated computer aided heavy-lift planning system, employing 3D graphics display to animate crane motion on a construction job-site. These systems demonstrated the feasibility of a CAD simulator to perform planning functions such as interference checking and lifting capacity evaluation. Hornaday (1992) proposed a structure for a computer-aided planning system for construction of heavy lifts in an analytical method for the optimization of rotary crane location and lift path. Al-Hussein et al (1999-C) demonstrated the effective use of information technology including 3D-CAD in planning heavy and critical lifts. Al-Hussein et al (1999-D) demonstrated the effective use of 3D-animations in planning and executing heavy and critical lifts. Other 3D-CAD model for graphical simulation of mobile crane has been developed by Dharwdkar et al 1994.

2.2.7 General Applications

The module **CRANES** (Gray and Little 1985) was developed to assist the users in the selection of appropriate cranes and their locations on construction sites. It has two components, the graphics routine, which considers the implications of the building's shape, and the load distribution and possible crane location. The system is based on mathematical calculations rather than knowledge; it requires a change of the number and the size of the selected crane(s) during the course of the project construction. Such practice is inconvenient and usually unacceptable to the contractors. Al-Hussein et al (1999-E) described the performance, challenges, and opportunities faced during the implementation of a computer system for crane selection. Zhang et al (1999) developed a methodology to optimise the locations of groups of tower cranes, focusing on the balanced workload, minimum likelihood of conflicts with each other, and high efficiency of operations. Leung et al (1999) presents a methodology for predicting the hoisting time for tower cranes for public housing construction in Hong Kong.

2.2.8 Commercial Systems

Combo Crane (Doug Williams 1996 Demonstration) is a commercial software used to assist in planning lifts operations, and it requires the user to select the crane, and then assists in producing lifting planes. **ALPS** (Williams and Bennett 1996) is an automated lift planning system developed by Bechtel to assist in the planning and visualization of crane selection, rigging analysis and 3D lift simulation. Wen 1993 and Lin 1993 have reported the following commercial systems: Computer-Aided Rigging system (CAR), which has been specifically developed to aid Brown & Root Braun in their single crane heavy lift planning. CAR is described as a computer-based drafting board that combines some basic rigging analysis and Intergraph software to automate the calculation and documentation of professional rigging planes. These were developed using Micro-Station Development Language (MDL). Cimlinc system is a 2D-CAD package running on SUN Workstation, and is used for crane design and some lift planning (Cranes Today March 1992-A). Design View is a computer-based system to assist users in creating product geometry of the site (Cranes Today March 1992-B). Engineers at IRVING EQUIPMENT have described their developed systems in three articles: 1) CADD is a 3D imaging module based on AutoCAD drawings to display sections of a drawing and multiple views (Cranes Today March 1992); 2) The benefits to using the system are described (Heavy Construction News August 1996); and 3) a system which involves lift design and planning is also described (international Cranes March 1995).

2.2.9 Literature Review Summary

Figure 2-1 shows a summary of the literature review for the last three decades. Considerable effort to automate the process of equipment selection and to satisfy the potential users was reported in the literature. Attempt to automate the process was reported as early as 1972, followed by other researchers in the early 80's. Users were not able to adapt these studies due in part to the complex mathematical formulations used. In mid 80's KBES were reportedly studied by researchers, however, the technology (i.e. DOS-based applications) becomes a barrier, which prevents full utilisation of these systems. In the late 80's, research shows emphasis and concentration on providing applications supported by user-friendly interfaces. The construction process in the 1990's show considerable changes; planning engineers start to construct their projects using bigger prefabricated elements, relying on the increasing capacities and outreach of the newly-manufactured cranes. Therefore, a considerable effort has been reported in developing methodologies to assist users in utilising heavy or critical lifts. This period of time shows infuses in using optimisation techniques, KBR and DBMS. Other researchers found that the industry's resistance to the use of innovation or new technology, is due in part, to the industry culture of using cranes (see Shapira and Glascok 1996). The main objectives of this research work are to develop a practical methodology for automating the crane selection process, combining integration and data management.

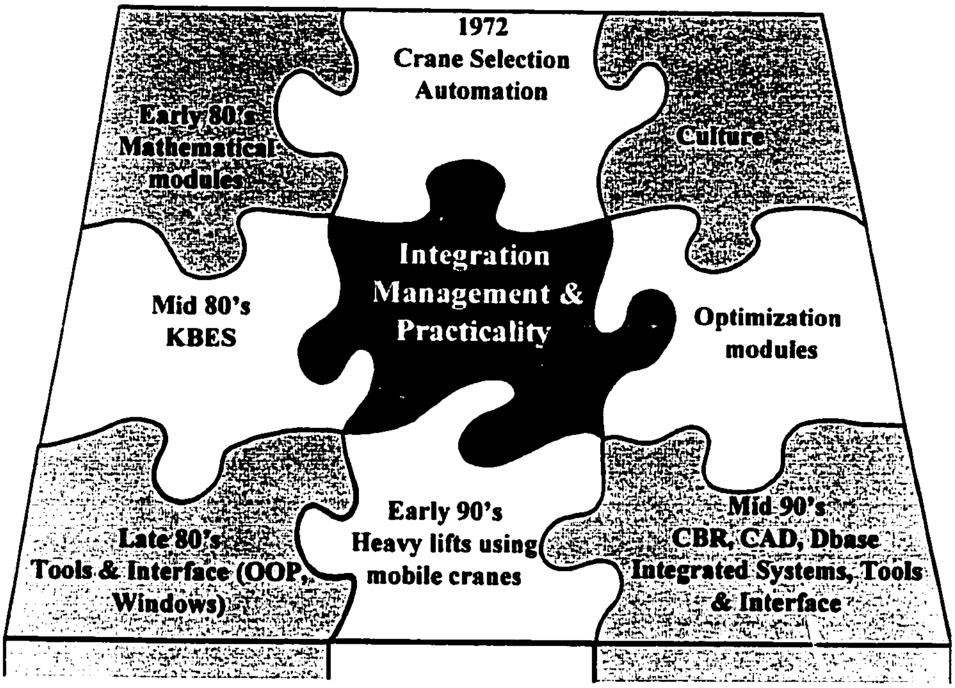


Figure 2-1 Main Trained in the Literature

2.3 KNOWLEDGE AND REQUIREMENT ACQUISITION

User requirements are essential in developing a methodology for crane selection. Experts from the domain of crane selection were identified, their knowledge and requirements was solicited during interview sessions. During this work, experts in the area of the crane selection were classified into groups based on their areas of specialisation: general contractors, rental companies, project managers, government authorities, training institutions and instructors, expert with academic and practical background, design professionals, crane operators, and crane manufacturers. This grouping simplified the process of accumulation and codification of their requirements. Two methods of knowledge acquisition procedures were used: structured interviews, and prototyping.

2.3.1 Structured Interviews

Experts were asked to describe the crane selection process with the emphasis on the factors affecting their selection. They were asked also to list their requirements to a system. which will be used to assist them in this process. It was found that. decisions made at various stages most be tested in the light of discrepancies bound to arise between the experts. All decisions require prediction as to the consequences of the choice that is to be made. Company's interests some times restrict the decision. Therefore. different experts have different point of view in the process.

2.3.2 Prototyping

This involved the development of a prototype at an early stage of the knowledge and requirements acquisition process. Information and requirement collected from experts were classified. coded, and represented in a prototype module. This module was presented to the experts for criticism, feed back and to test its effectiveness. The demonstration of the prototype proved to be valuable since it helped in revealing new knowledge and more efficient requirements. The procedure was repeated until the experts finally approved the system.

2.3.3 Knowledge and Requirements Acquisition Finding

Experts decisions are sometimes affected by their company's interests and their area of specialisation. Selecting a crane for a building project is viewed differently by each party in the project. For example, the structural engineer is interesting in selecting a light enough crane so the structure can carry its total load with minimum change in the design. The architect, on the other hand, may view the crane as regular equipment, which should not have any impact on the architectural facade, while the general contractor may perceive it as the most profitable and productive equipment on site. The rental company often perceives the crane as the most preferable piece of equipment on a construction site, while the project manager views it as a piece of equipment that ensures, efficiency, higher productivity, and safety. Subcontractors focus on the crane's efficiency and capacity, government officials stress safety, while crane operators interest is in the crane's capability to carry all lifts and it is located in a clear position.

A sample representing these groups was selected and interviewed during the knowledge and requirement acquisition stage. The following is a list of the different experts whose were interviewed:

a- *In-house Experts. (Experienced engineer currently doing graduate studies at Concordia University).*

b- *Colleagues from other Universities.*

c- *Experts with academic and practical background.*

d- *General Contractors.*

e- *Rental Companies.*

f- *Design professionals.*

g- *Project Managers.*

h- *Instructors from a Training Institute.*

i- *Government authorities.*

j- *Crane Operator.*

2.4 CURRENT PRACTICE FOR CRANE SELECTION

Crane selection is commonly carried out by general contractors, crane suppliers, or both in an interactive manner. General contractors aim at increasing their profit margins and completing their work on target schedule and within specified quality. To maximize profit, contractors try to minimize equipment costs, especially that of cranes. Normally they prefer to use the smallest size crane capable of completing the task on schedule. Contractors may or may not own cranes and may either rely on external expertise or on their in-house professionals for identifying the type of cranes to be used. In this regard, general contractors can be classified in four groups: (a) general contractors with in-house professionals, who own a number of cranes; (b) general contractors with in-house professionals who rely on rental companies for the supply of cranes; (c) general contractors who own a number of cranes and depend on outside professionals for advice on the crane selection; and (d) general contractors who rely on rental companies for the supply of cranes and use the rental companies' experts or outside professional firms for advice on crane selection.

2.4.1 Current Practice Followed by General Contractors

Figure 2-1 illustrates the crane selection process used by group (a) (i.e. General Contractors with in-house professionals and own a fleet of cranes). The process generally starts with a report prepared by the crane manager, which may directly recommend the selection of a particular crane(s), or the decision will be taken in a meeting with experts from different areas (i.e. design professionals, architects, and financial professionals). This report generally includes information about the project (i.e. the shape of the building, the type of the structure, the material used, the construction program, and the site constraints). The selected crane(s) usually satisfy all contractual conditions and account for a number of technical and financial factors, including the cranes' availability, its capacity to meet the construction program in view of its production rate, and its cost effectiveness. This decision is further followed by the crane manager, project manager, site supervisor, and crane operator to determine the suitable types of attachments and most appropriate location(s) for the selected crane(s). The final output consists of the number, type(s), position(s) of crane(s), and may include its costs.

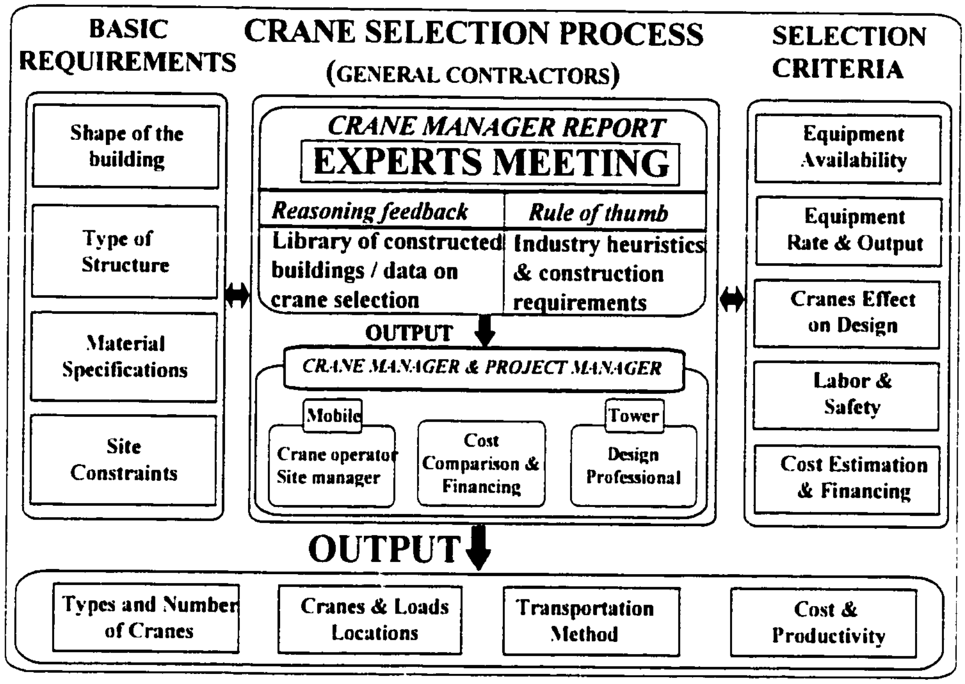


Figure 2-2 Crane Selection Process Followed by General Contractors

2.4.2 Current Practice Followed by Rental Companies

The selection process used by rental companies, on the other hand, involves selection, transportation, and scheduling of the entire fleet of cranes. Crane managers (sales representatives) play a main role in the selection process, as shown in Figure 2-3.

The selection process generally starts by receiving a telephone inquiry from the end-user (i.e. the contractor or the owner) providing information about his/her project (i.e. information about lifts and site constraints). In many occasions the crane manager visits the site, and as a results he/she prepares a report. This report may directly contain a recommendation for the selection of a particular crane and/or a fleet of cranes, or may simply call for a meeting of the in-house experts. Based on the sales representative report, the experts select the size and type of crane(s) that meet the lifting requirements and comply with the manufacture's load charts. This is done in close consultation with the dispatcher, who keeps a record of the entire fleet and determines the availability of the selected crane, delivery time and the transportation method. The final output consists of the number, type(s), position(s) of crane(s), transportation method, permits, the service contract including terms and conditions, and the method of payment.

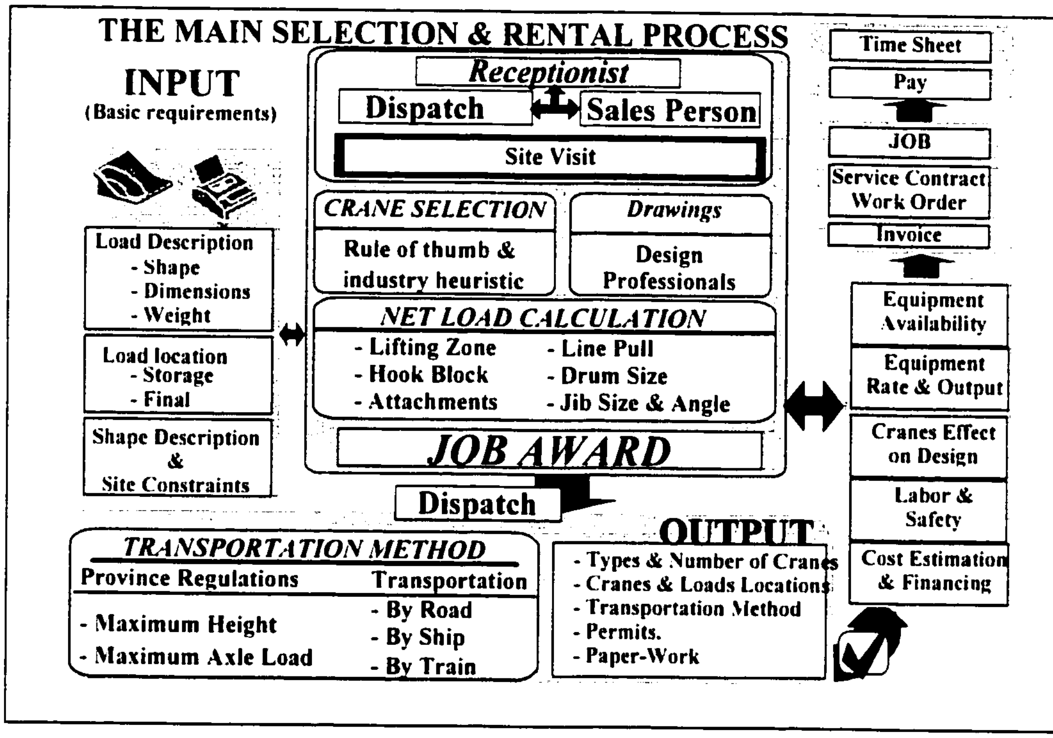


Figure 2-3 Crane Selection Process Followed by Rental Companies

2.4.3 Current Practice in Large Size Projects

This section describes a method for selecting a fleet of cranes, for material handling in construction, considering feedback on work progress from the job site and interactive exchange of information between the service provider (the crane supplier) and the-end user (the contractor) early in the planning stage and during construction. It focuses on the scope of the work and examines what needs to be done how it will be done and when it will be done. It also focuses on alternatives used for reducing costs. In a way, it utilises some form of value analysis or value engineering. The section illustrates the method using the case of the Prince Edward Island (PEI) 12.9km bridge, which connects the PEI to the mainland, and the role of the crane supplier GUAY Inc (see Moselhi et. al. 1997). in providing the cranes needed on site. The section addresses the topic in a holistic manner, encompassing contractual practices, selection processes, deployment of the fleet to the job site, maintenance and administration, and demobilisation.

Project Characteristics: The PEI Bridge forms an S-shape along its 12.9 km length, connecting PEI at Borden and New Brunswick at Bayfield. The bridge is of reinforced pre-cast pre-stressed concrete construction, supported by gravity-based foundation piers. Construction activities were performed at the two ends of the bridge. Only the Borden site is considered in this study. The site was rather congested, laid out primarily for the efficient fabrication and transportation of the pre-cast concrete elements of the bridge (see Figure 2-1).

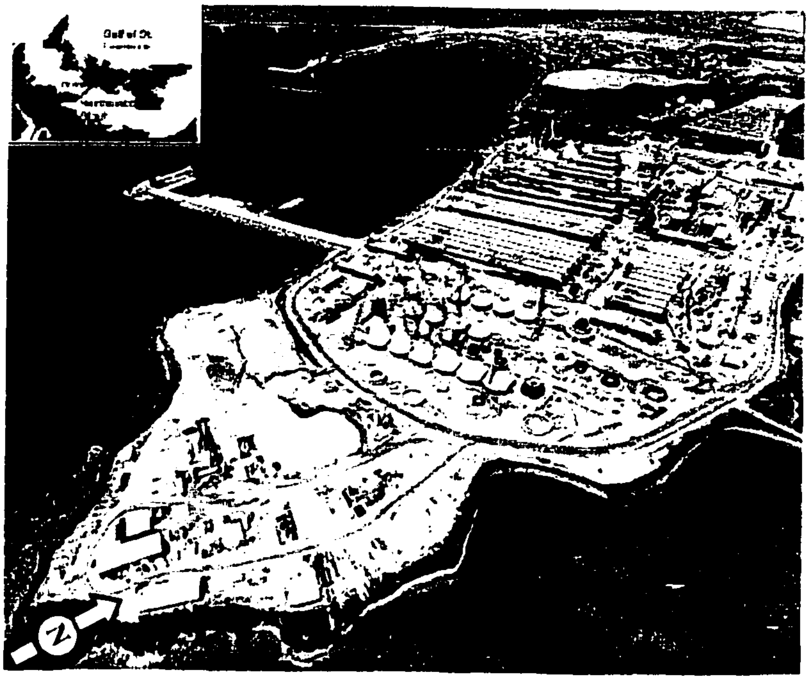


Figure 2-4 PEI Case Site Layout

(Ref. Internet web site Northumberland strait crossing bridge)

Selection Process: The process utilised in fleet selection and configuration is shown in Figure 2-5. The input, i.e. the required information, is prepared by the end user (the contractor). The service provider (crane supplier) studies the information provided and reviews his workload and resource availability. At this stage, critical assessment of certain important elements to consider: 1) contractual requirements (supplying cranes with or without operators, delivery time and schedule requirements, demand period for each crane in the fleet), 2) field operations and work processes (material handling requirements, including size and weight of required lifts), 3) site layout and associated constraints (issues considered in this regard include access to the job site, adjacent facilities, safety requirements, site topography, traficability congestion and potential interference), 4) crane(s) capabilities (reach, hook height, lifting capacity, operating conditions), 5) resource availability, and 6) costs including billing conditions, transportation, assembly, operation, and demobilisation costs. It should be noted that in this process the crane supplier tries to fulfil all contractual requirements (item 1), ascertain technical feasibility (items 2 to 5), and achieve cost effectiveness (item 6). In so doing, field operations and work processes can be revised based on an interactive exchange of information between the contractor and the crane supplier early in the planning stage and later during construction. This makes the selection process an interactive one, permitting team co-operation and feedback on operating conditions and work progress as shown in Figure 2-5.

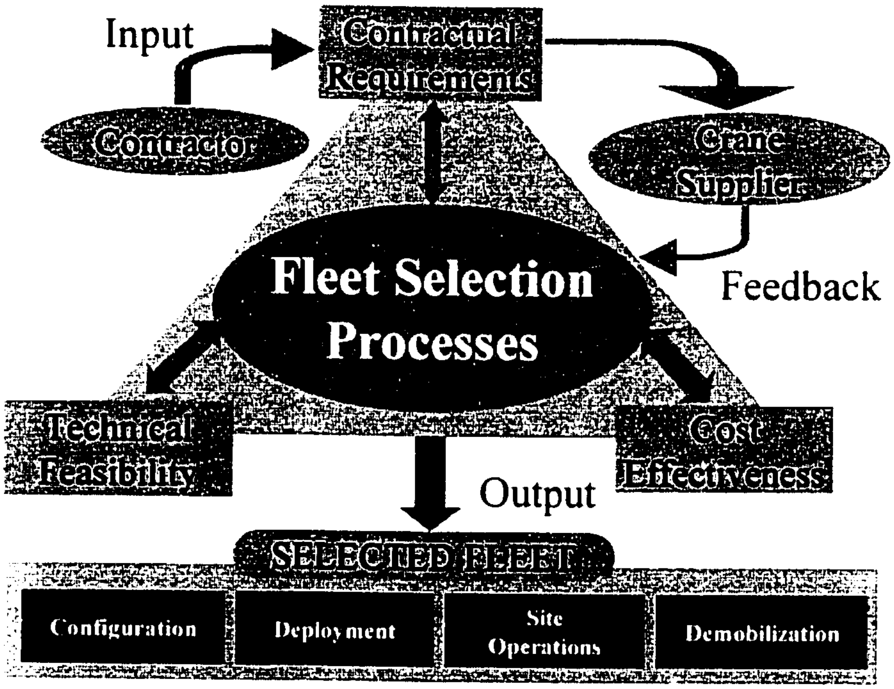


Figure 2-5 PEI-Bridge Crane Selection Process

The process described above was utilised in the case of the PEI Bridge. The primary work processes and site operations for the fleet, described in this section, are those used in the manufacturing of the pre-cast concrete elements used in the construction of the bridge. Figure 2-6, shows the process followed in this case. The contractor initially issued a bid package, requesting quotations for the supply of a number of cranes with specified types and capacities. The bid package also indicated that cranes were to be supplied without operators. Upon 1) examination of the bid package including the scope of work and production requirements, 2) assessment of the availability of cranes and operating conditions, and 3) consultation with the contractor, particularly regarding production methods and delivery schedules, the crane supplier (GUAY Inc.), proposed an alternative fleet that is technically feasible, contractually acceptable and cost effective. Of interest her to note the value analysis process performed and the teamwork involved played key roles. Cranes with larger capacities than originally specified were used, and reinforced cages for piers and shafts were assembled on the ground and hoisted to their respective final locations, rather than being assembled directly in their final positions. This resulted in cost savings, improved productivity and facilitated quality control efforts. Another rather interesting issue in this process was the planned operating conditions and the limitations on the resource pool of operators. In addition to the fleet supplied by GUAY Inc. other rental companies supplied the contractor with more cranes. A total of 75 cranes were used on the job site, operating on two shifts. Available resource pool of operators was just adequate to provide 150 certified operators from PEI and the neighbouring provinces of New Brunswick, Nova Scotia, Newfoundland, Ontario and Quebec.

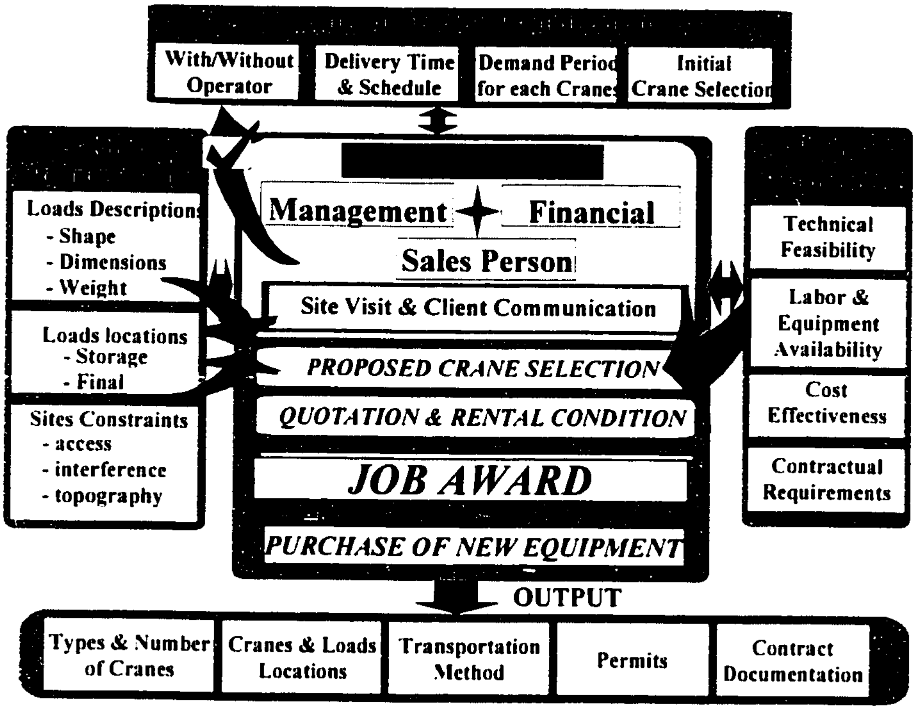


Figure 2-6 PEI-Bridge Contract Evaluation and Crane Selection

The selected fleet consisted of 8 tower cranes, 3 cranes mounted on rails and 5 cranes on fixed bases, located to support the on-site fabrication and planned production operations. This encompassed the installation of 2 concrete batch plants and 3 gantry cranes, assembly of formwork, and placement of reinforcing cages. Except for a limited number of concrete elements, transportation was not performed by cranes, but rather by using a dedicated, specially designed transportation system. The hook height, radius and lifting capacity of these cranes vary from 44.5 to 62.5 m, 51 to 75 m, and 60 to 400 tons, respectively. The tower cranes were further supported by 14 mobile cranes (13 are crawler mounted) ranging in capacity and reach from 60 to 400 tons and 120 to 350 feet, respectively. The material handling operations were planned over a period of 3 years and involve primarily lifting and placing formwork, rebars and each of the match-cast concrete templates, connecting the piers and the main girder. The weights lifted by the cranes ranged from less than 0.5 to 100 tons.

2.5 Factors Affecting Crane Selection

Based on examination of the current practice and study of the literature, the factors that affect the crane selection were identified and classified under technical, contractual, and economical factors (Al-Hussein et al 1995-B and Moselhi et al 1997), as shown in Figure 2-7.

FACTORS AFFECTINGCRANE SELECTION

- ***Technical Factors***
  - Site constraints
  - Site topography
  - Access to the site
  - Terrain condition
  - Site layout
  - Shape of the facility
  - Weight and size of material
  - Cranes capabilities
- ***Contractual Factors***
  - ***Project Factors***
    - Method of operation
    - Project schedule
  - ***Global Factors***
    - Cranes & technical support
    - Influence of regional project
    - Unfamiliarity with all types of cranes
    - Rental market
    - Subcontracting
    - Employment pattern
- ***Economical Factors***
  - Running cost
  - Dismantling method
  - Size and number of cranes
  - Purchase Vs rent

Figure 2-7 Factors Affecting Crane Selection

Technical Factors generally address the feasibility of the selected crane(s) to perform the task at hand. They are mainly sites, lift (load), and equipment related, as shown in Figure 2-8. The site-related factors include the shape of the building, the presence of adjacent facilities, such as buildings and power supply cables, site topography, and site layout (i.e. the availability of sufficient space for cranes' components for erecting, dismantling, and cranes maneuvering). Lift-related factors include shape, weight, size of the planned lifts during construction, and locations of critical (heavy) lifts. Equipment-related factors include the type of the cranes (tower or mobile). In the case of tower cranes, the mast type (free standing, climbing, or real mounted), and the jib type (luffing or saddle jib). In the case of mobile cranes, the crane mounting configuration (all terrain, rough terrain, crawler mounted, or truck mounted) the boom type (lattice or telescopic) and the jib configuration.

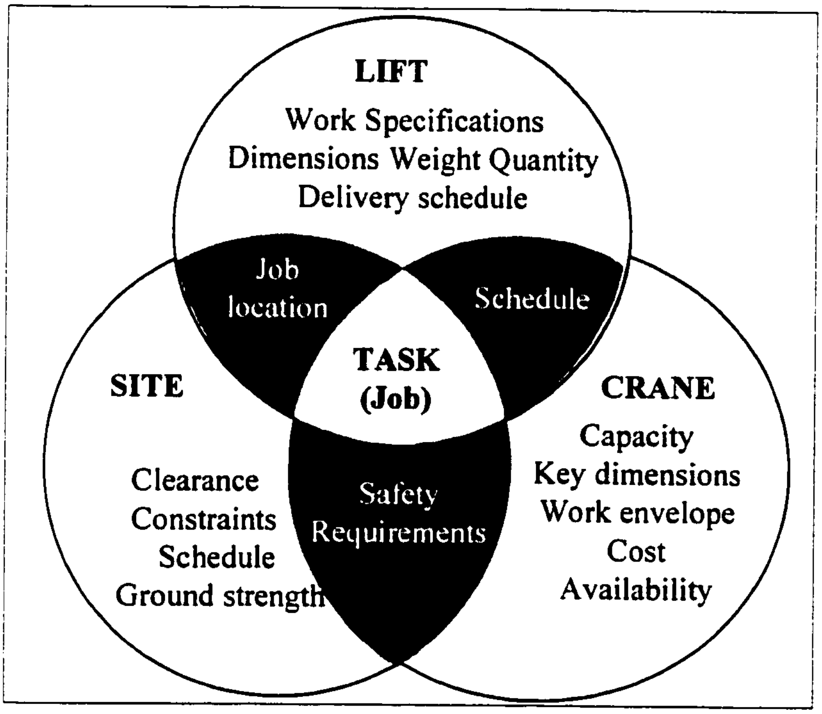


Figure 2-8 Technical Feasibility Factors

Contractual Factors generally account for project and market conditions. Factors related to project conditions include method of operation, frequency of lifts, speed, maximum utilization of cranes, types of lifts including dimensions and weight, which should be considered so as to satisfy the project target completion date. Other factors, which affect crane selection, include building structure and stipulated method of construction and type of material (structural steel, cast-in-site concrete, pre-cast concrete or composite construction).

Market conditions include regional availability of cranes, technical support during its operation, and the prevailing business culture. Selecting a mobile rather than a tower crane for example could at times be attributed to the business culture of a particular trade and what this trade is comfortable with (Shapira and Glascok 1996).

Economical Factors are primarily used to determine whether to rent or purchase a particular crane considering ownership and operating costs. Many variables are considered in ownership costs, such as investment, insurance, depreciation, replacement, and storage. Operating costs are sub-divided into four categories: direct operating (wages, spare parts, and repair service), maintenance overhead (maintenance, supervision, and utilities), operating expenses (fuel, oil, grease, tires, hoses, and cables), and startup and finishing (erection, dismantling, mobilization, demobilization, and transportation).

Chapter 3 PROPOSED METHODOLOGY FOR CRANE SELECTION

This chapter describes the developed methodology for crane selection and their location on construction sites. In developing the methodology, current practices were studied, through site visits, interviews with experts, and study of past projects. The work, being sponsored by a leading crane supplier, allowed for interactive consultation with the company's expert throughout the system development. Figure 3-1 illustrates the system architecture and its data flow, which is essentially in line with the current practice.

Based on the user's answers to a set of questions posed by the system pertaining to the project characteristics (shape/size of the lift and of the building and site constraints), the system guides the user through the selection process. The crane selection module, which integrates the crane and rigging databases assists in the calculations of geometry related to the selected crane (location, boom/jib lengths and angles to ground; and lifting radius and tip height) and provide the user with a list of technically feasible cranes and their configurations. The user is also provided with the gross and net capacity of the recommended cranes. Further, the user will have the option of graphically visualizing each alternative using the selection module on screen plan view of the site and the crane or alternatively he/she could use AutoCAD for lift plans drawings and 3D Studio for lift planning animations.

The selection methodology evaluates two selection criteria: 1) searching for crane configurations and lift settings capable of carrying the lift; 2) considering the least costly options. Crane configurations and lift settings are evaluated for their capabilities to place the lift in its final and/or initial position. They are identified based on their respective load capacity stored in the crane database. The least cost option is evaluated primarily based on the rental costs, crane configurations for lifts stored in the crane database are ranked based on their rental costs.

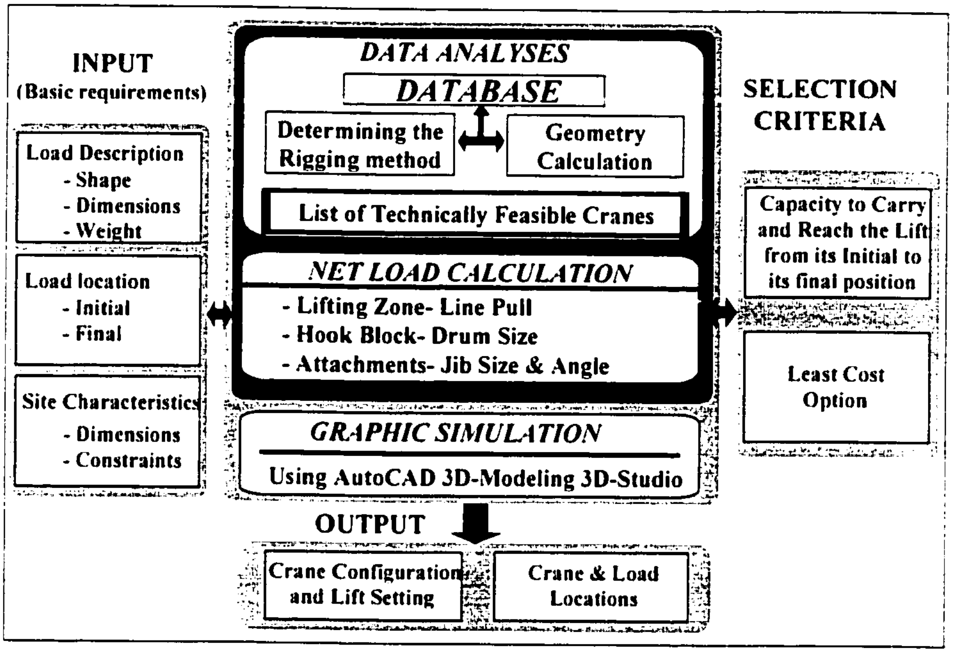


Figure 3-1 System Architecture

The process starts with entering the data pertaining to the lift, being considered the building and the site. The lift weight and size determine the rigging equipment. The user access the information stored in the rigging database and selects the rigging equipment required. After knowing the total lift weight (the weight of the lift and the rigging equipment), the selection module queries all crane configurations and their settings from the crane database to find one that can perform the lift, accounting for geometric constraints such as the dimensions of the lift and the buildings.

The developed system consists of four modules (i.e. the crane selection and location module, the crane location optimization module, the 3D-CAD module, and the 3D-animation module). All the modules share a system database, which consists of four databases dedicated respectively to cranes (geometry and load capacity charts), lift attachments, crane accessories, and projects and clients. In addition, there is a library of 3D drawings of cranes' elements, used for the 3D-CAD module and the 3D-animation module, as illustrated in Figure 3-2.

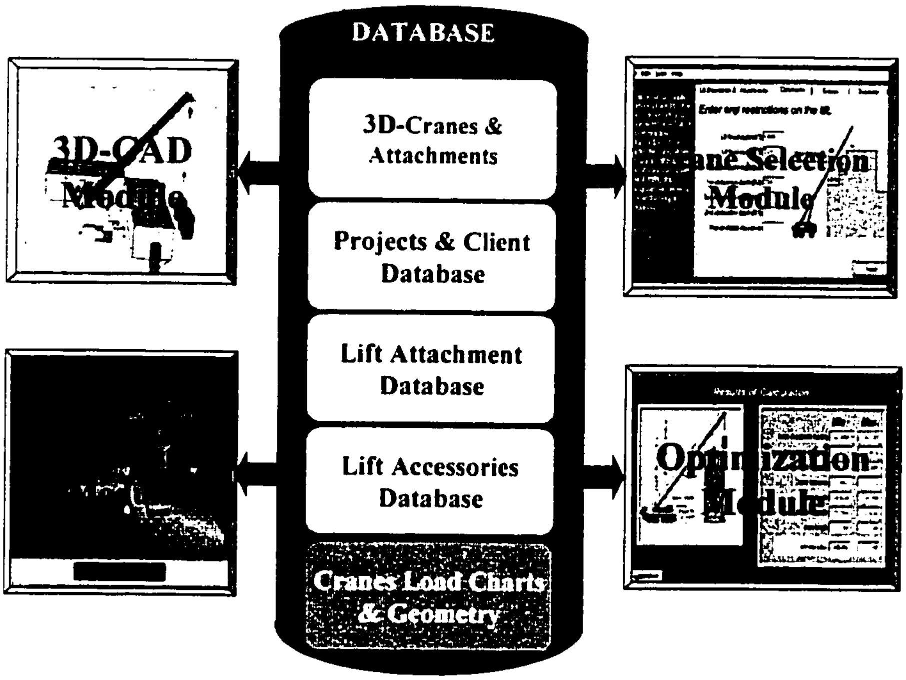


Figure 3-2 System Components

3.1 CRANES DATABASE

3.1.1 Overview

Manufacturers supply information about their cranes in different and inconsistent formats. The cranes database has been created to unify the variations and to replace the existing paper-based load charts and information for cranes and accessories, and store them in a computer in standard format. Storing this data on computer has many advantages; the main one is harnessing the power of computers to search through large amounts of data. Linking the database to a DSS for crane selection and location. becoming a valuable tool in the office and on the road. to assist in the day-to-day operations of cranes.

The design process of the database was carried out in two different stages: the conceptual stage and the implementation stage.

Stage one: the database conceptual design process. (This stage is described in this chapter). it follows the process described by Elmasri and Navathe 1995. as shown in Figure 3-1. This stage involves these two steps:

1) ***Requirement collection and analysis:*** During this step, the database specifications and functional requirements where written based on interviews with the prospective database users and the modules requirements, that are linked to the database.

2) ***Conceptual schema:*** After collecting and analyzing all the requirements. the next step was to create the conceptual database design. The conceptual design was carried out using the Entity-Relationship (ER) diagram. which is a popular high-level conceptual data model.

Stage two: the implementation stage (This stage will be described in the system implementation chapter) involves these two steps:

1) ***Logical database design (data model mapping):*** This design stage involves the actual implementation of the database, using a commercial DBMS. This database was designed using MS ACCES, and the conceptual schema was transformed from the high-

level data model (the conceptual schema) to an implementation data model. The result is a database schema in the implementation data model of the MS ACCES environment.

2) ***Physical database design:*** The internal storage structures and file organizations for the database were specified during this stage.

3) ***User Interface:*** When the database design was completed the user interface and the application program for data entry were developed.

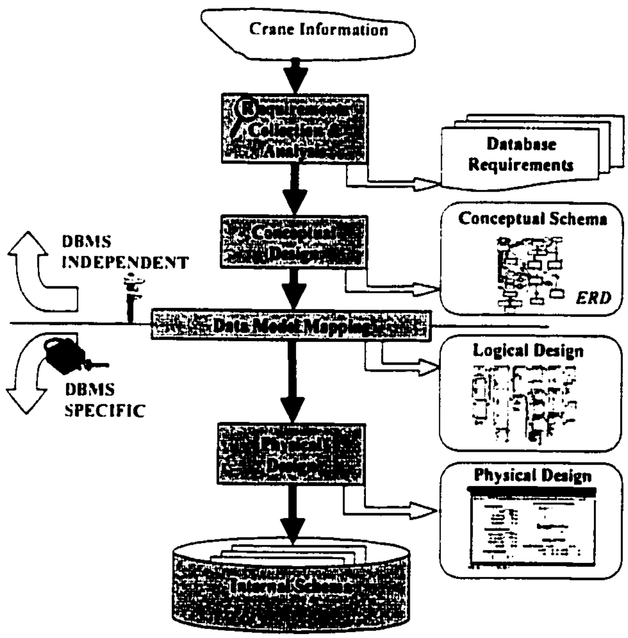


Figure 3-3 Database Design Process

3.1.2 Specifications

The specifications are essential to the conceptual design stage, because they provide a complete picture of the cranes and their components. Essentially, the specifications for cranes were written, and various components of the crane were defined, including the crane unit, boom and head unit, lift configurations and settings, and accessories and attachments. Each was described in non-scientific (natural language) form, stating the specifications for each component and its functional requirements as follows:

Mobile Cranes: *Each crane comprises of a support unit, a carrier unit, and a boom and attachments. Based on the carrier unit, there are five types of mobile cranes: Truck Mounted Conventional, Truck Mounted Telescopic, All Terrain, Crawler and Rough Terrain. Manufacturer's name and the model number identify the crane units. Some crane manufacturers also have a series name to encompass a range of models. Each crane (unit) has a boom, although some conventional cranes have several.. There are two boom types to consider; conventional and hydraulic. From the boom type, an assumption can be made as to the type of crane:. Rough Terrain, All Terrain and Truck Mounted Telescopic nearly always have an hydraulic boom; the others have a conventional boom. The company has an ID for each crane unit, which must be retained in the database.* ***The Carrier:*** *Every crane unit has a mounting pin for the boom. This pin location is referred to as relative to the centre of rotation of the crane unit. The centre of rotation of the crane unit is considered relative to the front and the rear of the carrier unit. The pin location does not vary with different booms. The database must store this information together with all the other dimensions that identify the crane and carrier units. Such dimensions include the physical size of the carrier (height and width), the size and overhang of the counterweights and the sizes of the cranes' supports. The supports are either outriggers or tracks. Outriggers are said to be set, partly set or free, tracks are said to be extended or retracted. Each position has different dimensions. Outriggers also have two different layouts, X or H pattern. This information is important to allow calculations regarding siting the crane. To raise the boom conventional cranes have a mast and telescopic cranes have a hydraulic ram. The location and dimensional information for these two parts, as well as the cross sectional dimensions of the boom, must be stored.* ***The Boom Head:*** *At the end of each boom is a tip. Hydraulic booms have only one built-in standard tip (head). Conventional booms, however, may have a variety of tips (heads) to suit different applications (taper tip, standard head, hammerhead,*

head-high and head for super lift). The tip is characterised by the size and number of sheaves, the location of the centre of the sheaves relative to the centre of the main boom, and the size of the cables accommodated by the sheaves. Booms are not symmetrical, therefore the height of the pin above the centre of the boom must be stored. Different heads may work with different booms of the same type of cranes. ***Crane Accessories:*** *Should further reach be required, an accessory (extension or jib) can be attached to a boom. A jib has a built-in head of its own, which has the same attributes as the head of a boom. The location of the pin to connect the accessory to the boom is relative to the pin centre of the boom. The relative dimensions must be stored. In addition, if the crane is used to lift on the main boom with the accessory still attached, the accessory effective weight on the boom needs to be stored. An accessory can be used with different booms, though usually only with those from the same manufacturer. There are several different types of accessories, fixed jib, luffing jib, extension and power-pin fly. The extensions and power-pin flys work with hydraulic booms. In some cases, a power-pin fly will be fitted as well as an extension. Apart from the luffing jib, the others form a fixed angle with the boom when fitted. Depending on the configuration, different fixed angles are used, which must be stored in the database. A luffing jib varies its angle, but the boom angle remains fixed. This fixed angle must be stored. In some cases, a luffing jib and the main boom vary their angles, forming the most complicated scenario.* ***Lift Attachments:*** *Cables and hooks are needed to perform the lift. A crane may have more than one cable and more than one hook, depending on the capacity. It is important to know the linear mass of the cables, their dimensions and capacities (strength). The hooks have various capacities and sizes, number of sheaves, masses, together with a minimum clearance, which is needed when calculating the lift. Hooks and cables are particular to a crane and are identified by name. When using any of the above mentioned equipment, notes and exceptions apply as specified by the manufacturer, these should also be stored in the database.* ***Lift Configurations:*** *When performing a lift, a crane is assembled from the range of compatible equipment available. The type, size and reach of lift to be undertaken define the* *assembly. The crane will be of a certain type, with a certain boom and perhaps a jib or other accessory. A counterweight mass will be appropriate to the capacity. For a given combination of equipment, a crane will have varying capacities. These depend on the length of the boom, the length of the jib, the angle of the boom or the angle of the jib, the support configuration and the lifting zone. All this information is required. The lifting zone is the area where the crane makes the lift: over the rear of the carrier, over the side, over the front or all around (360°). For any jib/boom length, jib/boom angle, there will be a radius, which is the horizontal reach of the crane. There will also be a tip height, which is the height of the crane lift. For a given lift, only certain hooks and cables will be suitable, depending on their capacity. Exceeding the manufacturer's stated capacity will fail the crane in two ways: the crane will either fail structurally or tip over, the database must store the one that applies. Any relevant manufacturer's notes should be included with the lift data.*

3.1.3 Conceptual Schema

The conceptual schema provides a comprehensive description of the database requirements, highlighting its entities and their respective relationships. The development was carried out using the ER diagram shown in Figure 3-1. The diagram consists of ***entities***, ***relationships***, and ***attribute***, and serves two purposes: 1) simple and transparent communication with the database users; 2) reference for the developer to ensure that all the users' requirements are modeled without any conflicts between entities and relationships.

Entities: are basic objects with an independent *physical* or *conceptual* existence. The proposed database consists of 24 entities: 15 physical entities (e.g. hooks, cables, counterweights (CTWT), support system (outriggers), accessories, etc.), and 9 conceptual entity (e.g. lift configuration, lift settings, etc.), see Figure 3-1. Below is a brief description of the attributes and relationships associated with the 24 entities.

Attributes: different types of attributes were used in the development of this database including composite, simple, single-valued, multi-valued, null-valued, derived, and key attributes. Composite attributes either form a hierarchy or are divided into smaller parts with each having it's own independent meaning as in counterweight dimensions where they are sub-divided into lower and upper heights. Simple or atomic attributes are used to identify whether the crane is hydraulic or conventional. Single-valued attributes are used to identify crane manufacturer names, series number, and model. Multi-valued attributes are used to define the different boom lengths. Derived attributes are used to calculate the boom angle and tip height from the stored boom length and working radius for lifts on the main boom for example. Not all manufacturers classify their cranes by model and/or series numbers, the crane in this case will have a null-valued attribute for series number and/or model. Attributes that distinguish entities are called key-attribute, in some cases several attributes are combined to form a key. One attribute concerning the rental cost of the crane is added to the crane entity, which is used to rank the selected cranes based on their rental cost. This is a numeric attribute, each crane from the company fleet is assigned a ranking number.

Relationships: two different level of relationships are used in the design of *D-Crane*: 1) a *binary* relationship type (i.e. only two entities are related at a time), such as the relationship between the crane entity and the hooks entity; 2) A *ternary* relationship (i.e. relationship between more than two entities), e.g. the relationship between the accessory length, main boom configuration, and the hydraulic main boom length as shown in Figure

3-1. Other relationships have assigned attributes, i.e. the relationship between the main boom and accessory configuration involves different main boom and accessory angles. Relationship type is not limited to one-to-one (1:1), they also include one-to-many (1:M) and many-to-many (M:N). A one-to-one relationship exists in the relationship between three entities mentioned above. A one-to-many relationship exists between the crane entity and the manufacturer notes entity. Many-to-many relationship exists between the crane entity and the attachment (accessory) entity. The type of relationship also articulate the dependency of one entity on another, for example, the existence of the manufacturer notes entity, hook entity, and cables entity, depends on the existence of the crane, but the crane exists without these entities. Therefore, the participation of the crane entity is considered *partial participation* and the participation of the dependent entities is *total or full participation.*

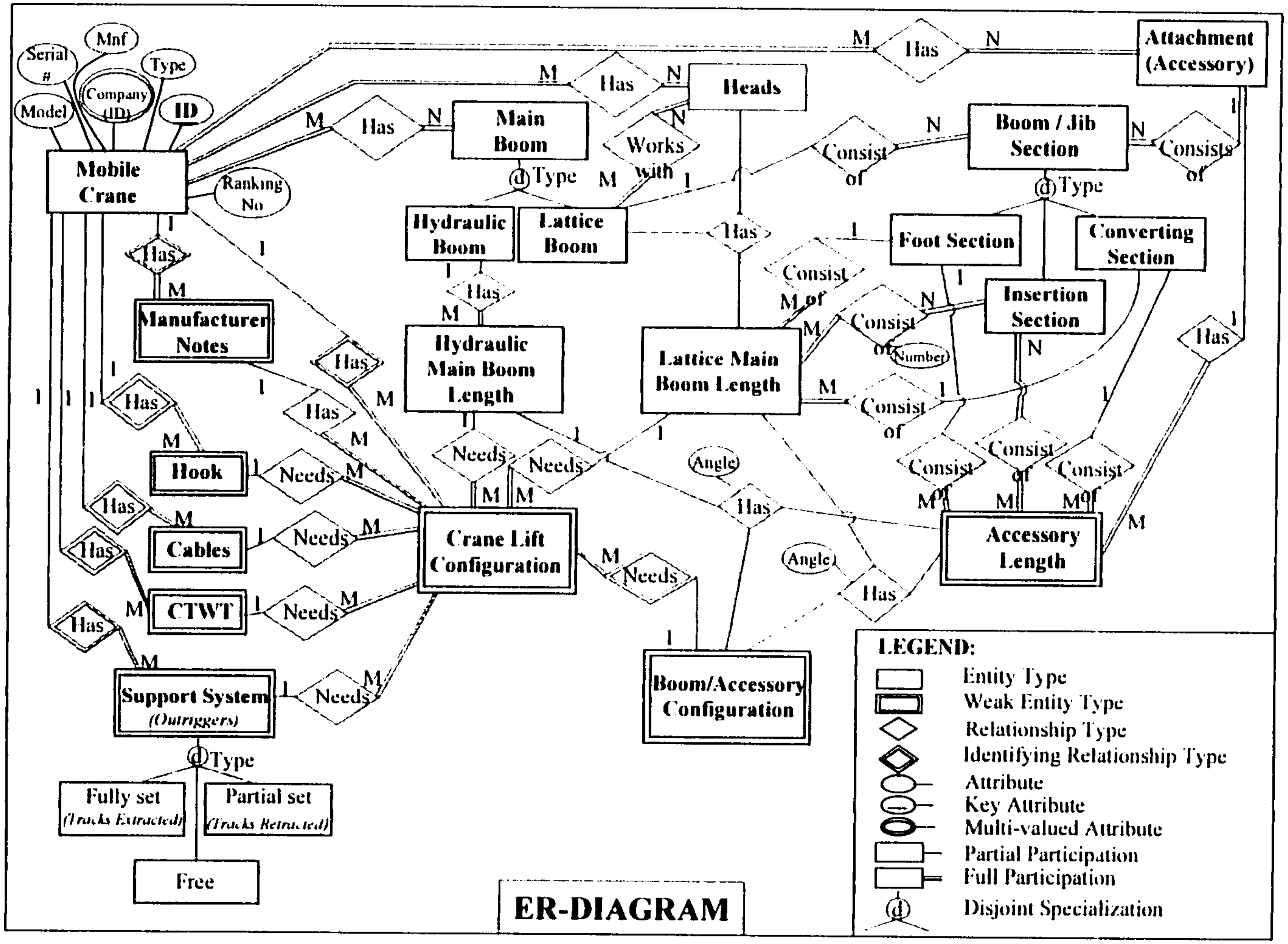
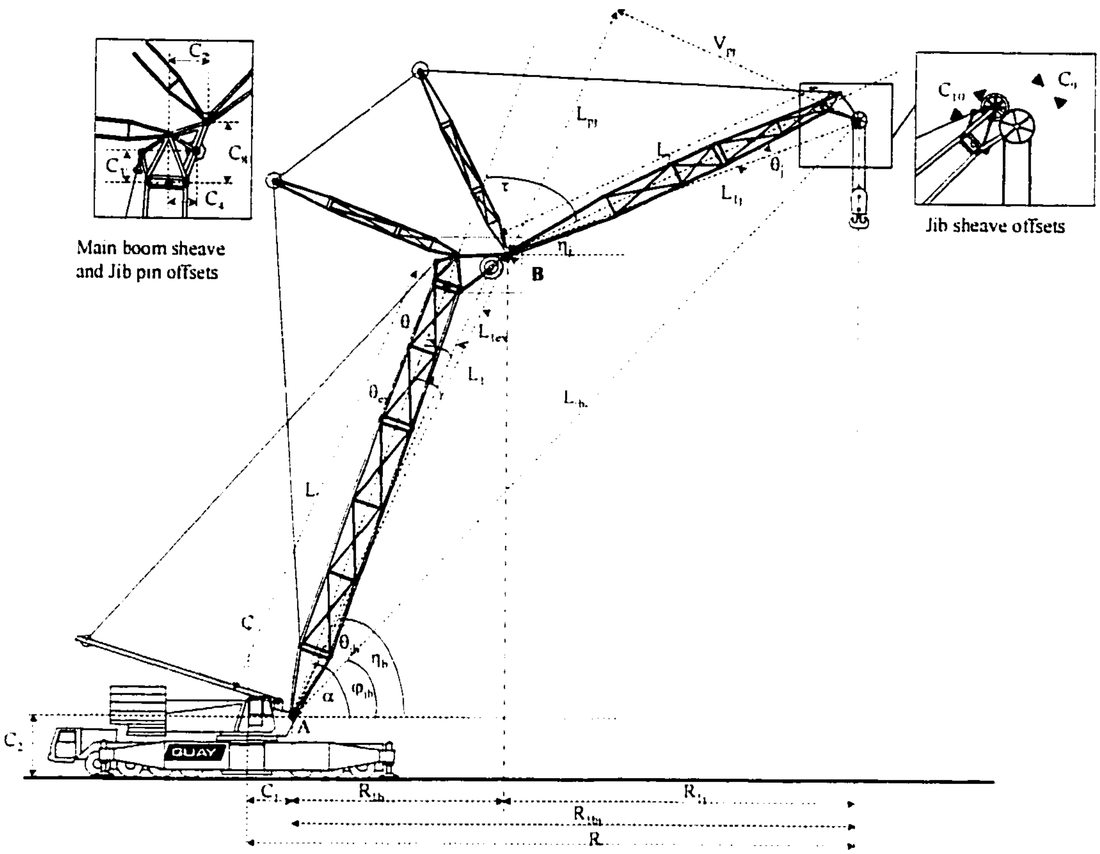


Figure 3-4 Database Entity Relationship (ER) Diagram

3.2 CRANE GEOMETRY ALGORITHM

Manufacturers often supply part of the information needed for crane selection. They supply, for example, the boom length and radius, leaving the user (in the case of lifts on the main boom) to calculate the tip height and the main boom angle. This becomes more complicated when using a jib and a main boom where the user in such a case is required to calculate the tip height and the angles associated with the boom and the jib. In the developed database all the parameters are automatically calculated, providing higher accuracy and saving time for users. A set of "*If-Then*" type rules has been developed along with an algorithm to calculate the missing data. The offsets resulting from the sheaves location and their diameters along with the pin offsets of main booms and jibs are considered in the developed algorithm (see Figure 3-1). Considering these offsets improves the accuracy of the geometrical calculations and makes the database more reliable in the selection process, particularly when the site poses critical space limitations.



1. ***Parameters stored in the database.***

C_1	Boom foot to centre
C_2	Boom foot to floor
C_7	Jib horizontal pin offset
C_8	Jib vertical pin offset
C_9	Jib vertical sheave offset
C_{10}	Jib horizontal sheave offset

2. ***Variables –based on load charts***

L_j	Jib length
L	Main boom length
R	Lift radius
H	Tip height
α	Main boom angle
τ	Jib offset angle

3. ***Variables – Calculated***

L_l	Length boom pin to main boom sheave centre
θ_{ex}	Angle, main boom centre line to L_{lex}
L_{lj}	Length, accessory pin to accessory sheave centre
θ_j	Angle, accessory centre line to L_{lj}
L_{jb}	Length, boom pin to accessory sheave centre
V_{pj}	projection of accessory sheave centre to boom
L_{pj}	Horizontal Jib Projection
R_{lb}	L_l reflection to floor
L_{lex}	Main boom pin to accessory pin
θ	Angle, main boom centre line to L_l
θ_{jb}	Angle, L_{jb} to L_{lex}
φ_{jb}	Angle, L_{jb} to ground
R_{ljb}	Horizontal reflection of L_{jb}
R_{lj}	Jib reflection to floor.
φ	Angle, L_l to ground

Figure 3-5 Crane Variables

For the most part, simple trigonometry is used and five possible scenarios are defined based on the nature of the lift (i.e. lift on the main boom, main boom and jib or accessory). Table 3.1 presents the characteristic of the five scenarios for crane configurations considered in the database.

Table 3.1 Five Scenarios used in the Algorithm

Scenario	Equipment	Given	Calculate
1	Main Boom	Boom length and lift radius	Boom angle and tip height
2	Fixed Jib	Main boom and jib length, lift radius, and fixed jib offset	Main boom angle and tip height
3	Fixed Jib	Main boom and jib length, main boom and jib angles	Lift radius and tip height
4	Luffing Jib	Main boom and jib length, lift radius, and main boom angle	Jib offset and tip height
5	Luffing Jib	Main boom and jib length and angles	Lift radius and tip height

Scene 1: This scenario involves lift on the main boom. The main boom length (***L***) and the lifting radius (***R***) are given. The required main boom angle to ground (α). Equation 3.1. and the lifting tip height (***H***), Equation 3.2, are calculated as follow:

$$\alpha = \theta + \varphi \qquad \textbf{3.1}$$

$$H = C_2 + \sqrt{L_1^2 - R_{1h}^2} \qquad \textbf{3.2}$$

In which:

$$R_{1h} = R - C_1$$

$$\varphi = \arccos\frac{R_{1h}}{L}$$

$$\theta = \arctan\frac{C_5}{L + C_6}$$

$$L_1 = \sqrt{(L + C_6)^2 + C_5^2}$$

Scenario 2: Involves lifts on a luffing main boom and a fixed jib, in this scenario the boom length (***L***), jib length (***L_j***), lifting radius (***R***), and the jib offset to the centre line of the main boom (τ) are given. The required main boom angle to ground (α), Equation 3.3, and the lifting tip height (***H***), Equation 3.4, are calculated as follow:

$$\alpha = \theta_{ex} + \theta_{jb} + \varphi_{jb} \qquad 3.3$$

$$H = \sqrt{L_{jh}^{2} + R_{1j}^{2}} \qquad 3.4$$

In which:

$$\theta_{ex} = \arctan\frac{C_7}{(L + C_8)}$$

$$\theta_{jh} = \arccos\frac{L_{1ex} + L_{pj}}{L_{jh}}$$

$$\theta_{jh} = \arccos\frac{L_{1ex} + L_{pj}}{L_{jh}}$$

$$L_{1ex} = \sqrt{(L + C_8)^2 + C_7^2}$$

$$L_{pj} = L_{1j}\cos(\tau + \theta_j)$$

$$L_{1j} = \sqrt{(L_j + C_{10})^2 + C_9^2}$$

$$L_{jh} = \sqrt{(L_{1ex} + L_{pj})^2 + V_{pj}^{2}}$$

$$V_{pj} = L_{1j}\cos(\tau + \theta_j)$$

$$\theta_j = \arctan\frac{C_9}{Lj + C_{10}}$$

$$R_{1jh} = R - C_1$$

Scene 3: Involves lifts on a luffing main boom and a fixed jib, in this scenario the boom length (***L***), jib length (***L_j***), main boom angle to ground (α), and the jib offset to the centre line of the main boom (τ) are given. The required lifting radius (***R***), Equation 3.5, and the lifting tip height (***H***), Equation 3.6, are calculated as follow:

$$R = \pm C_1 + R_{1b} + R_{1j} \qquad 3.5$$

$$H = \sqrt{L_{1ex}^2 - R_{1b}^2} + \sqrt{L_{1j}^2 - V_{1j}^2} + C_2 \qquad 3.6$$

In which:

$$L_{1ex} = \sqrt{(L + C_8)^2 + C_7^2}$$

$$\theta_{ex} = \arctan\frac{C_7}{(L + C_8)}$$

$$\eta_b = \alpha - \theta_{ex}$$

$$R_{1b} = L_{1ex}\cos\eta_b$$

$$L_{1j} = \sqrt{(L_j + C_{10})^2 + C_9^2}$$

$$\eta_j = \alpha - (\tau + \theta_j)$$

$$\theta_j = \arctan\frac{C_9}{Lj + C_{10}}$$

$$R_{1j} = L_{1j}\cos\eta_j$$

Scenario 4: Involves lifts on a fixed angle to ground main boom and a luffing jib. in this scenario the boom length (***L***), jib length (***L****j*), lifting radius (***R***), and main boom angle to ground (α) are given. The required jib offset to the centre line of the main boom (τ), Equation 3.7, and the lifting tip height (***H***), Equation 3.8, are calculated as follow:

$$\tau = \alpha - (\eta_j + \theta_j) \qquad 3.7$$

$$H = \sqrt{L_{1ex}^2 - R_{1b}^2} + \sqrt{L_{1j}^2 - R_{1j}^2} + C_2 \qquad 3.8$$

In which:

$$L_{1ex} = \sqrt{(L + C_8)^2 + C_7^2}$$

$$\theta_{ex} = \arctan\frac{C_7}{(L + C_8)}$$

$$\eta_h = \alpha - \theta_{ex}$$

$$R_{1h} = L_{1ex} \cos \eta_h$$

$$L_{1j} = \sqrt{(L_j + C_{10})^2 + C_{10}^2}$$

$$\eta_j = \arccos\frac{R_{1j}}{L_{1j}}$$

$$\theta_j = \arctan\frac{C_9}{Lj + C_{10}}$$

$$R_{1j} = R - (C_1 + R_{1j})$$

Scenario 5: Involves lifts on a fixed angle to ground main boom and a luffing jib. in this scenario the boom length (***L***), jib length (***L_j***), jib offset to the centre line of the main boom (τ), and main boom angle to ground (α) are given. The required lifting radius (***R***), Equation 3.9, and the lifting tip height (***H***), Equation 3.10, are calculated as follow:

$$R = C_1 + R_{1h} + R_{1j} \qquad \textbf{3.9}$$

$$H = \sqrt{L_{1ex}^2 - R_{1h}^2} + \sqrt{L_{1j}^2 - R_{1j}^2} + C_2 \qquad \textbf{3.10}$$

In which:

$$L_{1ex} = \sqrt{(L + C_8)^2 + C_7^2}$$

$$\theta_{ex} = \arctan\frac{C_7}{(L + C_8)}$$

$$\eta_h = \alpha - \theta_{ex}$$

$$R_{1h} = L_{1ex} \cos \eta_j$$

$$L_{1j} = \sqrt{(L_j + C_{10})^2 + C_9^2}$$

$$\theta_j = \arctan \frac{C_9}{Lj + C_{10}}$$

$$\eta_j = \alpha - (\tau + \theta_j)$$

$$R_{1j} = L_{1j} \cos \eta_j$$

3.3 Crane Selection Module

The objective of this module is to assist the user in selecting the most appropriate crane(s) for a given project based on the lift, building characteristics and site constraints. In order to accomplish this task, the module integrates an algorithm in its geometry calculation, which is capable of calculating the crane's location(s), satisfying all specified clearances, i.e. clearances between the crane, the lift, and the buildings. The database was designed to incorporate the lift settings. As mentioned in the previous section, these settings are stored along with information about cranes' lift configurations, their capacities, and all geometry needed for the crane selection module. These crane's geometry are divided into four categories:

1) Information about the crane unit including the geometry of the carrier, the outriggers, and the counterweights.

2) Information about the booms, including their pin offset relative to the rotation centre of the crane, the boom dimensions, and the boom sheaves dimensions and offsets. In addition to the information about the jibs, including their pin offset relative to the boom centre line, the jib dimensions, and the jib sheaves dimensions and offsets

3) Information about the lift setting, including lift working radius boom and jib angles to ground, and lifts tip heights.

4) Lifting area, each lift settings includes the lifting area, which is important information when positioning cranes on sites.

Each lift setting retrieved from the database is checked for the following:

1) **Lift Capacity Check**: Lift capacities are compared to the total lift weights (the weight of the lift and of all the accessories). The crane's lifting capacity at any given configuration should be greater then or equal to the total lift weight.

2) **Crane Fit on Site Check**: Cranes are checked for potential collusion between the crane carrier, the outriggers, and counterweights with the surrounding buildings, and to ensure that the crane fit on site.

3) **Boom/Jib with building Crash Check:** Lift settings are checked for potential collusion between the boom and the jib with the buildings.

4) **Lift with Boom/Jib Crash Check:** Lift settings are also checked for potential collusion between the lift and its accessories with the boom and/or the jib.

3.3.1 Crane Lifting Capacity Check:

Involves the selection of crane configuration and lift settings that are capable of carrying the total lift weight. This requirement had its effect on the design of crane load charts database, crane configurations and their lift settings were categorized as such to allow the use of different search limits criteria.

3.3.2 Crane Fit on Site Check:

Involves the fitting of the crane carrier, outriggers, and counterweights (tail sawing) on the site. Based on the lifting zone (area), there are four different possible lifting zones, i.e., lifting over rear, lifting over side, lifting over front, and lifting over 360° as shown in Figure 3-6. The shape of these lifting zones (areas) is specific for different crane models or manufacturer. Please refer to Dicky (1989).

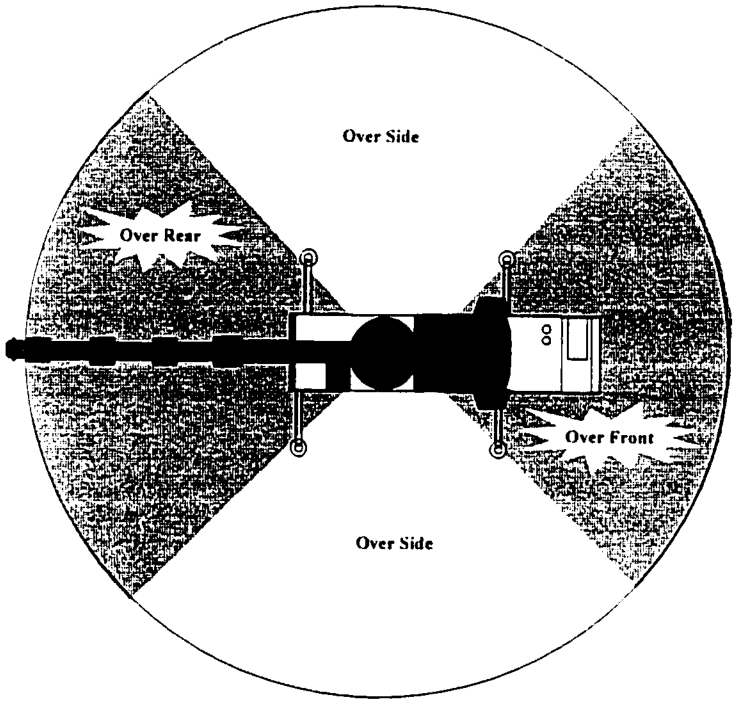


Figure 3-6 Cranes Lifting Zones

3.3.2.1 Lifting Over Rear:

Scenario 1: The building or the obstruction is located in the area of the lift (i.e. in the same as over rear of the crane), as shown in Figure 3-7. Based on the site characteristics, the calculation module checks the crane carrier and outriggers for fit on the ground. The crane's lifting radius (**R**) must be equal to or grater than the total Building/obstruction Width ($\mathbf{TB_W}$) plus crane rear to its centre of rotation (**R2C**), Equation (3.11).

$$R >= TB_W + R2C \qquad 3.11$$

In which:

$$TBw = \sum_{i=1}^{n=3} Di$$

Where:

R – Lifting Radius

TB_W – Total Building/obstruction Width (known as final lift location depth)

R2C – Crane Rear to its Centre of Rotation

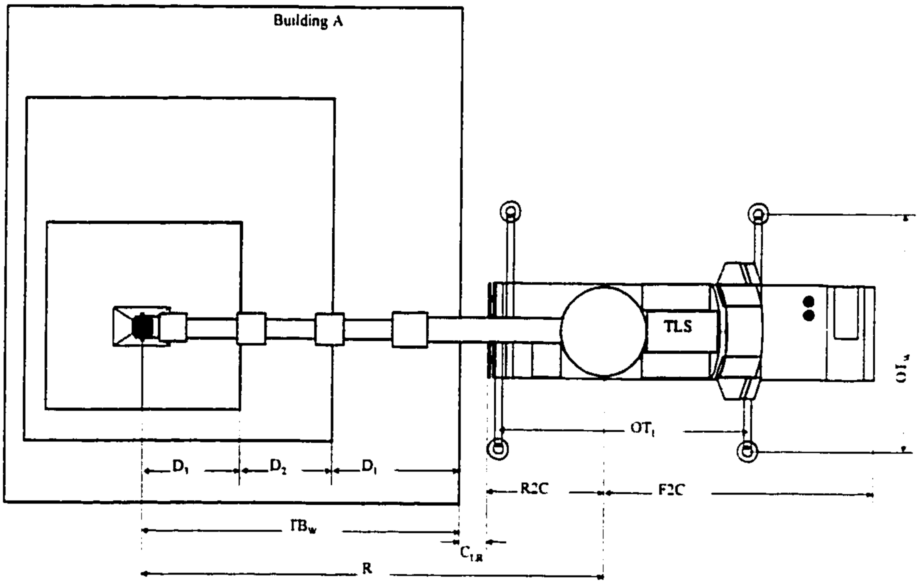


Figure 3-7 Lifting Over-Rear & Obstruction Over-Rear

Some crane outriggers are extended beyond the crane's rear to their centre of rotation. as shown in Figure 3-8. In such a case the crane's lifting radius (**R**) must be equal to or grater than the total Building/obstruction Width (TB_W) plus half of the outrigger's length (**1/2 OT_L**), Equation (3.12).

$$R >= TB_W + \frac{1}{2} OT_L \qquad 3.12$$

Where:

OT_L - Outrigger's Length

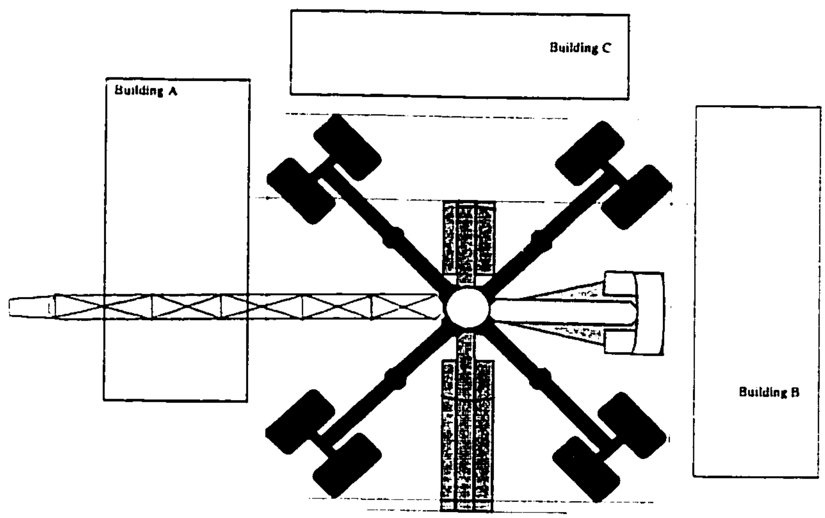


Figure 3-8 X-Shape Outriggers

Should these two criteria be satisfied, the crane clearance to the building (C_{LR}), as shown in Figure 3-7, for any lift setting, is the smallest of the carrier or the outrigger clearances Equation (3.13), which is calculated as follows:

$$C_{LR} = R - (TB_W + R2C) \text{ or } C_{LR} = R - (TB_W + \frac{1}{2} OT_L) \qquad 3.13$$

<u>**Scenario 2:**</u> The building or the obstruction is (are) located on the side of the crane while lifting over-rear, as shown in Figure 3-9. The selection module evaluates the crane configuration for fit on the site, allowing for adduct clearance for the outriggers and the counterweight tail swing. In such a case, the maximum allowable space from the side of the crane (**$MaxS_S$**) must be grater than half of the outrigger's width (**1/2 OT_W**), Equation

(3.14) and if needed greater than or equal to the counterweight tail swing (**TLS**), Equation (3.15).

$$\mathbf{MaxS_S \geq ½\, \mathit{OT}_W} \qquad 3.14$$

$$\mathbf{MaxS_S \geq ½\, TLS} \qquad 3.15$$

Should these criteria be satisfied, the crane clearance to the building (C_{LS}) located on its side of the crane, as shown in Figure 3-9, is the smallest of clearance to the outriggers or the counterweight tail swing Equation (3.16), it is calculated as follow:

$$\mathbf{C_{LS} = MaxS_S - ½\, OT_W \text{ or } C_{LS} = MaxS_S - TLS} \qquad 3.16$$

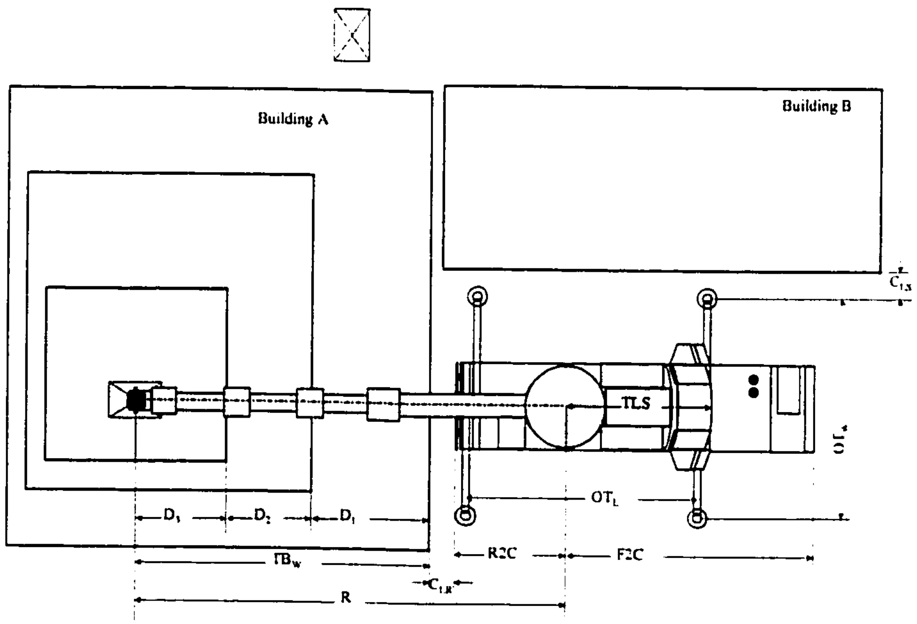


Figure 3-9 Lifting Over-Rear & Obstruction on the Side of the Crane

<u>**Scenario 3)**</u> Building or obstruction in front of the crane while lifting over-rear, as shown in Figure 3-10. In such a case, the crane configuration for lifts is restricted by the allowable distance **MaxR,** which, imposes the following constraints:

1) Constraints regarding the size of the carrier of the crane, **MaxR** must satisfy Equation (3.17):

$$\mathbf{MaxR >= C_L + R2C + F2C} \quad 3.7$$

2) Constraints regarding the size of the outriggers, **MaxR** must satisfy Equation (3.18):

$$\mathbf{MaxR >= C_L + R2C + ½\, OT_L} \quad 3.8$$

3) Constraints regarding the length of the tail-swing, **MaxR** must satisfy Equation (3.19)

$$\mathbf{MaxR >= C_L + R2C + TLS} \quad 3.9$$

Where:

MaxR – Maximum space for the crane on the ground

TLS – Counterweight tail-swing

F2C – Crane front to centre of rotation

Should these three conditions be satisfied, the crane clearance to the building (C_{LF}) as shown in Figure 3-4, for any of these settings, is the smallest clearance of the carrier, the counterweight tail-swing, or the outriggers, which are calculated as follows:

1) Clearance from the carrier Equation (3.20):

$$\mathbf{C_{LF} = Max\ R\text{-}\ (CL + R2C + F2C)} \quad 3.10$$

2) Clearance from the outriggers Equation (3.21):

$$\mathbf{C_{LF} = Max\ R\text{-}\ (CL + R2C + ½\, OT_L)} \quad 3.11$$

3) Clearance from the tail-swing Equation (3.22):

$$\mathbf{C_{LF} = Max\ R\text{-}\ (CL + R2C + TLS)} \quad 3.12$$

Where:

C_{LF} - Clearance to the building in front of the crane, when lifting over rear

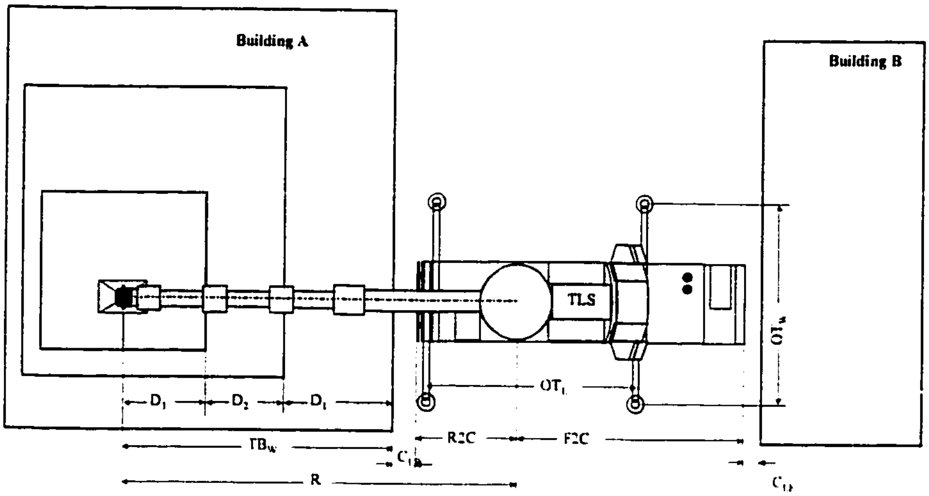


Figure 3-10 Lifting Over-Rear & Obstruction in Front of the Crane

3.3.2.2 Lifting Over Front:

Similar steps are taken for lift over front, the lifting radius is checked to allow for the following spaces, as shown in Figure 3-11:

1) Space in front of the carrier or the outriggers (C_{LF}).

2) Space in the rear of the crane for the outriggers and counterweight tail-swing (C_{LR}).

3) Space on the side of the crane for outriggers fit (C_{LS}).

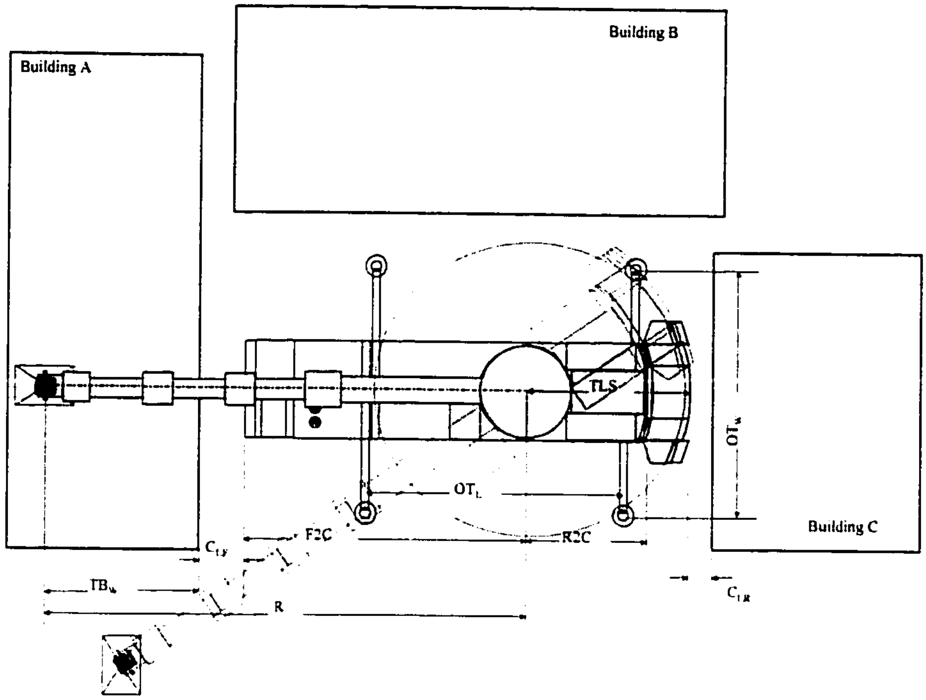


Figure 3-11 Lifting Over-Front

3.3.2.3 Lifting Over-Side or 360°:

The calculation module checks the crane's outriggers for potential collision with the building or obstruction in one or both sides and behind the crane as shown in Figure 3-12. In such a case the crane's lifting radius (**R**) must be equal to or grater than the total Building/obstruction Width (**TB_W**) plus half of the outrigger's length (**1/2 OT_L**). Equation (3.23):

$$R \geq TB_W + ½\, OT_W \qquad 3.23$$

Where:

OT_W – Outriggers Width (Tracks width for crawler mounted cranes)

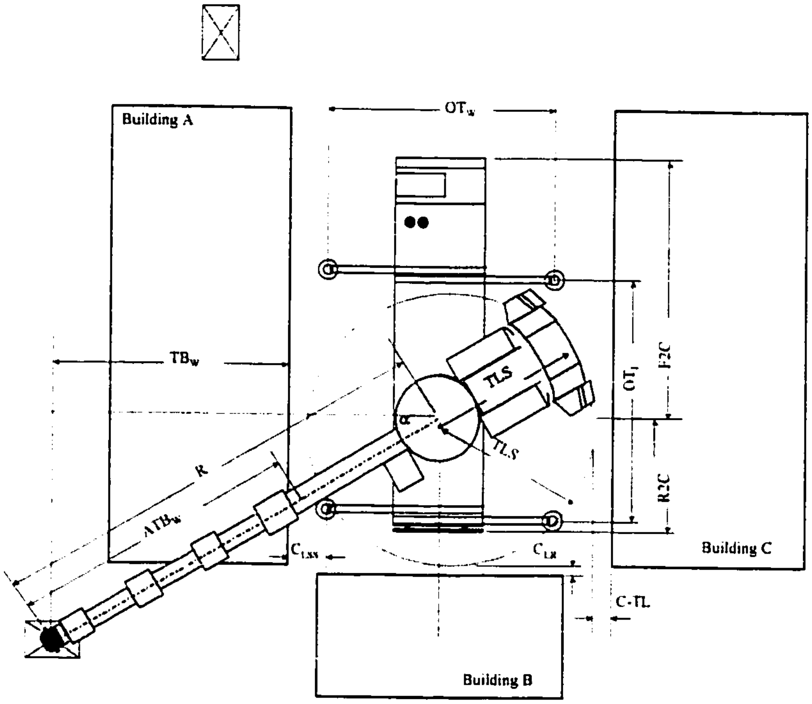


Figure 3-12 Lifting Over-Side or 360°

Only the outriggers clearance is considered in this case, because the outriggers (fully or partially extended) are wider than the width of the carrier of the crane. When crawler cranes are used, the tracks (extended or retracted) are considered. For ringer cranes, the diameter of the ring is considered.

Should this condition be satisfied, the crane clearance to the building (C_{LS}), is derived by the outrigger clearances Equation (3.24).

$$C_{LS} = R - (TB_W + \tfrac{1}{2} OT_W) \qquad 3.24$$

In addition, the selection module counts for obstructions, which could exist on both sides of the crane or at both ends (front or rear) of the crane as shown in Figure 3-12. The crane configurations are evaluated for fit on the site, allowing for adduct clearance for the crane carrier, for the outriggers and for the counterweight tail-swing. The crane must be positioned in such a way that the distance from the crane's centre of rotation to the nearby buildings (**MinS**) satisfies all of the following constraints:

1) Constraints regarding the size of the crane's carrier. **MinS** must satisfy Equation (3.25):

$$\mathbf{MinS \geq R2C \ (or\ F2C)} \qquad \mathbf{3.3}$$

2) Constraints regarding the size of the outriggers. **MinS** must satisfy Equation (3.26):

$$\mathbf{MinS \geq \tfrac{1}{2}\, OT_L} \qquad \mathbf{3.4}$$

3) Constraints regarding the tail-swing. **MinS** must satisfy Equation (3.27):

$$\mathbf{MinS \geq TLS} \qquad \mathbf{3.5}$$

Where:

MinS – Minimum Space for the Crane from Building B

3.3.3 Boom and Jib Clearance Check

Crane configurations that satisfy conditions 1 and 2 (i.e., the crane's capacity and the crane's fit on site) are evaluated for the boom and jib clearance with the load and the surrounding buildings.

3.3.3.1 Lifts on main booms:

Main boom clearance to building: Main boom must provide sufficient clearance above the building or obstruction (i.e. above points T_1, T_2, $\ldots T_i$) as shown in Figure 3-1. The distances (G_iF_i) must be larger then the building height (H_i) or (G_iT_I, in the Figure) Equation (3.28), which is extended to equation (3.29).

$$G_iF_i \geq G_iT_i = H_i \qquad \mathbf{3.1}$$

In which:

$$G_iF_i = G_iI_i - F_iI_i$$

$$G_iI_i = G_iA_i = A_iI_i$$

$$A_iI_i = AA_i * \tan(\alpha)$$

$$AA_i = R - (AA_r + \sum_{i}^{n} D_i)$$

$$A_iI_i = [(R - (AA_r + \sum_{i}^{n} D_i))] * \tan(\alpha)$$

$$G_iI_i = G_iA_i + [(R - (AA_r + \sum_{i}^{n} D_i))] * \tan(\alpha)$$

$$F_iI_i = IF \div Cos(\alpha)$$

$$G_iF_i = [IF \div Cos(\alpha)] - \{G_iA_i + [(R - (AA_r + \sum_{i}^{n} D_i))] * \tan(\alpha)\} \qquad \mathbf{3.2}$$

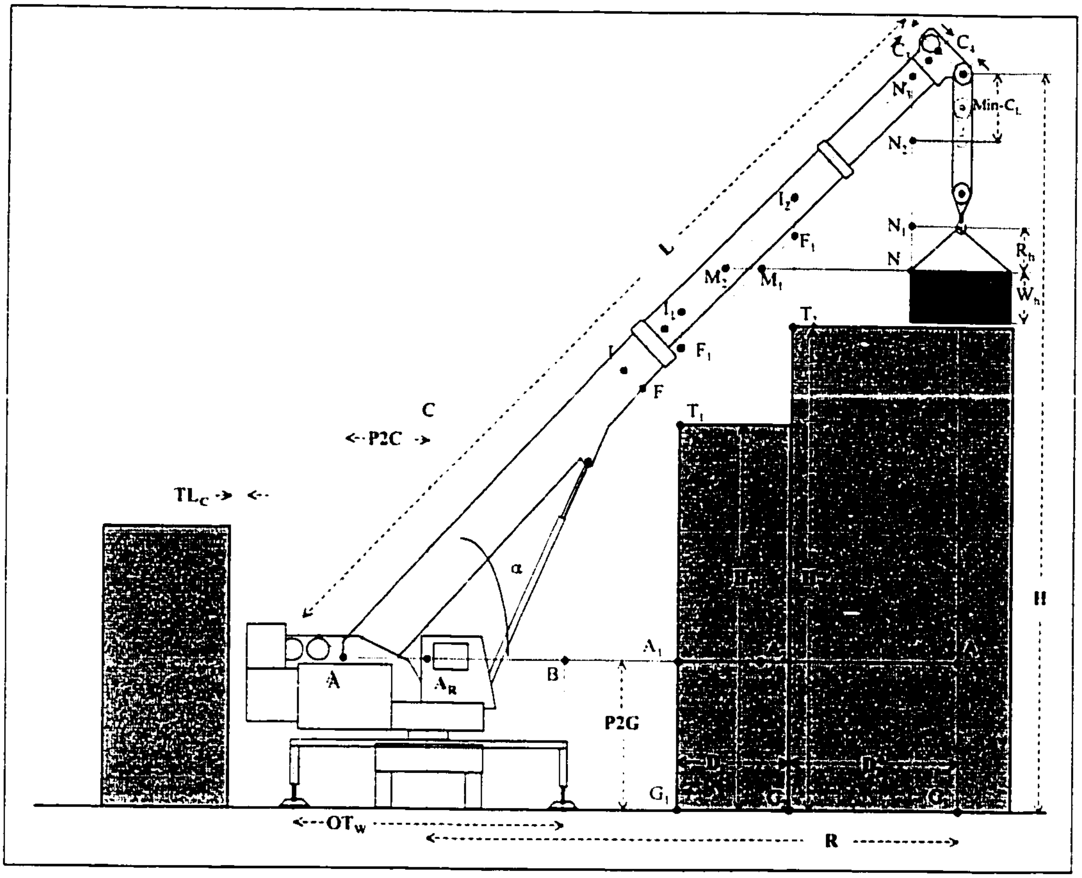


Figure 3-13 Crane & Main Boom Clearance

Lift height clearance: The lift settings height (H), must be grater than or equal to the total of the building height (H_i), the lift height (W_h), the rigging height (R_h), and the minimum hock clearance (Min-C_L) Equation (3.30).

$$H \geq H_i + W_h + R_h + MinC_L \qquad \textbf{3.30}$$

Load clearance to boom: Half of the lift width dimension (1/2 W_l) must satisfy equation (3.31).

$$(1/2)W_l \leq [H - (W_h + H_3)] * Tan(\alpha) - MM_1 \qquad \textbf{3.31}$$

In which:

$$MM_1 = IF * Tan(\alpha)$$

Therefore, equation (3.31) is extended to Equation (3.32):

$$(1/2)Wl \leq \{[H-(Wh=H3)]*Tan(\alpha)\} - IF*Tan(\alpha) \quad 3.5$$

3.3.3.2 Lift on jibs:

Lifts performed on jibs are calculated for main boom and jib clearance to building and lift (load) clearance to jib. The main boom clearance is calculated for points T_i (See Figure 3-1), as described in the previous section. Jibs also must provide sufficient clearance above the building or obstruction (i.e. above points T_1, T_2, ...T_i) as shown in Figure 3-1. The distances (G_iF_i) must be larger then the building height (H_i) or (G_iT_I that shown in the figure) Equation (3.33), which is extended to equation (3.34).

$$G_iF_i \geq G_iT_i = H_i \quad 3.1$$

In which:

$$G_iF_i = G_iQ_i + Q_iF_i$$

$$G_iQ_i = G_iC_i + A_iQ_i$$

$$A_iQ_i = L_{1ex} * Sin(\eta_h)$$

$$G_iQ_i = G_iA_i + L_{1ex} * Sin(\eta_h)$$

$$Q_iF_i = Q_iI_i - I_iF_i$$

$$I_iF_i = IF \div Tan(\eta_i)$$

$$Q_iI_i = MQ_i * Tan(\eta_i) \quad MQ_i = R - [C_1 + (\sum_{i=i}^{i-ii} D_i) + L_{1ex} * Cos(\eta_i)]$$

Therefore, Equation (3.33) becomes extended to Equation (3.34):

$$G_iF_i = [G_iA_i + L_{1ex} * Sin(\eta_h)] + R - [C_1 + (\sum_{i=i}^{i-ii} D_i) + L_{1ex} * Cos(\eta_i)] \quad 3.2$$

The lift (load) clearance to the jib is calculated in the same way, as it was for the main boom, with parameters specific to the jib.

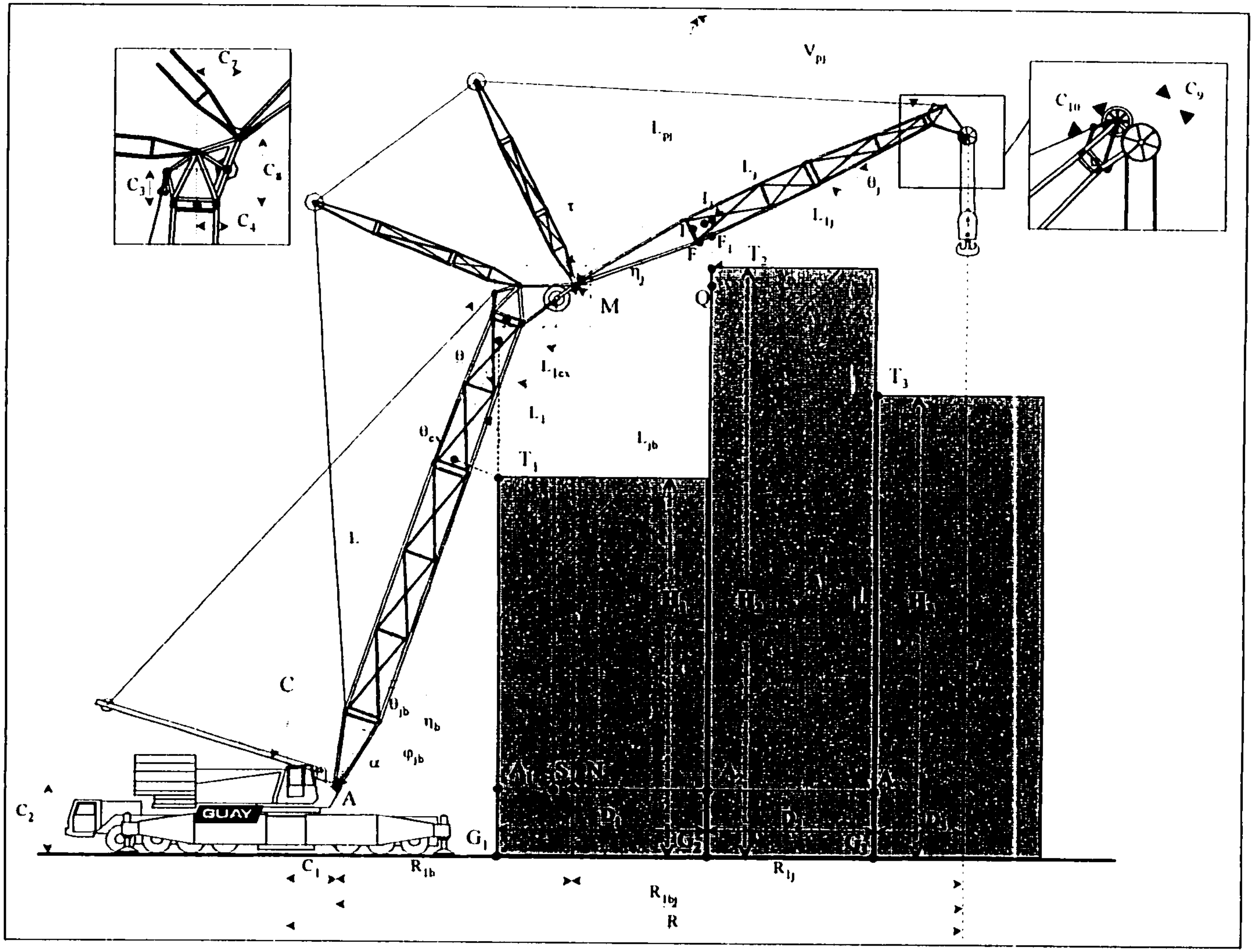


Figure 3-14 Jib Clearances

3.4 OPTIMIZATION MODULE

Optimization techniques using linear and/or non-linear programming have proven to be effective tools to solve industry-related problems. Crane selection cases lead their solutions to a maximization of performance. However, performance measure or value is specific to each case. To elaborate, in some cases, the intent is to maximize the lifting capacity, by minimizing the lifting radius or maximizing the boom angle, depending on the situation. These are objectives that call for different functional constraints and objective functions. Practitioners, when selecting a crane, need to know the range possible for the location of the crane, i.e., they would want to know the maximum and minimum radiuses of the selected crane configuration, while accounting for all of the site's constraints. The crane configurations stored in the database include the boom and jib lengths. However, their angles to ground are subject to change when the lifting radius changes. Therefore the crane-lifting radius becomes the objective function of this study, Equation (3.35) for lifts on main booms and Equation (3.36) for lifts on jibs. Both equations (3.35) and (3.36), are function of the crane geometry, boom/jib lengths, and their prospective angles to ground, which are calculated as follows:

3.4.1 Lifts on main booms

The objective is to optimize the lift radius, i.e., providing the minimum and the maximum radius (R), Equation (3.35). The parameters used in this equation are shown in Figure 3-1.

The Objective Function:

Min/Max. Radii $R = \pm C_1 + l_1 * Cos(\alpha - \theta)$ **3.1**

Constraints: The function's solution is subject to the constraints (clearances) imposed by the lift, the crane, and the site, which include the following.

1) Boom Clearance to Buildings (K_1):

$$TiFi * Cos(\alpha) \geq K_1$$

2) Min Hock Clearance (K_2):

$$[H - (H_2 + W_h + R_h)] \geq K_2$$

3) Load Clearance to Boom (K_3):

$$\{(1/2)W_l - \{[H - (W_h + H_3)] * Tan(\alpha) - MM_1\}\} * Sin(\alpha) \geq K_3$$

4) Carrier Clearance for lift over the side and/or 360° (K_4):

$$\{[L_1 * Cos(\alpha)] - (\pm C_1 + 1/2OT_w + \sum_{i=1}^{i=3} Di)\} \geq K_4$$

5) *Tail-Swing Clearance (K_5):*

$$(R - \sum_{i=1}^{i=3} Di) + \begin{pmatrix} F2C \\ R2C \\ TLS \end{pmatrix} \geq K_5$$

Subject to: these constraints and the objective function are subject to the change of the main boom angle to ground (α)

3.4.2 Lifts on jibs:

The objective is to optimize the lift radius, for lifts on jibs, i.e., providing the minimum and the maximum radius (R), Equation (3.36). The parameters used in this equation are shown in Figure 3-1.

Objective function:

$$\textbf{Min/Max. Radii } R = \pm C_1 + l_{jb} * Cos(\varphi_{jb}) \qquad \textbf{3.1}$$

Constraints: The function's solution is subject to the constraints imposed by the lift, the crane, and the site, which include the following clearances.

1) Boom Clearance to Buildings:

$$TiFi * Cos(\alpha) \geq K_1$$

2) Jib Hock Clearance:

$$[H - (H_2 + W_h + R_h)] \geq K_2$$

3) Load Clearance to Jib:

$$\{(1/2)W_l - \{[H - (W_h + H_3)] * Tan(\eta_j) - MM_1\}\} * Sin(\eta_j) \geq K_3$$

4) Carrier Clearance for lifts over the side and/or 360°:

$$\{[L_{jb} * Cos(\varphi_{jb})] - (\pm C_1 - 1/2OT_w + \sum_{i=1}^{i=3} Di)\} \geq K_4$$

5) Tail-Swing Clearance:

$$(R - \sum_{i=1}^{i=3} Di) + \begin{pmatrix} F2C \\ R2C \\ TLS \end{pmatrix} \geq K_5$$

Subject to: Based on the type of the boom and the jib, these constraints and the objective functions for lift on jibs are subject to the changes of the following:

1) Lift on luffing main boom and fixed jib angle: the changes are subject to the change of the main boom angle to ground (α).

2) Lift on a fixed main boom angle and luffing jib, the changes are subject to the change of the jib angle to ground (η_j).

3) Lift on luffing main boom and a luffing jib: the changes are subject to the change of the main boom angle to ground (α) and the jib angle to ground (η_j), (this type of crane is expected to be available in the market by some of the crane manufacturer).

The variables used in the above mansion equations are:

$\mathbf{H_i}$	Building Heights	$\mathbf{L_l}$	Main-Boom-Pin to Cheave-Centre
H	Lifting Hock Height	$\mathbf{C_l}$	Boom-Pin to Rotation-Centre
$\mathbf{W_h}$	Load Height	$\mathbf{OT_W}$	Outriggers Width
$\mathbf{C_2}$	Main Boom Pin to Ground	**R**	Working Radiuse
α	Main Boom Angle	$\mathbf{D_i}$	Buldings Depth (Wedth)
η_j	Jib Angle to Ground	$\mathbf{L_{jb}}$	Distance, Jib-Pin to Sheave-Centre

Chapter 4 IMPLEMENTATION PROCESS

This chapter presents the process used to develop a computer integrated system for crane selection and on sites utilization. The chapter describes the development of the system databases, the crane selection and location module, the optimization module, and the implementation of the 3D-CAD and the 3D animation modules.

4.1 DATABASE IMPLEMENTATION

This step aims at developing the database schema utilizing the ER-diagram by mapping its entities, relationships, and attributes within the DBMS. This has been carried out in the MS Access 97 environment in three stages: 1) the initial design; 2) the modified design; 3) the final design.

The crane and its attachments are modeled conceptually in 24 entities, paving the way for the development of the database. These entities have been modeled in five objects (four-physical and one-conceptual). The physical objects represent the crane unit, the boom and head units, the accessories, and the attachments. The conceptual object involves the lift capacities. Lift capacities are function of various combinations of equipment, for example, a boom has no lifting capability without a crane and accessories have no capacity without a boom to be attached to. Figure 4-1 illustrates the dependency between the five main objects along with their data flow.

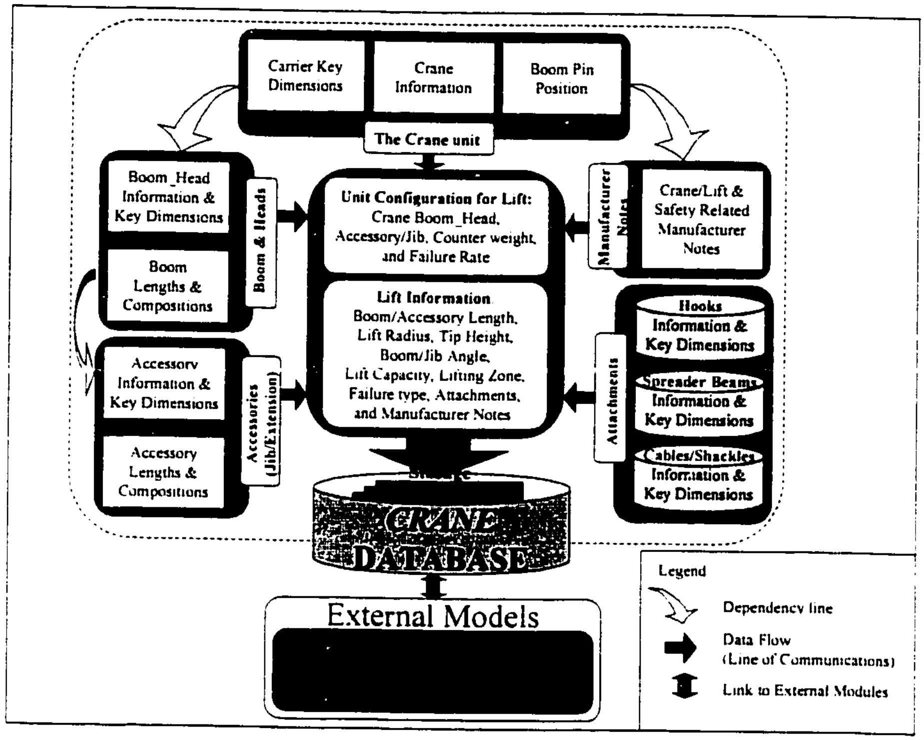


Figure 4-1Crane's Objects Included in the Database

4.1.1 Initial Design

Having established which data were relevant and how they related to one another, the first approach took into account each type of object that made up the crane combination. Every object type would have an ID that would link it to other objects, thus linking all the parts of a crane setup together. Figure 4-2 shows an example of crane objects linkage.

This arrangement allows an item to be linked with its parent. It is simple to see that *Shank Hook* no.4001 goes with *Crane A*. The problem with this kind of arrangement lies with the way the database software (Access 97) accepts data. To enter the Shank Hook into the database, it can be seen that the tip has to be present first, or the link cannot be established. Therefore, to implement this structure, the user would have to navigate through a series of forms: first entering all the cranes, then all the booms for each cane, then the tips for each boom for each crane, and so on. Other items such as Jibs, which have been omitted from this example, further complicate the process.

Crane ID	Model
0001	Crane A

Crane ID	Boom ID	Boom
0001	2001	77h

Boom ID	Tip ID	Tip Type
2001	3001	Taper Tip

Tip ID	Hook ID	Hook Name
3001	4001	Shank Hook

Figure 4-2 Example of Crane Objects Linkage

4.1.2 Modified Design.

The crane was broken down into smaller elements, which are reassembled by the database. In essence, the main elements consist of the crane, the boom and tip and the jib. The logic behind this follows the fact that the crane is a fixed, unchangeable unit. The boom is incomplete without the tip (head). The jib is a complete unit (with built in tip). In addition, constraints with the crane assembly limit how things are stored. Not all booms will work with all types of tip (heads). By associating a tip with a boom at entry time, the danger that an impossible boom/tip combination will be linked to potentially thousands of lift capacities is eliminated.

The advantage is that fewer tables are required, and thus fewer links. Normally with a relational database, a larger number of tables is encourage. This does not apply in this case much of the data doesn't need to be searched for independently. The database is thus a collection of tables, which contain grouped data. There is no need for the data to be split further, as independent searches will not take place. The key data are indexed for fast retrieval.

Three tables provide the core of the information about the cranes. These tables are named Cranes, Booms and Jibs. The names give a clear idea about the content. Table 4.1. lists some of the fields in the Cranes table. Some of these names may not give a clear indication of their contents, the description of table details should eliminate any confusion as descriptions are provided for each field.

In brief, each crane in the database has an identification number (ID). This ID is generated by the database and is unique to a crane. Crane attributes are connected with the crane and stored in the same table. These attributes include the crane name, make, model, dimensions, type, boom mounting positions, mast size/position and a picture of the crane. For a more complete list of the data in the Cranes table see Appendix D. As companies may use different naming conventions from those generated by the database *(Master ID)*, a lookup table is provided, linked by *Master ID*, which allows multiple names for a given crane. This permits a crane to be stored with only one entry, but under different types. The local crane names are stored in the "Local-Crane-Lookup" table. An index on the crane's name in the Local-Crane-Lookup table prevents duplicate names from being used.

Table 4.1 Sample Table "Crane Table" from D-Crane

Fields in Cranes Table	*Type*	*Size (Characters)*
Master-ID	Number (Long)	4
Mfr	Text	25
Series	Text	10
Model	Text	10
Type	Text	2
bmf2c	Number(Long)	4
bmf2f	Number(Long)	4
hvddista	Number(Long)	4
hvddistb	Number(Long)	4
hvdsistc	Number(Long)	4
hydmaxboomlength	Number(Long)	4
Pictur	Object	-
MisoData 1	Number(Long)	4
MisoData 2	Number(Long)	4
MisoData 3	Number(Long)	4
MisoData 4	Number(Long)	4
MisoData 5	Number(Long)	4
MisoData 6	Number(Long)	4
MisoData 7	Number(Long)	4
MisoData 8	Number(Long)	4
MisoData 9	Number(Long)	4
MisoData 10	Number(Long)	4
MisoData 11	Number(Long)	4
MisoData 12	Number(Long)	4
MisoData 13	Number(Long)	4
MastPinLocationHor	Number(Long)	4
MasThinLocationver	Number(Long)	4

The next main section comes in the form of the "Booms" table as shown in Table 4.2. Each record in the Booms table has a unique identification (ID). This ID is linked to the crane table through the crane *MasterID*. Each crane can have multiple entries in the Booms table. This represents the possibility of a crane having multiple boom/tip configurations. The Booms table contains data about the boom setup as a whole; it includes such information as boom name, tip type, tip dimensions, boom dimensions, tip and boom weights. Some duplication occurs where a boom can take more than one tip, but this is negated by the fact that the *boom* and *tip* make a unique combination.

Given any entry in the Booms table, it is easy to see that the crane *MasterID* provides a lookup to the crane unit itself. This prevents a boom or tip to be associated with the wrong crane. Appendix D contains a full description of the similar Booms table.

Table 4.2 Sample Cranes Database Table "Booms Table"

Fields in Booms Table	Type	Size
BoomMasterID	Number(Long)	4
MasterID	Number(Long)	4
BoomNameID	Number(Long)	50
TblTaperTip	Text	4
NoSheaves	Number(Long)	4
DiaSheaves	Number(Long)	4
WireGauge	Number(Long)	4
TibID	Number(Long)	4
Bmht	Number(Long)	4
Bmwid	Number(Long)	4
Pin2C	Number(Long)	4
Vsheaveoff	Number(Long)	4
Hsheaveoff	Number(Long)	4

The "Jibs" table, as shown in Table 4.3, works in a similar way to the "Booms" table. Information is stored about each jib and linked to the main "Cranes" table through the crane's *MasterID*. As with the *BoomMasterID* in the "Booms" table, which identifies a particular boom/tip combination for a crane, the *JibID* identifies a particular jib setup. Again, like the booms, a one-to-many relationship exists to the main "Cranes" table, allowing more than one jib to operate with any crane.

Information stored with jibs includes number of sheaves, sheaves diameter, weight, name, type and offsets. Jibs are more complicated than booms in that their different types require different information. Another table is related to the "Jibs" table, "Jib Angles", which stores angles for each jib. A one-to-many relationship binds it to the "Jibs" table using the "*JibID*" field. This allows more than one angle to be stored for each jib. This means that the multiple angles of fixed jibs can be stored for one jib entry. See Appendix D for similar table (booms table). Where a powered luffing jib is in use, the fixed boom angle is stored here instead. Refer to the **assumptions** section for further information.

Table 4.3 Sample Database Table "Jibs Table"

Fields in Jibs Table	*Type*	*Size*
JibID	Number (Long)	4
JibName	Text	10
JibType	Text	15
JibHead	Text	1
Jibsheaves	Number (Long)	4
JibShDiameter	Number (Long)	4
JibcableDaimeter	Number (Long)	4
MasterID	Number (Long)	4
Efweight	Number (Long)	4
Stwejght	Number (Long)	4
JibPinOffh	Number (Long)	4
JibPinoffv	Number (Long)	4
JibShvOffh	Number (Long)	4
JibShvOffv	Number (Long)	4

One or two other minor tables complete the setup to allow the addition of cranes through one simple form. These do not provide functionality to the database, but rather enhance the user interface. For example, the "Boom-Names" table keeps a list of boom names handy, this allows the lists to be provided for the combo boxes making the database easier to use. Items such as tip type and crane type use numerical values to save space and allow for easy searching. Lookup tables are provided to present the user with real world descriptions (Crane-Types and Head-Names). By storing head names (or crane types) in this way and having the user select from a list, the possibility of a typing mistake, thus effectively creating a new crane type, is removed. Database expansion is simply a matter of adding a new type to the relevant table.

A late addition to the database was the "Fixed-Messages" table. This has a many-to-one relationship with the "Cranes" table and allows storage of all the manufacturer's notes that come with a crane. These are vital and in some instances make the difference between a lift being possible or not. As with the "Crane-Types", this solution ensures that messages are typed in only once for each crane and that no typing errors can occur through repetition. If this solution were not implemented, then such notes would have to be entered for each lift for which they were applicable. The risk of error would be enormous in this case.

The second part of the database is based around the lift capacities. The "Lift Details" table (see Table 4.4) plays the main role here, backed up by the "Lift Data" group of tables. The latter is a group of tables because three tables contain essentially the same information, which is the capacity of the crane with a certain setup. The difference between the tables is the status of the outriggers. The Lift Data tables each have a one-to-one link with the Lift Details table. For a given setup, there is only one maximum capacity.

The "Lift Details" table describes how the crane is put together for the given capacity in the related Lift Data tables.

Table 4.4 Sample Table from the Cranes Database "Lift Details Table"

Fields in Lift Details Table	*Type*	*Size*
LiftID	Number(Long)	4
JibID	Number(Long)	4
CTWT	Number(Long)	4
BoomMasterID	Number(Long)	4
BoomLength	Number(Long)	4
Radius	Number(Long)	4
BoomAngle	Number(Long)	4
LiftRatingSt	Number(Long)	4
LiftRatingTp	Number(Long)	4
LibLen	Number(Long)	4
JibAngle	Number(Long)	4

The crane is described very simply. Choosing a crane *Master ID, a JIbID* and a *BoomMasterID,* any combination of the crane can be described. The first combination is related to the crane unit and all the relevant data, the second describes jibs and all jibs relevant data, and the third describes booms, tips (heads) and all booms/heads relevant data. Stored against these data is the boom angle, boom length, rating for the lifts, jib length and jib angle. The capacities for a given setup are then stored in the related tables depending on the outrigger position. See Appendix D for similar table (the boom table) . One other table related to the lift details, and that is LiftID2MsgLookup. This stores, through a one-to-many relationship, the manufacturer's notes, which apply to a given lift capacity. The LiftID is used as the linking field.

4.1.3 Final Design

Each entity and each relationship with assigned attributes is mapped into a table. Each table has been structured and its related attributes were added. Each attribute is assigned its data-type (text, numeric, picture, etc...), its constraints, and its data-integrity function.

Each table has its own key attribute(s) or foreign key(s). For example, the "Cranes" table, shown in Figure 4-3, has 30 different attributes that describe the crane's unit including manufacturing name, serial number, model, unit key dimensions, and the ranking number, which ranks the cranes based on their rental costs.

Cranes : Table

Field Name	Data Type	Description
MasterID	AutoNumber	Database serial number
Mfr	Text	Crane manufacturer
Series	Text	Crane series number
Model	Text	Crane model number
Type	Text	Crane type: 1-Conventional Truck; 2-Crawler; 3-Telescopic Truck; 4-Rough Terrain; 5-
bmf2c	Text	Locate the position of the boom mountings
bmf2f	Text	Locate the position of the boom mountings
hyddista	Text	Distance for hydraulic boom pin location
hyddistb	Text	Distance for hydraulic boom pin location
hydsistc	Text	Distance for hydraulic boom pin location
hydmaxboomlength	Text	Distance for hydraulic boom pin location
Picture	OLE Object	Picture of this type of crane
MiscData1	Text	Max Length
MiscData2	Text	Width
MiscData3	Text	Front to Centre
MiscData4	Text	Rear to Centre
MiscData5	Text	Max Cab Height
MiscData6	Text	Lower Counterweight height
MiscData7	Text	Upper Counterweight height
MiscData8	Text	Outer Counterweight to centre
MiscData9	Text	Counterweight width
MiscData10	Text	Full outrigger length
MiscData11	Text	Full outrigger width
MiscData12	Text	Partial outrigger length
MiscData13	Text	Partial outrigger width
Mastlength	Text	Length of the mast
MastPinLocationHor	Text	Horizontal location of mast pin
MastPinLocationVer	Text	Vertical location of mast pin
OutroggerSetup	Text	Defines the outrigger layout
Rank	Number	Cost/Usability ranking

Field Properties

General | Lookup |

Field Size	Long Integer
New Values	Increment
Format	
Caption	
Indexed	Yes (No Duplicates)

A field name can be up to 64 characters long, including spaces. Press F1 for help on field names.

Figure 4-3 Screen Snapshot of the "Cranes Table" from the Cranes Database

Similarly, all the entities and relationships with assigned attributes were mapped into tables. Each table has its function. The following is a brief description of the function for each of the tables in the database, listed in alphabetical order.

Booms — This table has an auto-number field which indexes the primary values, called BoomMasterID. The boom and tip combinations are stored here, together with the ID of the crane to which they relate.

	Relevant information about the boom and tip combination is also stored, such as dimensions, number of sheaves, etc.
BoomsDefinition	Contains the list of components used to make up a boom length, together with sizes and weights.
BoomsLength	Contains lengths of each boom. Indexed by BoomMasterID.
Cables	Stores the cables and capacities using a unique ID and a MasterID which relates to the crane on which a cable is used
ControlData	This stores programming data, such as which language (English or French) is being used, values to use for conversion and so on. The data and fields in this table vary depending on how the program executes.
Crane Types	This is a lookup table which returns a text string for a number, to provide a description of the crane types that are easily understood by the user.
Fixed Messages	Stores manufacturer's notes. An auto-number field provides a unique ID for each message, and the crane's MasterID is stored alongside each message to identify the parent crane.
HeadNames	This is a lookup table which allows display of tip types by name rather than by numeric value.
Hooks	Stores the hooks and capacities using a unique ID and a MasterID which relates to the crane on which a hook is used
JibAngles	Stores the offset angles for the jibs, together with a jib ID to relate the angles to a parent Jib.
Jibs	It retains all information about accessories, indexed by an auto-numbered field. The MasterID of the crane is carried across to identify the crane to which a given accessory belongs.
JibsDefinition	Contains the list of components used to make up an accessory length, together with sizes and weights.
JibsLength	Contains lengths and corresponding stowed and erected weights of each accessory. Indexed by JibID.
LiftCapacity	Stores capacities, support position and lifting zones. A one-bit field indicates metric data and another indicates structural failure.
Lift-Equipment	Contains an ID for the crane, the boom and the jib set, together with counterweight mass and failure ratings.
Lift-Support-List	Stores possible support positions.
Lift_ZoneList	Stores lifting zones to fill combo box on Lift_Capacity sub-form. As with Support-List, these data are stored in tables to enable further values to be added at a later date.

LiftCables	Stores the relation of the lifts with the cables by linking a CableID, a Master-ID and a LiftID.
LiftHooks	Stores the relation of the hooks with the lifts by linking a HookID, a MasterID and a LiftID.
LiftID2MsgLookup	Stores the numeric ID for the manufacturers notes which appears with a particular lift Using the LiftID.
List-Boom-Names	This table lists all the boom names which have been entered in the database.
List-Materials	This lookup table provides a list of the material types used in the Slings form. Using a table for a list in this way allows for easy database expansion.
Main-Shackles	Stores all the information about shackles, indexed by a unique ID.
Main-Slings	Stores all the information about slings indexed by a unique ID.
Main-Spreaders	Stores the non-variable information about spreader beam i.e. anything other than length and capacity (which vary depending on beam configuration).
Sub-Cranes-Local-ID	Stores the local IDs of cranes. IDs are linked to the main Cranes table using MasterID
Sub-Spreaders-Caps	Retains any information about spreader beams which is not stored in Main-Spreaders. This includes lengths and capacities. Entries linked to those in Main-Spreaders by SpreaderID.

These tables are related to each other as shown in Figure 4-4. These relations are the actual link that has been defined within Access. Some other relations exist, but do not affect the data structure.

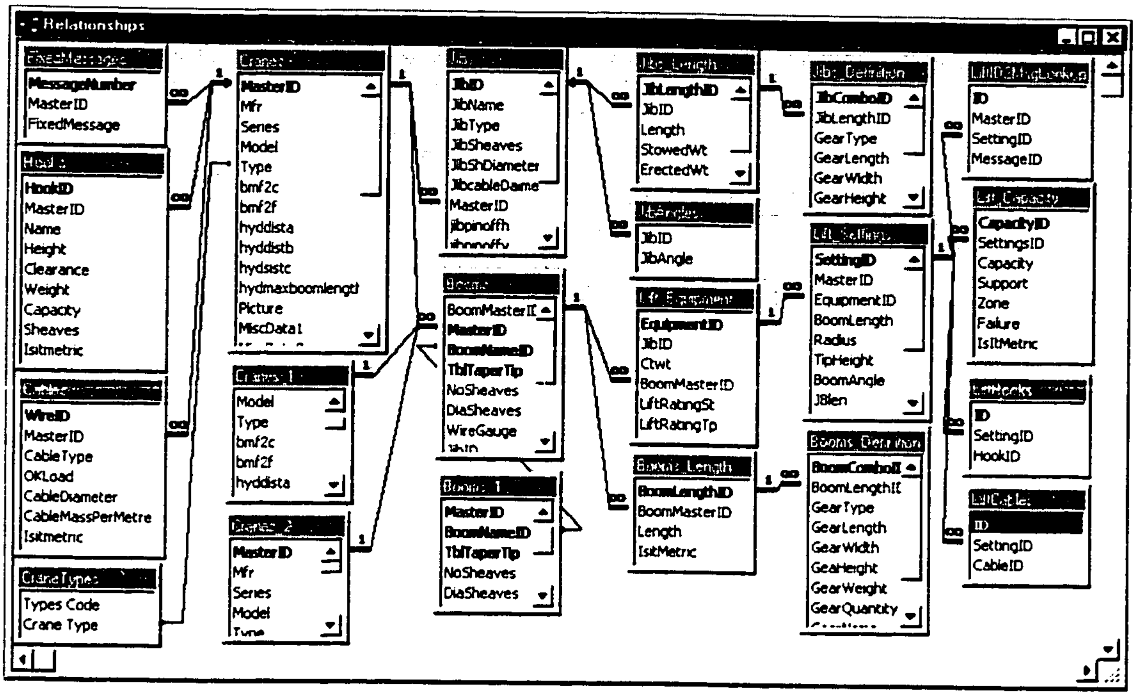


Figure 4-4 Database Tables and their Relationships

Bold text indicates a primary key in a table, and a connector line between two tables shows a relationship. The lines show the fields on which the relationship is based and the type of relationship. The main table in the database is the "Cranes" table shown in Figure 4-3. This has one primary key, the MasterID of the crane. Relations with other tables are mainly of the one-to-many type because several records exist in the other tables for each record in this table. The "Jibs" table has a one-to-many relationship with the Jib-Angles table, it allows for a number of angles to be entered for each jib (the relation exists on the "JibID" field). To define multiple accessory lengths, a one-to-many relationship links the "Jibs" table to the "Jibs-Length" table. This in return has a one-to-many relationship with the Jibs-Definition table.

The Booms table is the only one to have a multiple-field primary key as shown in Figure 4-5. This is to ensure that a unique combination of boom and tip is entered for each crane. The primary key is always indexed with unique values. The Boom MasterID is an auto-numbering unique field that identifies each entry in the table. To define multiple boom lengths, a one-to-many relationship links the "Booms" table to the "Booms-Length" table. This in return has a one-to-many relationship with the "Booms-Definition" table.

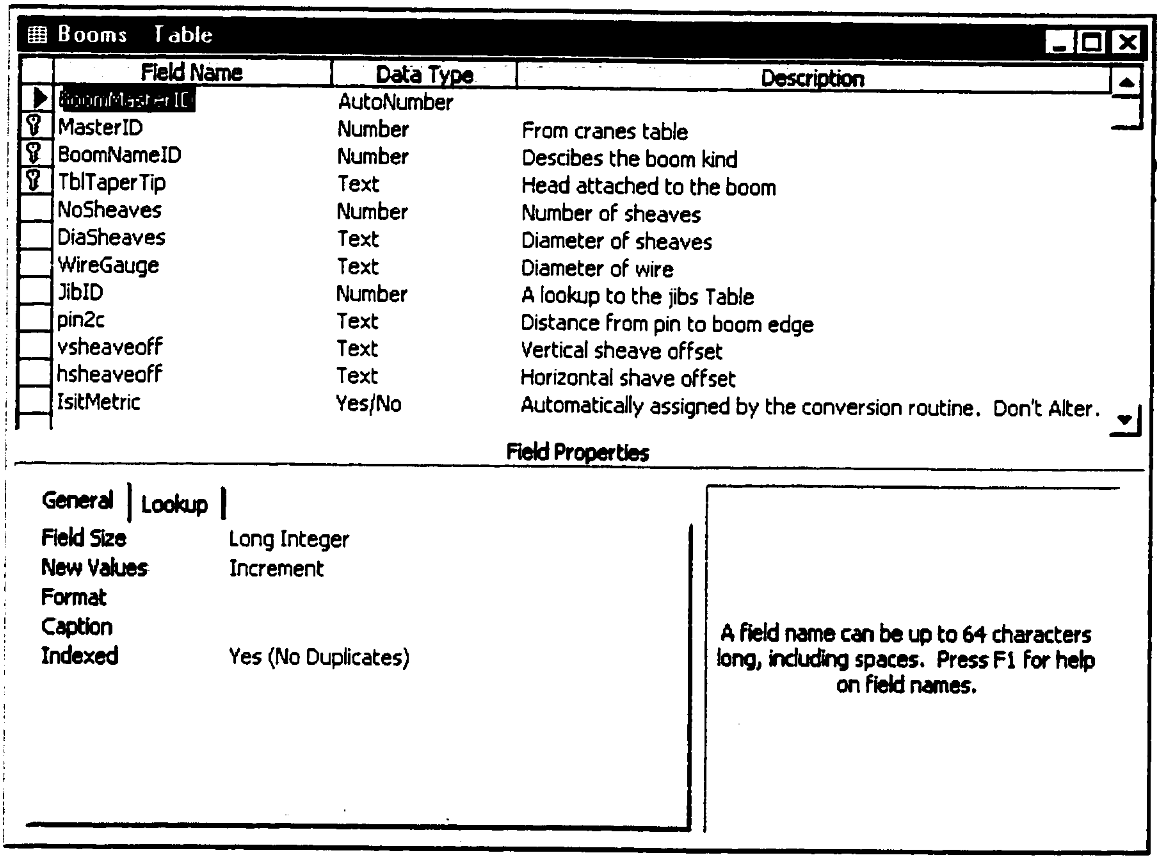


Figure 4-5 Screen Snapshot of "Booms Table" from the Cranes Database

"Lift-Equipment" *(known in the text of this thesis as "Lift Configuration")* links to the "Booms" table with a many-to-one relationship. The link exists here because a given Boom MasterID represents a crane, boom and tip combination (the minimum requirements for a lift). A jib is not essential, and thus there is no link to the "Jibs" table. One-to-many relationships bind the settings to the lift-ID because a crane setup may have many boom lengths, jib lengths, boom angles and jib angles. Each possible combination of this gives rise to many capacities, depending on the outrigger position; therefore a one-to-many link exists between Lift-Settings and Lift-Capacities.

The cables, hooks and messages that are relevant to a given lift are stored in the relevant tables and are related to the lift through the Setting-ID. These relationships are one-to-many, thus allowing a lift setup to be associated with more than one item.

4.1.4 Assumptions

The database uses several assumptions depending on the supplied data. Obvious candidates for this treatment are the changes made to the forms, which depend on the crane type. More importantly, the actual data stored is not accurate without making the same assumptions that the database used when storing it. Examples of this include the position of the tracks on a crawler crane: "tracks extended" capacities are stored with "Outriggers Set". Whether or not the crane has tracks or outriggers is not obvious until all the associations are checked to find out the type of crane related to a given lift capacity.

Similar assumptions are used more imaginatively with the jibs. When jibs are added (with the cranes) a drop down panel provides accommodation for the various angles of a fixed jib. If the jib is a luffing jib, then one angle is stored here (i.e. the boom angle). By looking at the type of jib, the attribute to which the number relates can be found. For a more complicated scenario, assume that a crane could boom up and down with a luffing jib. Here, all the luffing angles of the jib could be stored, like fixed jib angles. When entering lift data, choosing the appropriate "fixed" angle and combining it with the boom angle would allow such a setup to be stored. Techniques such as this one should make the database valid for *any* type of known cranes.

4.1.5 Database Interface

Central to the design philosophy behind the database are the concepts of clarity and simplicity. The most time consuming process in the preparation of the system (after the application development) is entering the data. Although this is done only once when the crane information is entered, it is clear that users will spend hundreds of hours with the forms used to accomplish this. To help user comfort, as few forms as possible have been used, and each is laid out as a series of logical steps. The user is guided through the process of adding a crane by answering simple questions about the crane and its accessories in a similar manner to the Windows wizards found in other Windows applications. In addition to the clear text, graphics are used to simplify the data entry process.

Few forms do not mean the data have been compromised. The forms used throughout the entire system respond to the users' questions, changing and updating where necessary, based on a series of decisions taken by the program. For example, when a user selects a crane type, the form is changed and updated based on the program's predictions of which data will be displayed or entered. These decisions are carried through to other forms, giving a highly complex interface, which presents itself as simple and adaptive. The front-end application is event driven, this means that the system generates signals when events occur, that can be trapped with a customised response. For example, changing records generates an event *(OnCurrent)*, which can be used to refresh the form and change the layout depending on the type of crane being shown.

To achieve the goal of simplicity with entering data, a solution based on just two forms was chosen (see Figure 4-6 and Figure 4-7). The first form informs the database of the equipment available, the second form assembles the equipment and logs the capabilities in terms of lift capacity for such a setup. This solution requires careful design of the forms and data structures. To gather the information that is needed, this second approach combines information into one form what would have been split over ten or more with the initial design. Of vital importance is the link between the objects in the database. For example, for the database to work, it is not enough to note that a crane takes a particular kind of the boom; the boom has to be linked to the crane. This allows data about the boom to be stored as part of the crane.

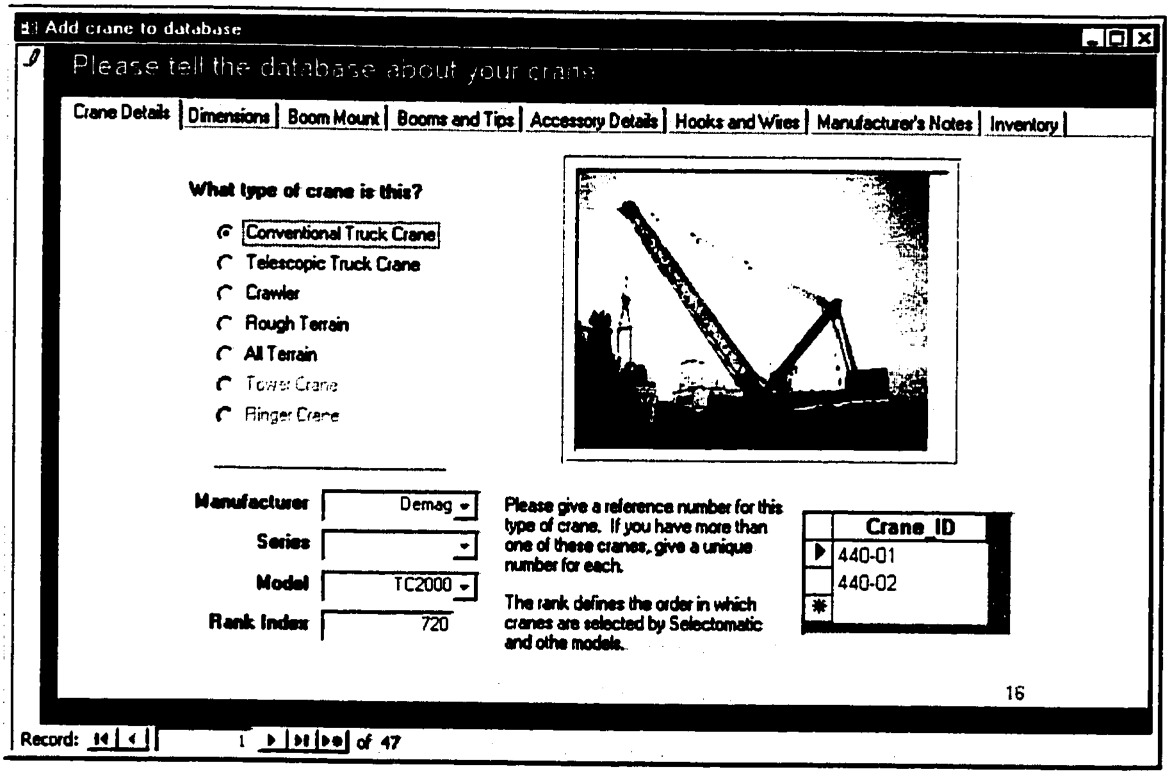


Figure 4-6 Crane Unit Information Data Entry Form

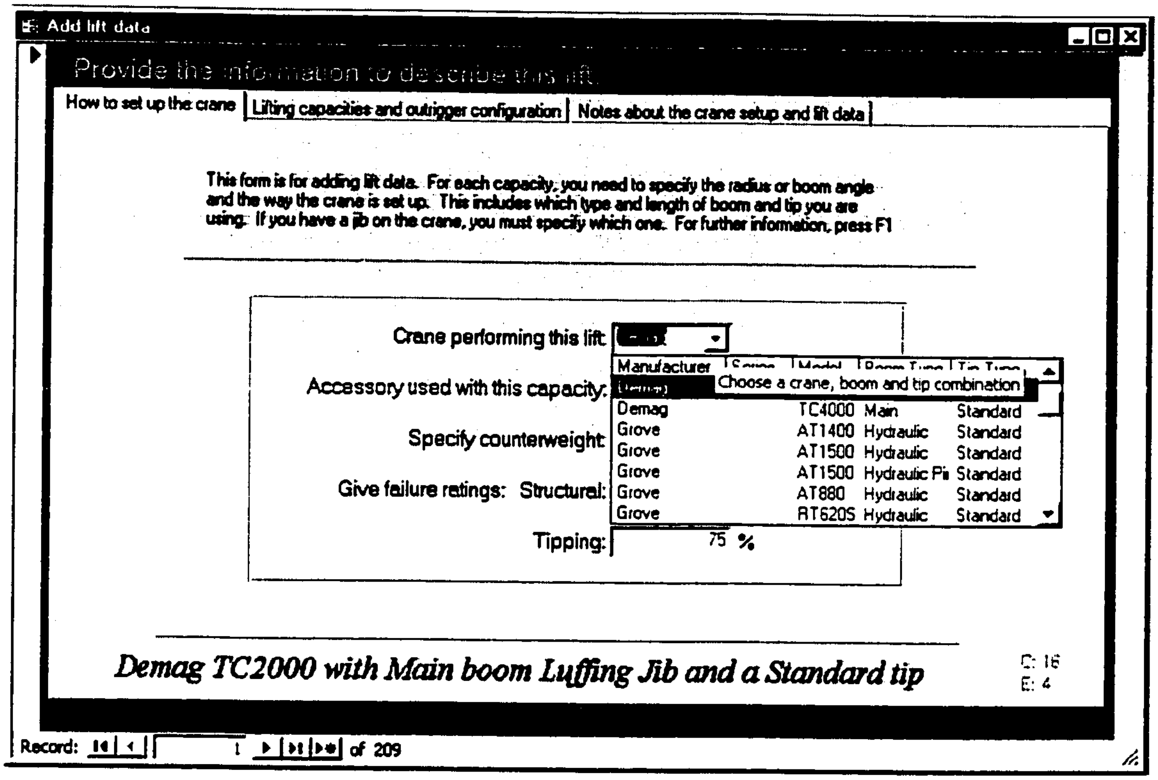


Figure 4-7 Lift Configuration Data Entry Form

The previously mentioned tables are all filled through the "Add Cranes to Database" form. This is the first of the adding data forms. The primary tool for data collection is the multi-page tab control. This device allows a series of questions to be asked in a logical order. As the questions are answered, the tables can be filled. Several sub-forms are used to add the boom, tip, jib, messages, and local crane ID information. A "sub-sub-form" exists in the Jibs section, this allows the angles for the jibs to be added as a subset of the jibs, which is in return a subset of the crane. Simple programming behind the form enables and disables control depending on the information entered. Apart from aesthetic reasons, this further reduces the margin for error: if a control is not available, it can't be wrongly used. The programming also assists the operator in certain situations, for example, if the type of crane chosen has an hydraulic boom, then "Hydraulic" is entered as a boom type. Such devices give a professional appearance to the front end and make the user feel comfortable with the software.

The lift capacities are entered through the "Lift Details2" form. The form is based on a query of the "Lift Details" tables and the "Booms" table. This allows access to all the fields in both tables. By using combo boxes (drop-down boxes) with the entry limited to lists, data entry is restricted, allowing control over the input. For example, only crane/boom/jib combinations, which have been previously defined and checked, can be used. This same approach is used to ensure that only manufacturer's notes that apply to a particular combination can be used. This has the added advantage of simplifying the operator's job. For example, rather than select a boom from a large list in the database, only those booms that will work with the chosen crane/boom/tip combination are listed.

When adding data, programming behind the form sets the form's default values to those of the last record. This means that data, which remains the same for several lifts, such as crane or lift rating, does not have to be re-entered. Sub-forms are employed to convey the lift capacities to the relevant tables and to select and store manufacturer's notes

4.1.5.1 Interface for crane's data entry

In terms of entering the data, the specifications of the equipment are entered first. Each crane model is entered once. With each crane, there are details of the booms: heads; accessories; hooks and cables that will operate with it. To allow for consistency in data entry special forms were designed using the same terminology, which will be filled in by the those entering the data about the crane, (see appendix B for examples of these forms). Manufacturer notes and lift constraints available with the equipment are also stored at this stage. The series of questions follows a logical progression; asking first about the crane, the carrier dimensions, boom mounting position. the booms and heads, accessories, hooks and cables and finally the restrictions imposed by the manufacturer. All these attributes are linked to the crane unit (Model), forming the list of equipment added to each crane model. called *lift configurations*. Therefore. the database can check the information stored about these lift configurations and allow the use of information entered on the crane assembly details when the *lift capacities settings* are added.

The lift capacities are another section of the database. As discussed previously. only an assembly of equipment (Lifting Configuration) has a lift capacity. To enter this. the *lift configuration* set-up is defined by selecting the appropriate *lift configuration* from the list formed in previous step as shown in Figure 4-7. The relevant capacities for this combination are then entered in the next tap-page. By making sure that the *lift configuration* was entered previously. only valid combinations can be used. For example, if a particular model of an American crane was originally entered with a 77H main boom with two different heads (Hammerhead. and taper-tip head). then the user will only be able to select from only these two when defining the *lift configuration* set-up.

The relational capabilities of the database software allow the lift details to be stored with just one serial number to represent the crane, counterweight, boom and head and accessory set-up. The boom length, accessory length and other variables are considered part of the *lift capacity settings*, as they change from lift to lift. Changing the length of a 77H boom, for example, doesn't change the fact that it is still a 77H boom, albeit a shorter one. This design allows the capacity for any crane to be stored, as long as the *lift configuration* is available, i.e. it has been entered through the correct forms.

Accessories, which have no bearing on the other two database sections, Cranes or Lift Details, are considered as a separate group. The data are only collected to assist with the crane selection as the effective weight and size of the accessories has to be considered in the calculations that determine the suitability of a crane for a particular lift.

To illustrate this, the addition of one crane is used as an example. This will allow all the steps of the database to be illustrated, together with a commentary of what happens at each stage. The main form, as shown in Figure 4-8, is a collection of textboxes, which are set to be transparent and border-less. The checkboxes are separate boxes. When the *mouse-over* event occurs for each box, the attached procedure changes the colour and the caption for the corresponding checkbox. The *mouse-over* event for the background causes all the boxes to be set to black. The arrangement of the controls is such that a small gap between the rows means that a mouse-over event *must* occur when moving the pointer between controls. This is necessary to un-highlight the previous control before highlighting the next. Clicking on an entry causes an *on-click* event, which causes the procedure to respond to the action. In most cases, this involves minimizing the current window and the opening of another. To perform the data entry for a new crane the ***Add a crane to the database*** option is selected.

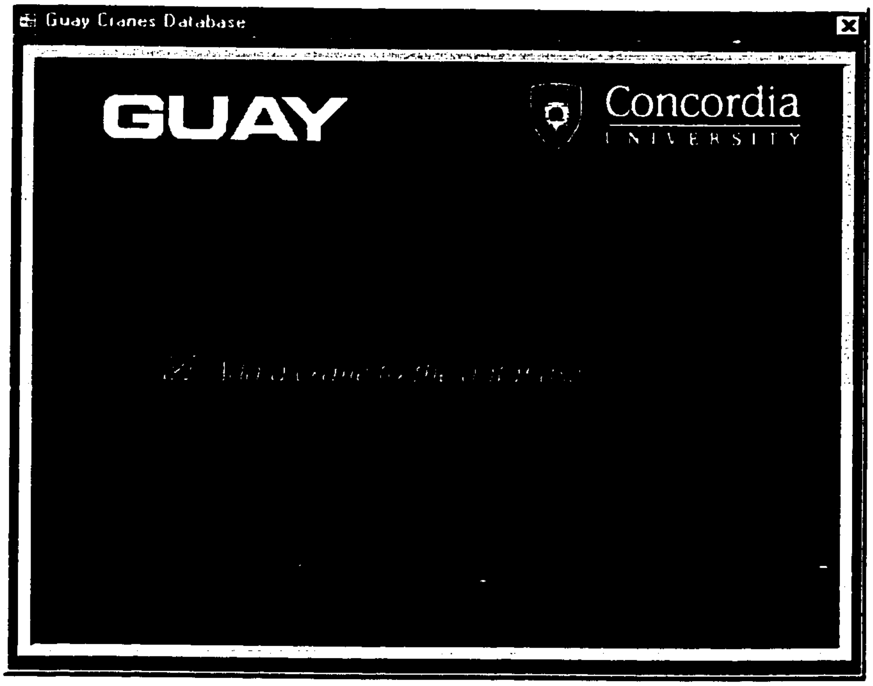


Figure 4-8 Database Main Menu Form

Opening, the Add Crane form shows the first page of the tab control as shown in Figure 4-9. The tab control gives the advantages of displaying the pages as a logical sequence for the user, and, more importantly, the *On-Change* event that occurs each time the user changes page, allowing user behavior to be tracked.

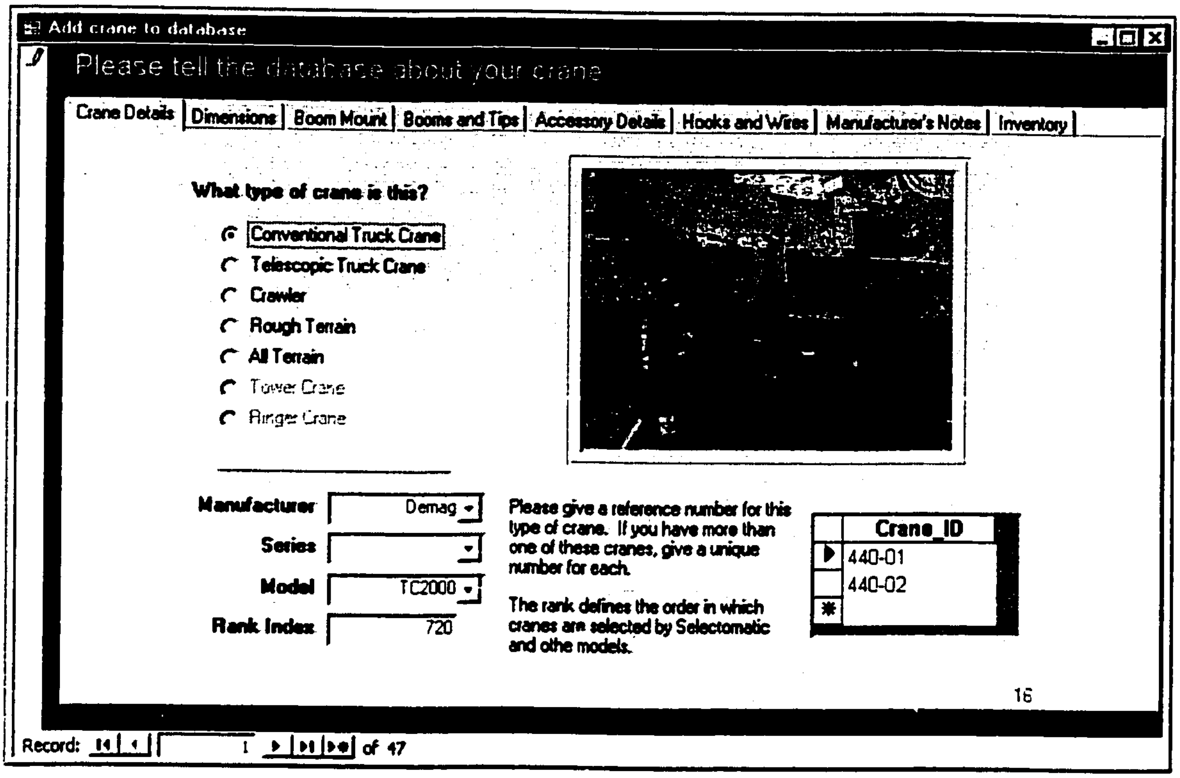


Figure 4-9 Add Crane to the Database Tap-Form

For a standard entry, the code checks the value of the option group that contains the crane type controls. Based on this (numeric) value, routines are called to repaint sections of the form to account for hydraulic or conventional booms. If the value is "null", then a new record is assumed. The form assumes a conventional boom; this ensures that if the form is browsed for a new record, a coherent set of options is shown.

Crane Type: The first question asked uses the option group to determine the type of crane (Conventional truck mounted, Telescopic truck mounted, Crawler, Rough terrain or All terrain). The option group returns a numeric value, which is used to call the repaint functions for the type of boom available on the crane selected. Using a numeric value allows simple math to be used to determine the crane type. For example, all values less than three might indicate a telescopic boom. The repaint functions are called through the *on-exit* event, which is quite complex.

Manufacturer, Series and Model: These three combo boxes allow direct text entry. For the convenience of the user, SQL queries behind the controls lookup unique values of relevant information in the tables. This allows values that are already in the database to be chosen without retyping.

Crane ID: This is a sub-form (Sub-Cranes-Local-ID) which is displayed in datasheet view. Using the Master-ID field, it is linked to the main form. This allows company identifiers for the cranes to be stored. As different firms use different identifiers, it is free text. This covers the possibility of companies having more than one crane of certain model. The user simply keys in as many identifiers as he wishes.

Dimensions: The second page of the form contains controls for the dimensional information of the crane, as shown in Figure 4-10. The *on-enter* event for each control is set to show a suitable diagram, showing details of the relevant dimension.. There is a diagram for each of the control groups Carrier dimensions that shown in Figure 4-10, Counterweight dimensions, as shown in Figure 4-11 and Outrigger dimensions shown in Figure 4-12. Clicking the background switches to the first diagram (i.e. Carrier dimensions) that shown in Figure 4-10. A two-button option control is used to select the outrigger configuration: X or H. All controls in the database show units, by having text boxes bound to their tags.

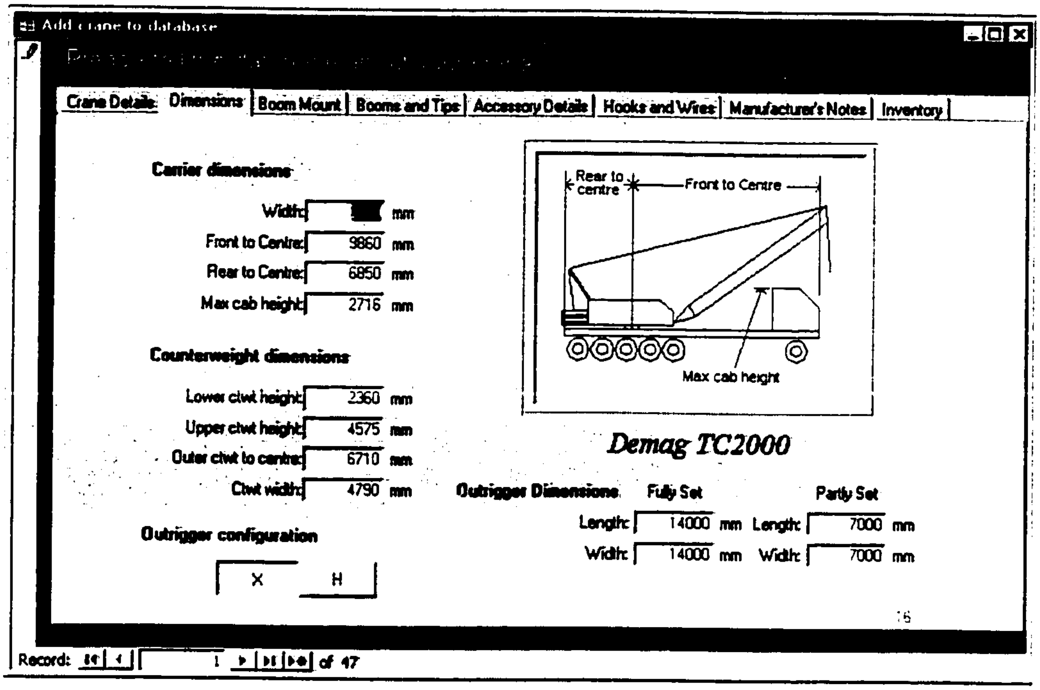


Figure 4-10 Crane Dimensions Data Entry Tap-Form

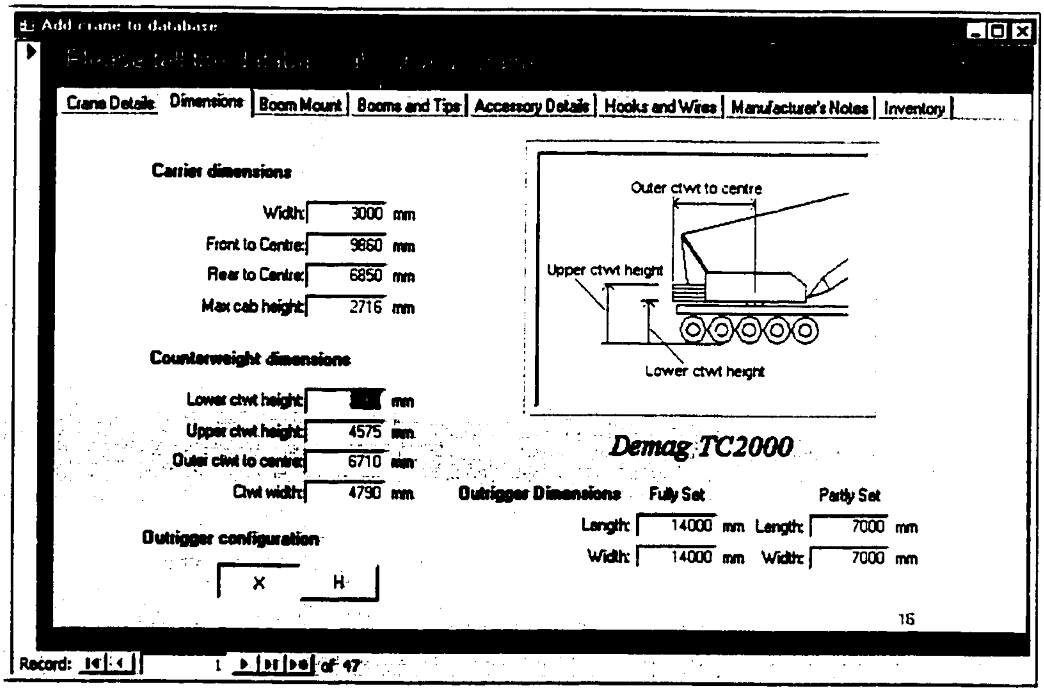


Figure 4-11 Crane Dimensions Tail-Swing Data Entry Tap-Form

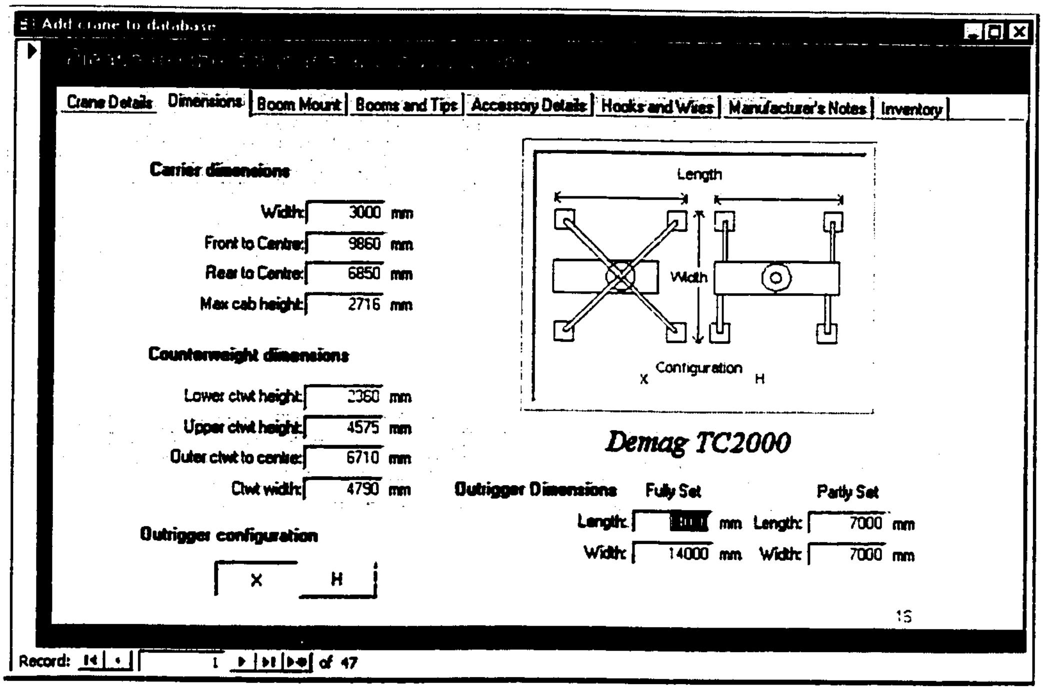


Figure 4-12 Outriggers Dimensions Data Entry Tap-Form

Boom Mounting Data: This third page, Boom Mounting Data shown in Figure 4-13, involves the determination of location of the boom pin on the crane. The user is reminded of the current crane by a text control. The control obtains its data by concatenating the data from the relevant controls on the first page of the form. The diagram used on this page is set by the *on-exit* event for the crane type option control on the first page. Extra text boxes are enabled for hydraulic cranes but their behavior is the same as those shown above.

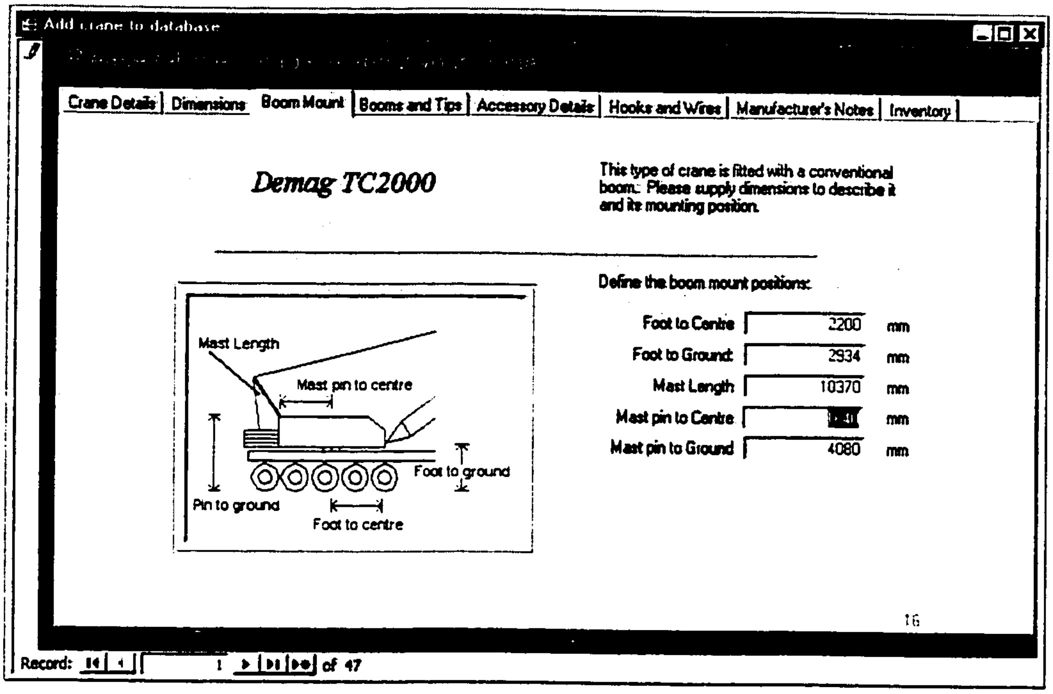


Figure 4-13 Boom Mounting Position Data Entry Tap-Form

Booms and Heads: The Booms and Heads page, as shown in Figure 4-14 is the same for all boom types, the only exception is that choosing a conventional crane allows the addition of more than one boom. As described in the methodology chapter, a boom and its head are considered as a single unit in the database. An hydraulic crane has a standard head and therefore the head type cannot be changed. The form is presented as a panel within the page. This reinforces the idea that it is a subset of the main crane. The panel is a sub-form. Each boom/head combination occupies one page of the sub-form, which is linked to the main form by the *Master-ID* field. Navigation buttons are provided to cycle through the boom/head records. All controls on the form dealing with linear or mass values have the tags set for the values to show units in the same way as those on the main form. Each boom must be defined to be stored in the database to create the *Lift Configuration.*

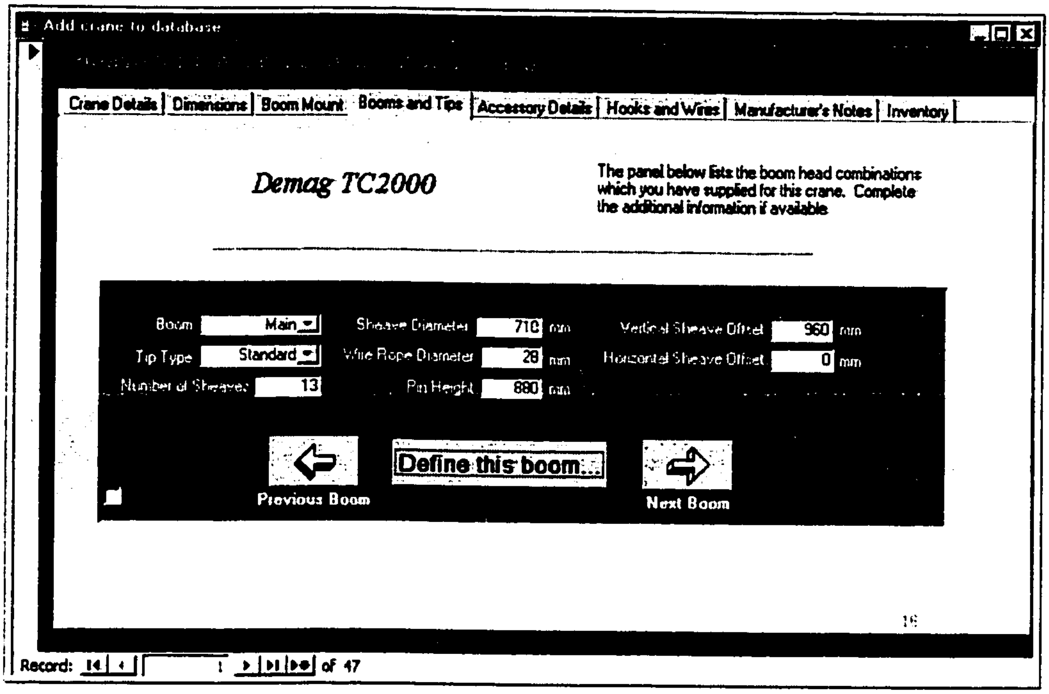


Figure 4-14 Boom and Head Data Entry Tap-Form

For the convenience of the user, the boom combo box presents a list of boom types already in the database, using an SQL query for the list source. For the tip type, a fixed list is provided and the user is forced to choose from the available list (i.e. standard, hammerhead, etc.).

Accessory Details: This fifth page, as shown in Figure 4-15, behaves in the same way as the Boom and Head page. To allow for more than one accessory, navigation buttons are provided to cycle through the jibs stored with the crane. Another sub-form appears on the jib sub-form - this allows the fixed jib offset angle to be stored. The sub-form will expand automatically to allow as many angles as needed. This feature allows the program to deal with all types of cranes, even those with main booms which can luff whilst the jib luffs.

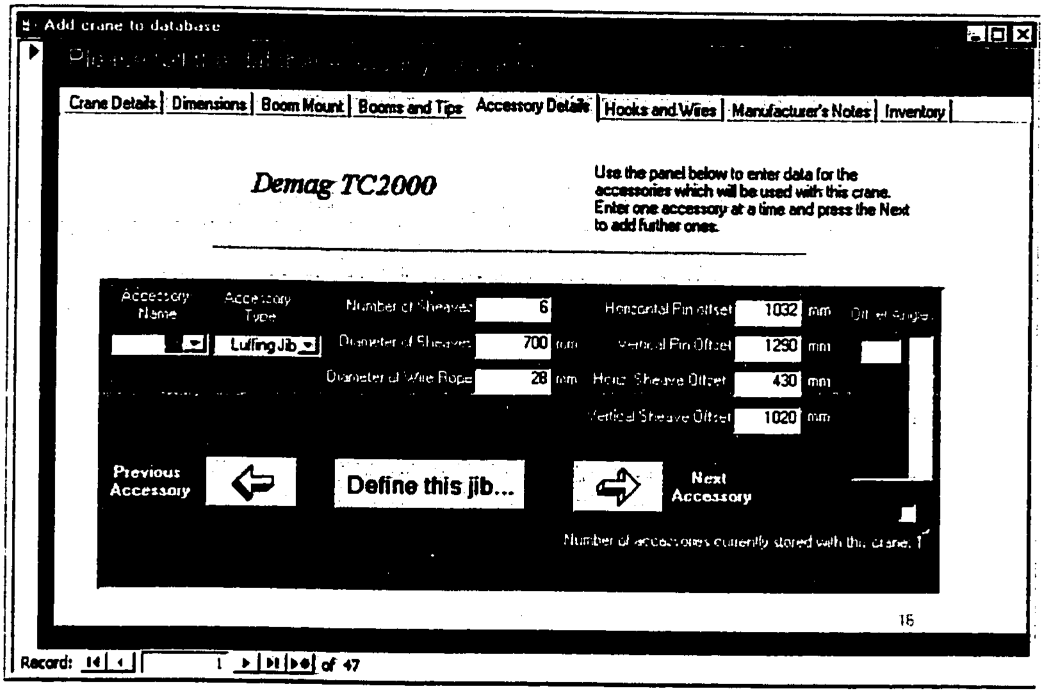


Figure 4-15 Accessory Data Entry Tap-Form

Boom and Accessory Definition: Both the Boom and Accessory pages have a button to define the object. Pressing the button on either form has the same effect. First, the current record is saved. Then the appropriate definition form is opened as showin in Figure 4-16. The same form is used for both booms and accessories, the only difference being that effective weight fields are included for the lengths when dealing with accessories. The query behind the form checks the current BoomMasterID or JibID and MasterID on the Main form and sets its local variables accordingly. The various lengths of the boom or accessory are then entered, and a subform is used to define the lengths in terms of foot sections, conversions and insertions. The names for the insertions are free text. The combo box on the name field has a query which checks the list of components for the current BoomMasterID or JibID. Its multicolumn property allows all the data about a component to be displayed. The widths of the columns are programmed to coincide with the columns on the form. The *OnExit* event for the combo box requiries the SQL to make the list valid for the next use and extracts the data from the different columns for the selected row. These data are then entered into the text boxes on the form as if typed by the user. Pressing the *"Return button"* saves the current record and returns the focus to the main form. The definition form is application modal to prevent the main boom from data being modified while the definition is being entered. Shown in the Figure 4-16 is the Accessories version of the form. The Booms version merely lacks the effective erected and stowed weights which are additonal fields on the Jib-Lengths table.

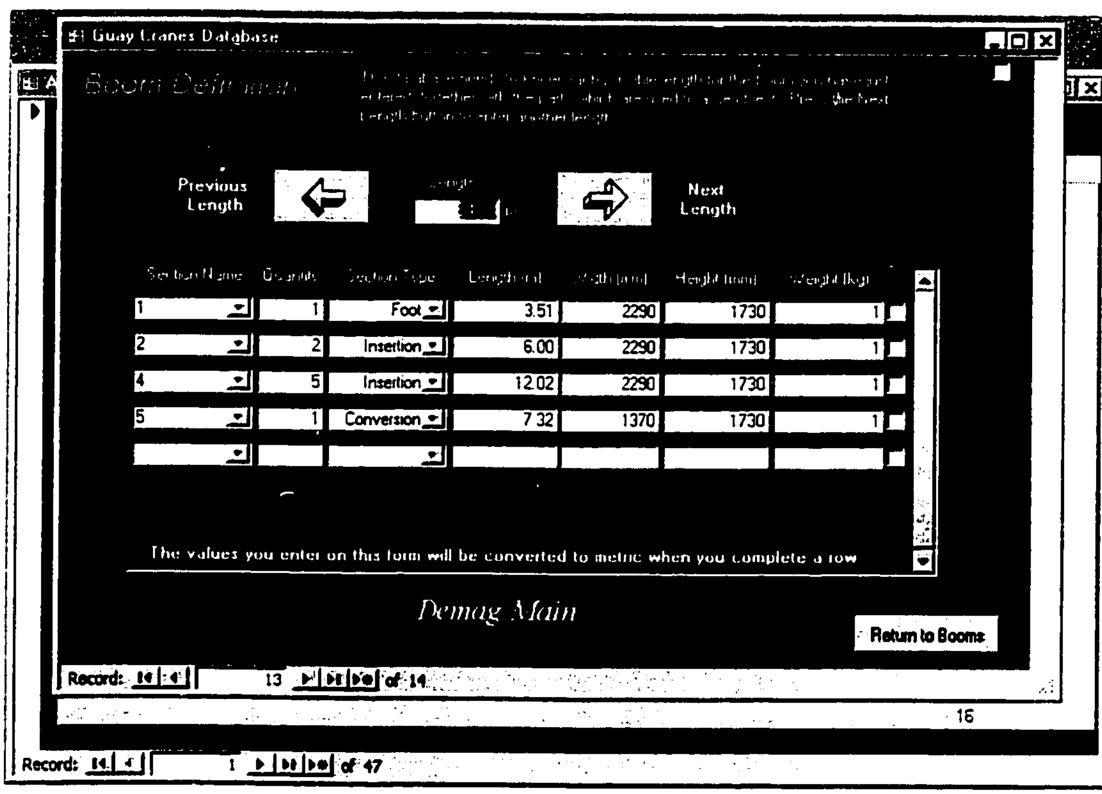


Figure 4-16 Boom and Accessory Definition Data Entry Form

Hooks and Wires: This page, as shown in Figure 4-17, uses the same devices as before to remind the user of the crane manufacturer and model. The rest of the form is divided into two panels, each of which contains a sub-form. Master-ID binds the sub-forms to the main form. Navigation buttons on each form allow the user to cycle through the records. Trapping the *On-Click* event for the buttons and including appropriate code take care of cycling, the code is the same as that for other navigation buttons in the database. The data from the sub-forms are stored in the Hooks and Cables tables, respectively.

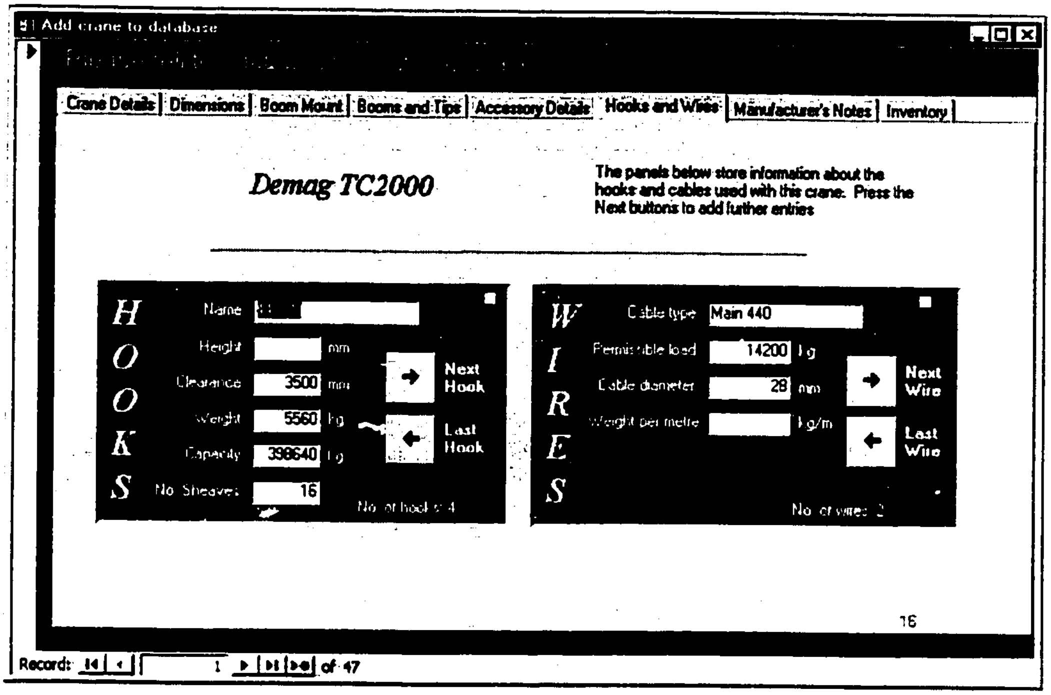


Figure 4-17 Hooks and Wire Ropes Data Entry Tap-Form

Manufacturer's Notes: All cranes have some sort of restrictions that are described by the load charts. These restrictions form a vital part of the data held about a crane. By adding all the notes on the charts at this stage, they can be referred to at a later date with minimal effort from the user. Each note, when entered, is assigned a unique number that is related to the crane, as shown in Figure 4-18. When the lift capacities settings are entered on the next form, the notes for a particular crane are presented to the user so he/she can choose whichever apply to the lift. The sub-form to allow multiple notes for each crane is linked to the parent form by *Master-ID*.

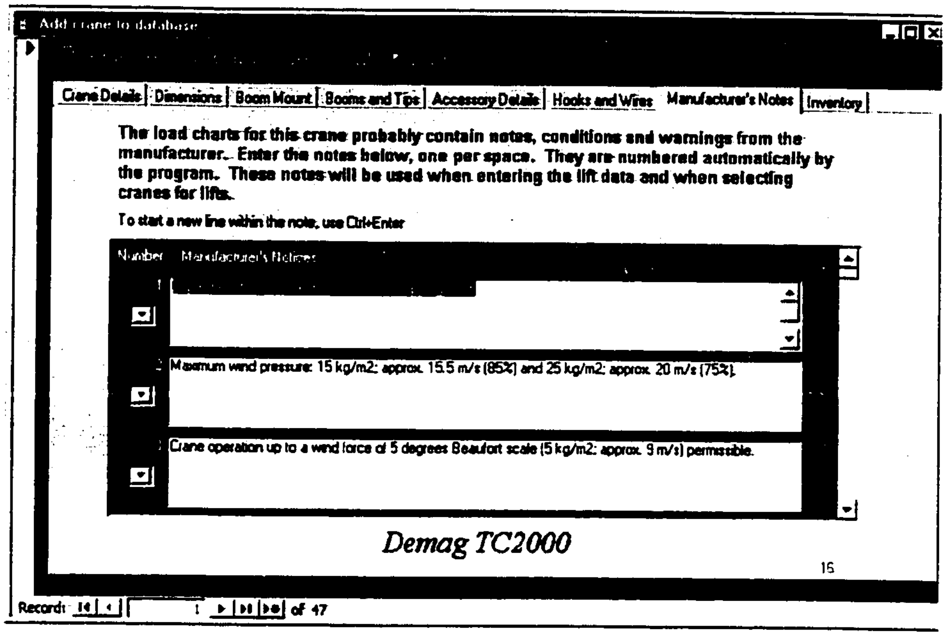


Figure 4-18 Manufacturer Notes Data Entry Tap-Form

Closing the form: The *Form-Close* event is trapped to restore the main switchboard for the user.

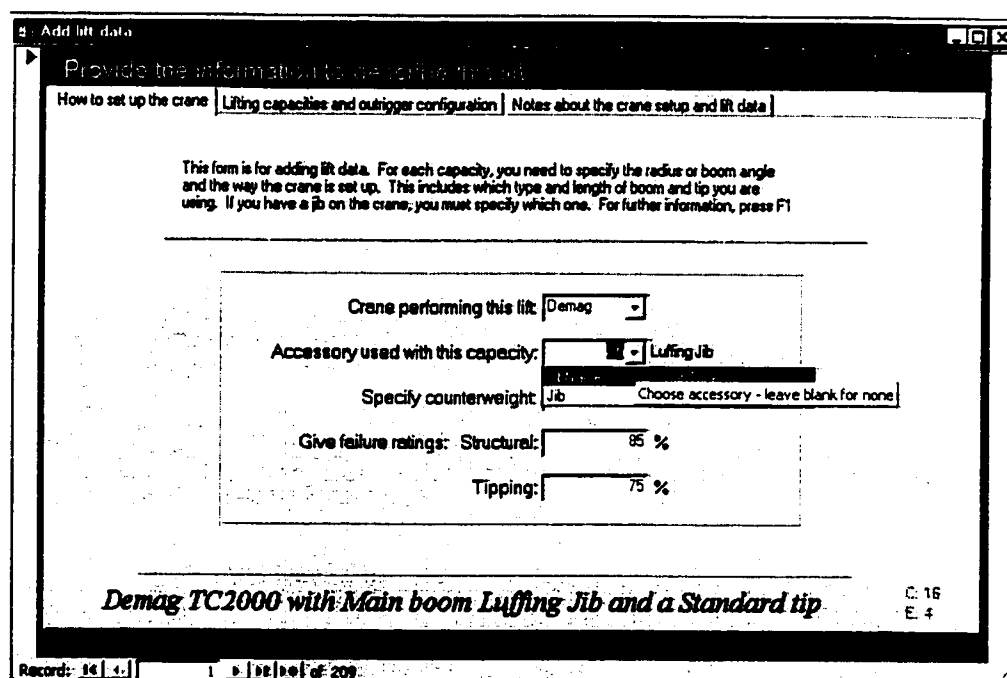


Figure 4-19 Choosing a Lift Configuration Tap-Form

Adding Lift Data: This form is used to define the crane configurations and lift settings used for a given lift. Each lift is entered as a set of capacities and is stored with numeric codes which define the lift configuration in terms of crane type, boom, and accessories. The settings are defined in terms of booms/jibs lengths and angles; and capacities in terms of capacity, lifting zone, failure type and support type and position.

Items such as the counterweight and the lift ratings will not vary from lift to lift. The form is therefore split into three pages: the first for data which are repeated i.e. lift configurations, the second to enter data which applies to each lift setting and capacity, and the third to redisplay information for the benefit of the user.

The *New-Record* property is used to check for a new record. If the record is new then the reminder text at the bottom of the form is disabled until a crane is chosen. The two combo boxes (select crane and select accessory) on the first form, as shown in Figure 4-19, are quite complex. The first box (crane performing this lift) is for obtaining the crane details, gets its source data from a named query, *Lift-Details-Combo-Source*. The query is external to the control as it depends on the *Link-Boom-Name-to-ID*. This combination allows for the choice of all possible combinations of crane, boom and head. This way the user can only make valid choices (maintaining data-integrity), an entry from the list has to be chosen. The value returned is numeric - the *Boom-Name-ID* which represents a given crane with a given boom and tip. Using an SQL statement based on this value, the combo box i.e. the second box (accessory used with this capacity), lists only those accessories, that have been stored for the chosen crane. A locked and disabled textbox has its data source bound to one of the columns of the accessory choice box this serves to remind the user of the type of accessory being used, (i.e. luffing jib, fixed jib, extension, etc). A similar device provides the data for the reminder text at the bottom of the screen: the crane model, boom, accessory and tip are concatenated with the text **"with","boom","and a"** to produce the reminder sentence. This text is a form control, not a tab-page control, ensuring that it is displayed regardless of which page the user is viewing.

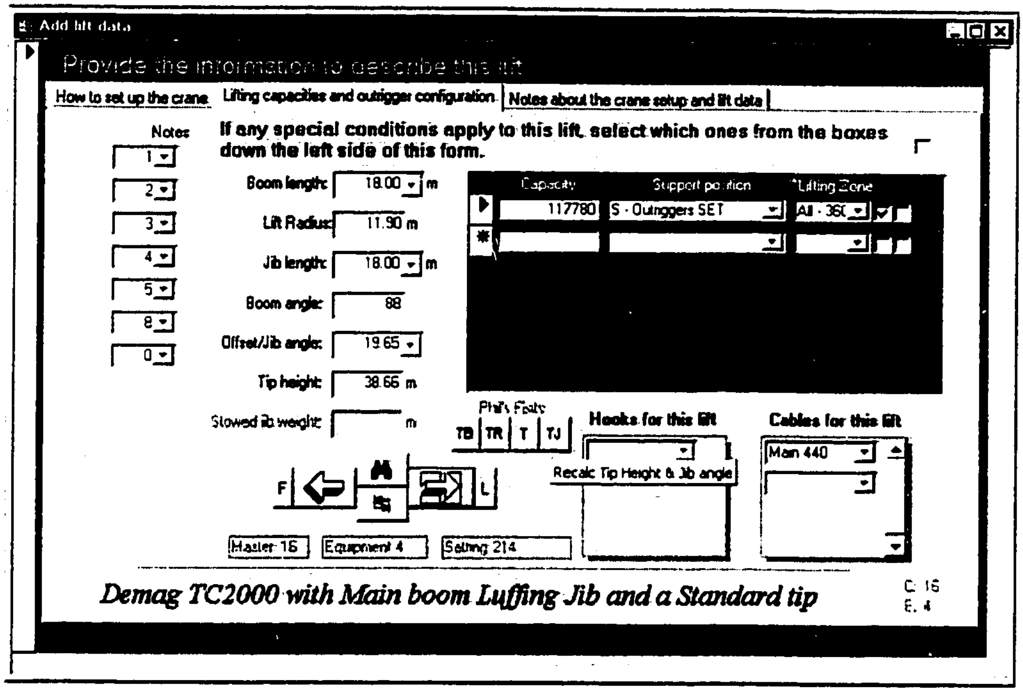


Figure 4-20 Lift Setting Data Entry Tap-Form

All the controls on the second page exist on a sub-form, with further sub-sub-forms for the cables, hooks, capacities and notes. This allows multiple settings for the equipment chosen on the first pages, without the user having to re-enter data. To maintain data integrity, the normal navigation buttons, which are standard for Ms-Access, are removed when the sub-form is displayed, as shown in Figure 4-20, preventing the user from accidentally entering capacities for the wrong crane. Boom lengths, accessory lengths and offsets are all chosen from combo box lists. This means that only the lengths previously entered when the boom or accessory was defined can be chosen, which is another way of ensuring data integrity. There is a variety of possibilities, in terms of tip height, boom angle and radius, regarding which data are and are not supplied by manufacturers. For consistency and to enable searching on different criteria, the *Calculate-Details* function is called when the user exits the tip height box. This function checks each control to see which values are missing and calculates the missing values from the information present. If, for some reason, the calculation could not be performed, then the user is warned. Capacities for the lift are entered in the sub-form on the right of the form. Multiple capacities are possible depending on the support settings and the lifting zone. The support details and lifting zones are selected from a list to ensure consistency in the terminology. The list for the supports varies according to the crane type, to account for either outriggers or tracks.

Each lift can use more than one hook or cable depending on the mass of the lift. Two sub-forms allow cables and hooks to be selected. As with many other controls on this form, the hooks and cables are selected from lists which are generated by querying previously entered data. When the form is complete, and the lift setting stored, the user changes the lengths or radius of the new setting to be entered. This is done by pressing the Forward or Next buttons on the form, which work in the same way as all other Previous and Next option buttons within the database.

4.1.5.2 Interface for lifting attachments data entry

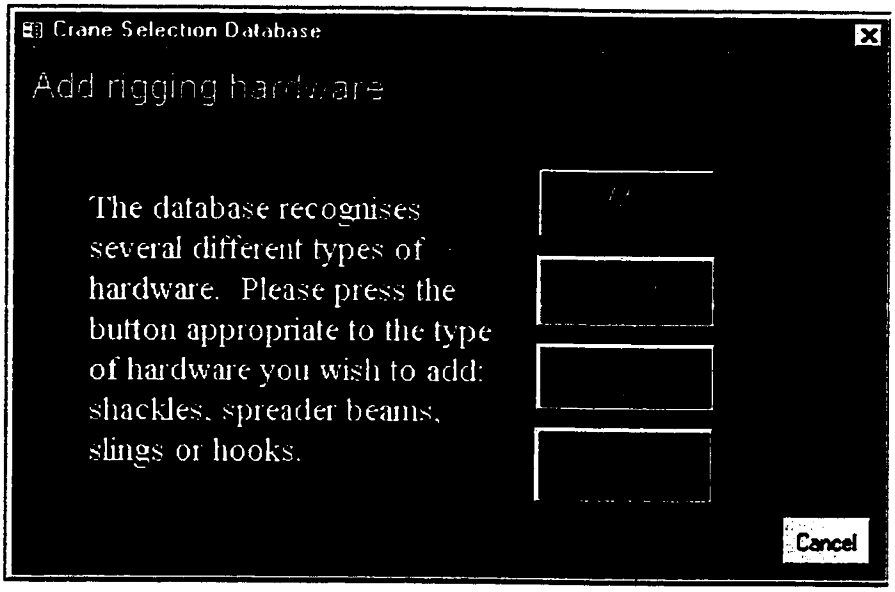


Figure 4-21 Lift Attachments Data Entry Main Menu

The final category for data includes the shackles, slings and hooks which are used to complete the lift. Such data are stored because the height and weight information of these accessories is used in the calculations to select the crane in the final model.

There are three distinct types in the database; slings, spreader beams and shackles, each entered using its own form. The forms are controlled from a switchboard, as shown in Figure 4-21, which is opened when the user opts to add this kind of data. Buttons on the form trap the *On-Click* event to load and open the correct form. Graphical indications of the buttons are backed up by a description of its function, which appears as control-tip text when the user pauses the cursor over the button. The final button (i.e. Hooks) is no longer used for data entry in the current version of the database, but it has been left to allow the user to browse the hook data.

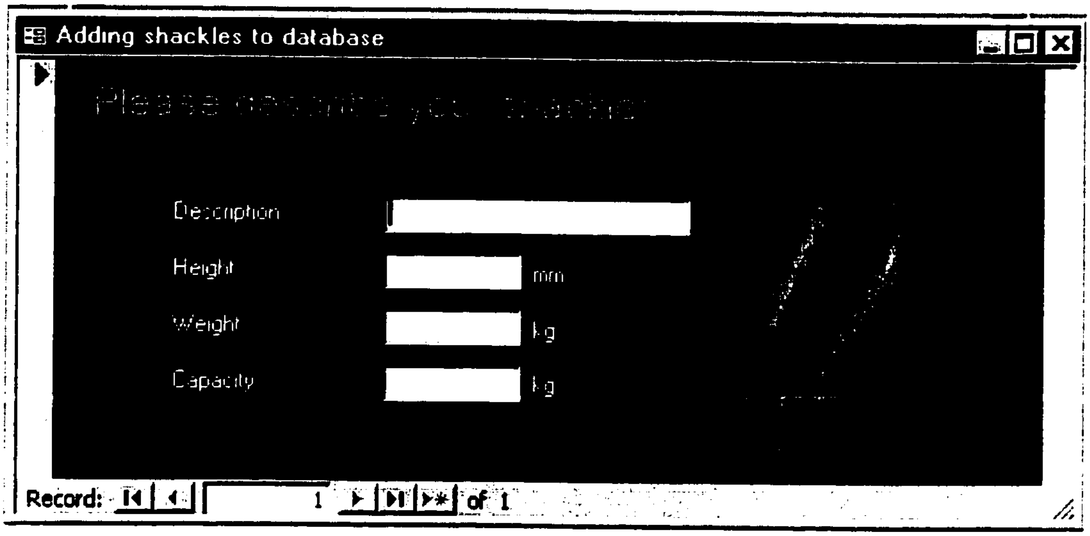


Figure 4-22 Shackles Data Entry Form

The Shackles form, shown in Figure 4-22, is bound simply to the MainShackles table. An AutoID is generated with each record. The *OnClose* event is trapped to restore the rigging switchboard. Metrification is present on this form and works in the same way as the other forms.

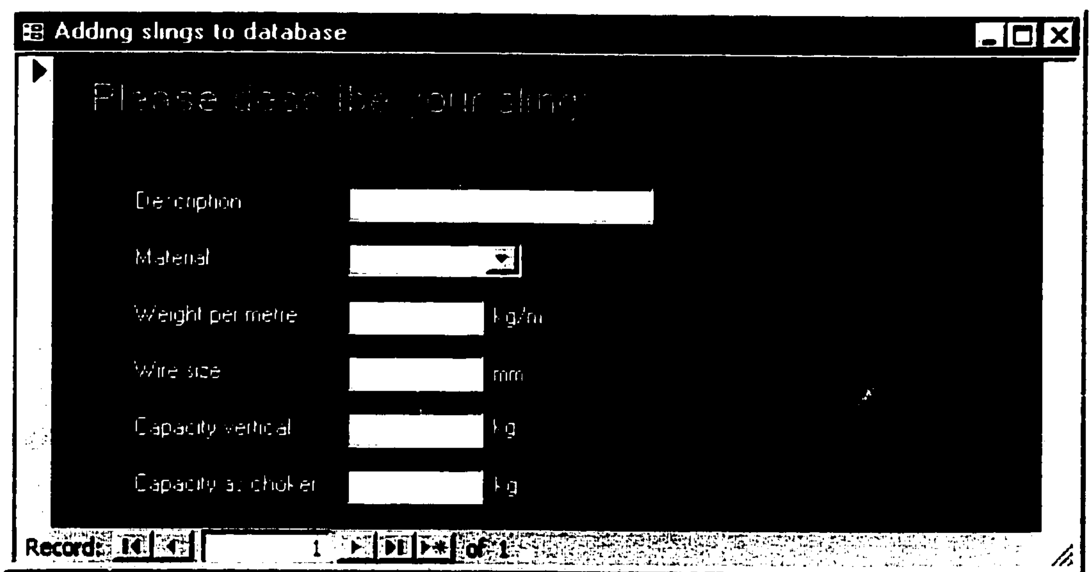


Figure 4-23 Slings Data Entry Form

The Slings form, shown in Figure 4-23, is similar to the shackles one, except for the fact it is bound to the Main-Shackles table. The *On-Close* event is trapped to restore the rigging switchboard.

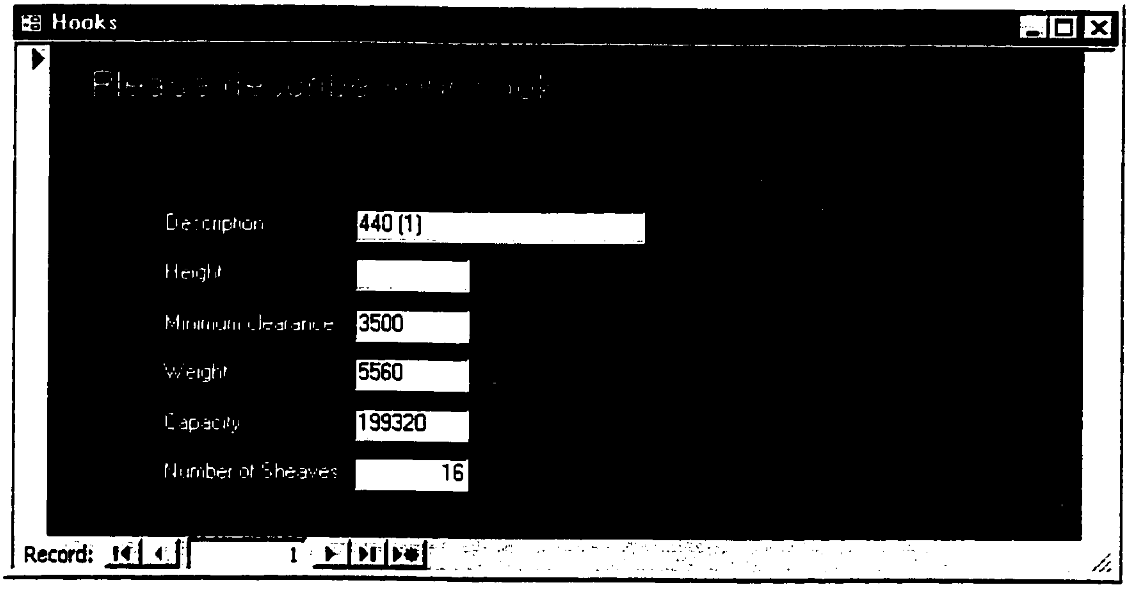


Figure 4-24 Hooks Data Entry from

The Hooks form, shown in Figure 4-24 is similar to the shackles one, except for the fact it is bound to the Hooks table. The *On-Close* event is trapped to restore the rigging switchboard. All controls on this form are disabled and locked, as it is used only to browse the data. The data are entered through the Hooks and Wires section of the Add Crane form.

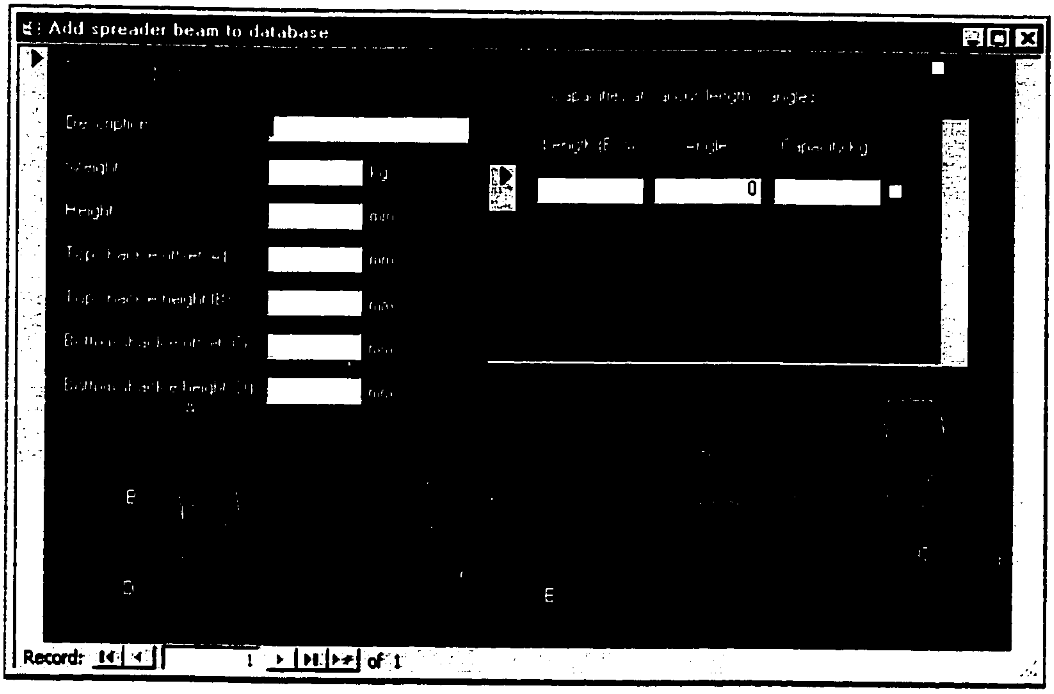


Figure 4-25 Spreader Beams Data Entry From

The Spreader Beams form, shown in Figure 4-25, is bounded to the Main-Spreaders table. It is slightly more complex then the other rigging hardware forms, as it contains a sub-form. The sub-form allows multiple lengths of the same sub-form to be stored. each length has different capacities. The sub-form is linked to the parent through the spreader beam ID, which uniquely identifies the beam.

4.1.6 Forms Used in the Database

The forms used in the database were designed to provide user interface and to enable simple data entry. All the forms involved in the data-entry process are summarised in Table 4.5, and their linkage is presented in the chart shown in Figure 4-26.

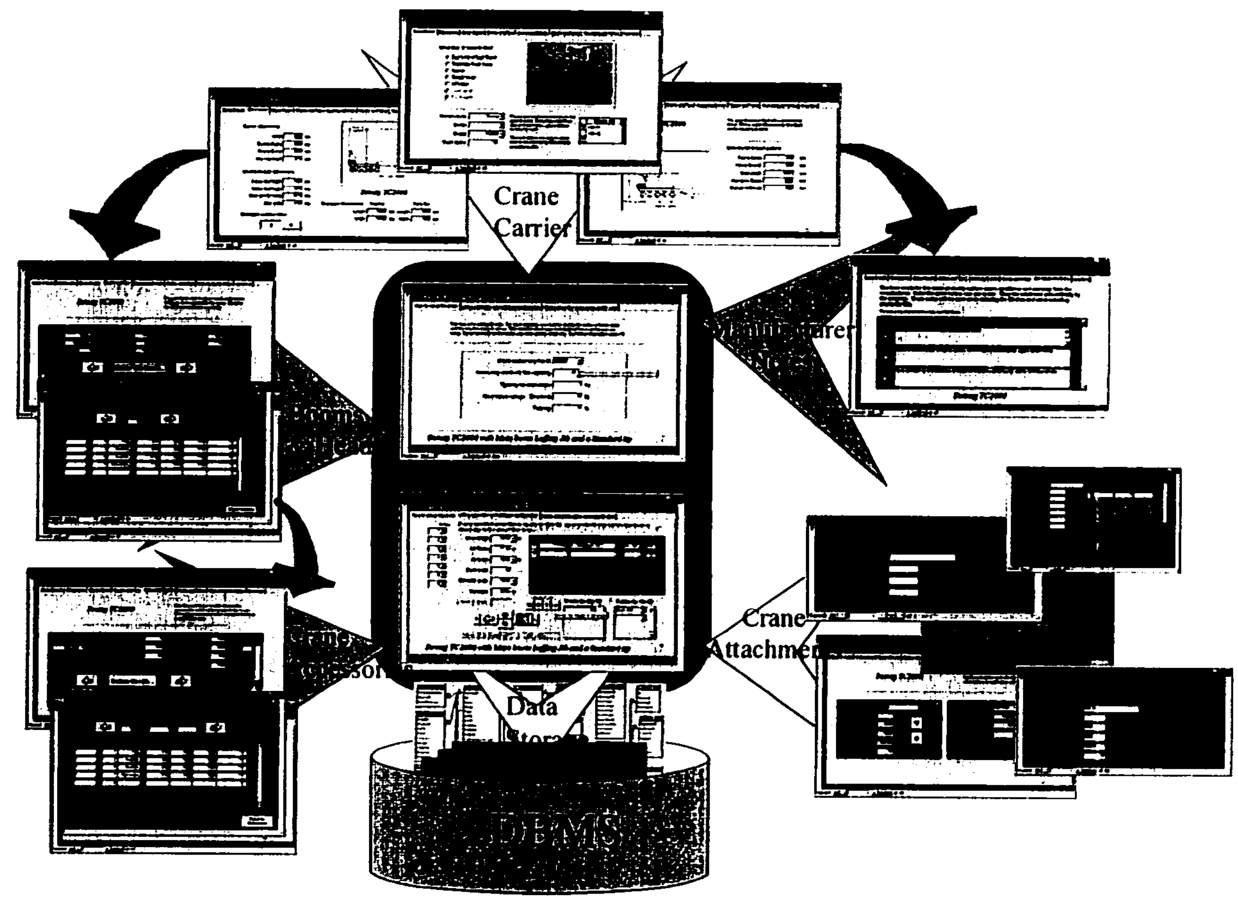


Figure 4-26 All Forms Used in the Database and their Linkage

Table 4.5 List of Forms Used in the Database

Form Name	Function
Add crane to database	*Main adding crane form*
Booms_Definition subform	*Subform to Booms_Length for component list and data*
Booms_Length	*For defining lengths of boom*
Cables subform	*Subform to Add Cranes for defining cables*
CompanyCraneID	*Subform for the local crane Ids*
Control Data	*Temporary and undocumented. Will be removed*
FixedMessages subform	*Used with the add crane form to add notes*
FixedMessages subform1	*Used with Lift_Settings to retrieve notes for lift details form*
HeadInformation subform	*Subform on Add cranes for adding boom/tip details*
Hooks	*Main hooks form displayed from Rigging Switchboard*
Hooks Subform	*Subform to Add Cranes for defining hooks*
JibAngles	*Subform for offset angles on Jib information subform*
JibInformation subform	*Subform on Add cranes for jib information*
Jibs_Length	*Defines lengths, stowed weights & erected weights of jibs.*
Jibs_Definition	*Subform to Jibs_Length. Holds component list and data.*
Lift Details2	*Main form for adding lift capacities - holds crane equipment info.*
Lift_Cables subform	*Used with Lift_Settings to specify cables to use with a lift*
Lift_Capacity subform	*Subform to Lift_Settings storing capacity, zone & outrigger settings*
LiftHooks subform	*Used with Lift_Settings to specify hooks to use with a lift*
Lift_Settings	*Subform to Lift Details2. Stores boom & accessory information*
LoadingMsg	*Asks user to wait: Loading form, please wait....*
MainShackles	*Form for adding shackle data*
MainSlings	*Used for adding slings data*
MainSpreaders	*Collects information about spreader beams*
MsgReference subform	*Used with Lift Details2 to display the wording of the notes*
RiggingSwitchboard	*Displayed when rigging hardware is selected*
SpreadersCaps SubformTRIAL	*Allows entry of capacities under Main Spreaders*
Switchboard	*Main front end menu for the database.*
Tempstart	*Temporary and undocumented - will be removed.*

4.2 Crane Selection Module Implementation

This module is used to assist in selecting the appropriate cranes, i.e. technically feasible, allowing for the choice of the least costly option. Though the module is required to undertake a set of calculations and computing efforts to search through a large number of data stored in the database about crane configurations and lift settings, users would want a system that requires as few parameters as possible. To achieve the goal of simplicity, a solution based on just one form was chosen. The primary tool for the collection of information on the project is the multi-page tab controls with five main input-screens. This solution requires careful design of the forms and data structure, accounting for the module and user requirements. For illustration purposes a numerical example based on an actual case is considered in this chapter.

> *The case considered involves the replacement of the top portion of the main burner for a paper pulp manufacturer, located in Quebec, Canada. Gazes from the burned material in the main burner cause corrosion to its top portion, a common problem in the pulp and paper industry, particularly for plants built during the past four decades. The only feasible solution to the problem is to cut and replace its top portion, which weighs 165,344lb (75,000kg) and is encased within a 225ft (67m) high facility. This solution requires selecting an appropriate crane to perform the lift. The site in this case was very congested. The burner is located within the 225ft (67m) high facility, surrounded by other buildings, which obstructed the crane reach. These building obstructions added 51ft (15m) of horizontal distance at a height of 80ft (24m).*

The lift weight and its key dimensions are entered first as shown in Figure 4-27. Then the user is provided with an option to select the rigging equipment from those stored in the rigging database or alternatively to enter the height and the weight of the rigging of his/her choice as shown in Figure 4-27. Unless entered by the user, the selection module generates a default value for the rigging's weight and height as 10% of the lift weight and 10ft (3m) high respectively. For this particular case two slings 36ft (10.97m) long, weighing 3,249lb (1,473.75kg), and a 5,000lb (2,268kg) hook block were selected. The hook block weight is not considered all the time because some of the load-charts for some crane models include the weight of the hook block as part of the given crane lifting capacity. The shape of the building, the final lifts location, and the site constraints are entered next as shown in Figure 4-28.

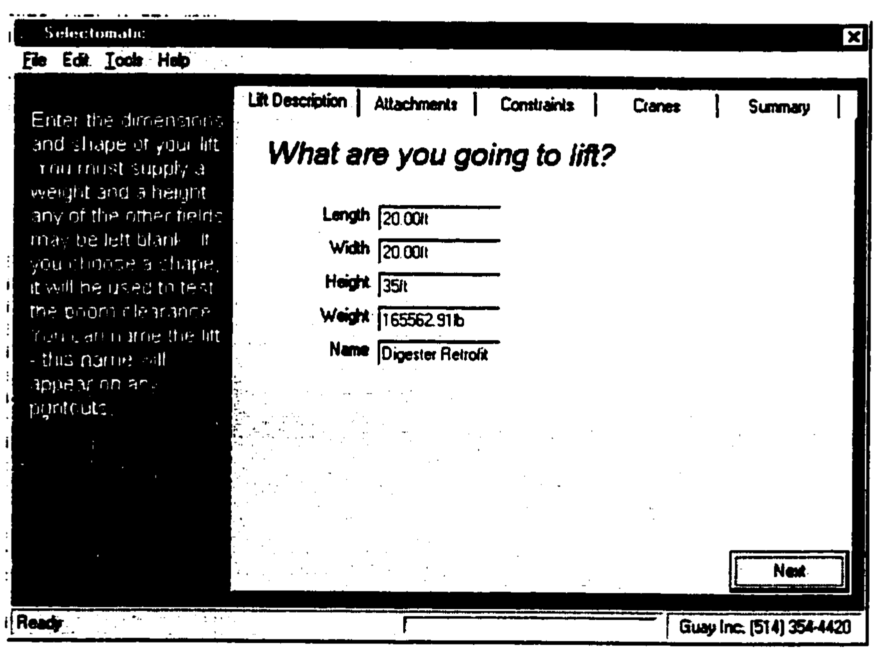


Figure 4-27 Crane Selection Module Weight Evaluations Tap-Form

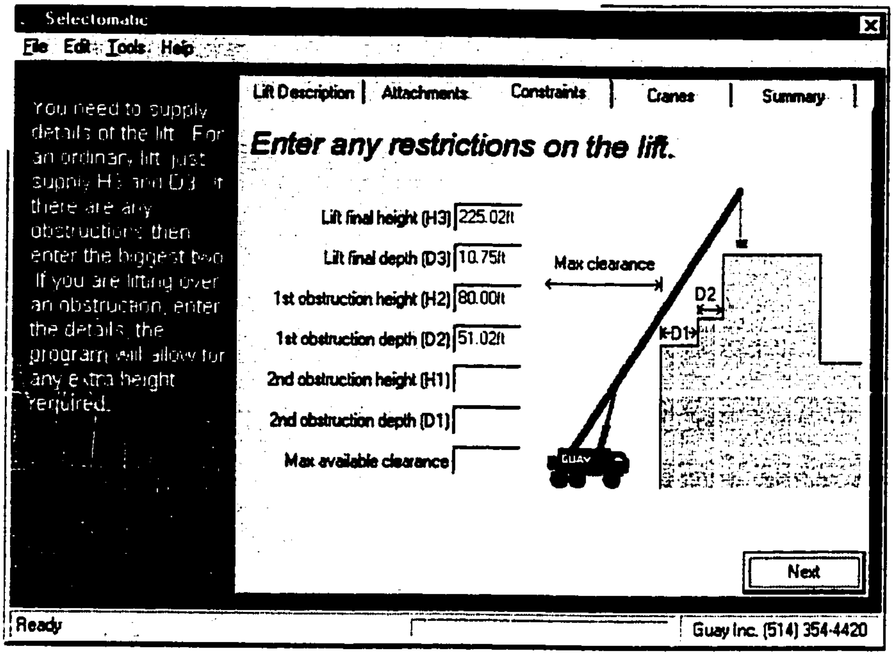


Figure 4-28 Crane Selection Module Site Evaluations Tap-Form

Three (3) levels of obstructions are allowed for the user to input along with the maximum allowable radius on ground, which is considered during the evaluation of the crane fitting on the site. In addition, the user is provided with the flexibility to account for the boom clearance to the building by accepting the default value of one foot (1ft) (0.305m) or alternatively, consider a value of his/her own.

The search for technically feasible crane configurations and their lifts settings starts by choosing the "list cranes" option, shown in Figure 4-29. To limit the search and increase the searching speed the selection module provides the following options: 1) limiting the search by choosing a manufacturer's name; 2) selecting a particular crane model; 3) selecting a crane type (conventional or hydraulic); and 4) choosing a particular boom and/or jib length. This step ends by displaying a list of technically feasible crane configurations and their lift settings, ranked in a descending order based on their rental costs. The list shown contains 11 different lift settings that are capable of carrying the lift. These lift settings are generated from two configurations of the Demag TC 4000 crane (i.e. lifting on the main boom and a main boom with a luffing jib installed). The highlighted Demag TC 4000 with boom length of 354ft (107.89m), a radius of 112ft (34.14m), and a lifting capacity of 174,000lb (78,926kg) was selected.

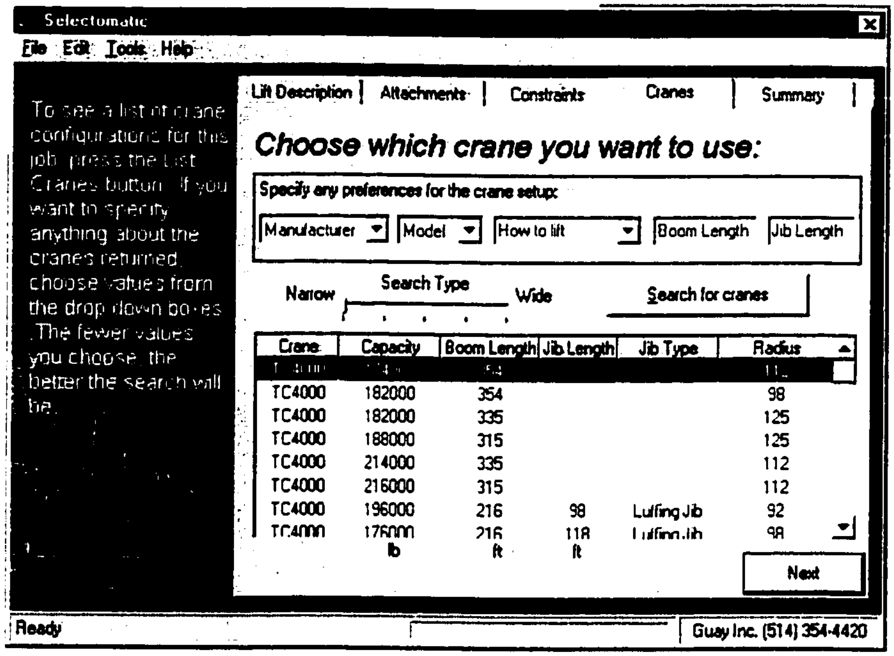


Figure 4-29 Crane Selection Module List of Technically Feasible Cranes Form

Upon choosing a particular crane configuration and a lift setting from the list, more details about these particular configuration and lift settings are displayed in the summary screen shown in Figure 4-30. This screen displays information, which includes the type of crane, lifting radius, tip height, boom and jib lengths, boom and jib angles, clearances, and crane capacity. In addition, this summary report includes the results of the lift evaluation, analysis, i.e. the percentage of lift to the crane lifting capacity. Finally report as shown in Figure 4-31, that can be printed, or viewed on screen, is produced, which includes a summary of relevant information about the project, crane configuration, lift capacity, clients and names of participants, along with a 2D-elevation view of the crane and the building. The report contents are stored in a separate transactional ***project database***.

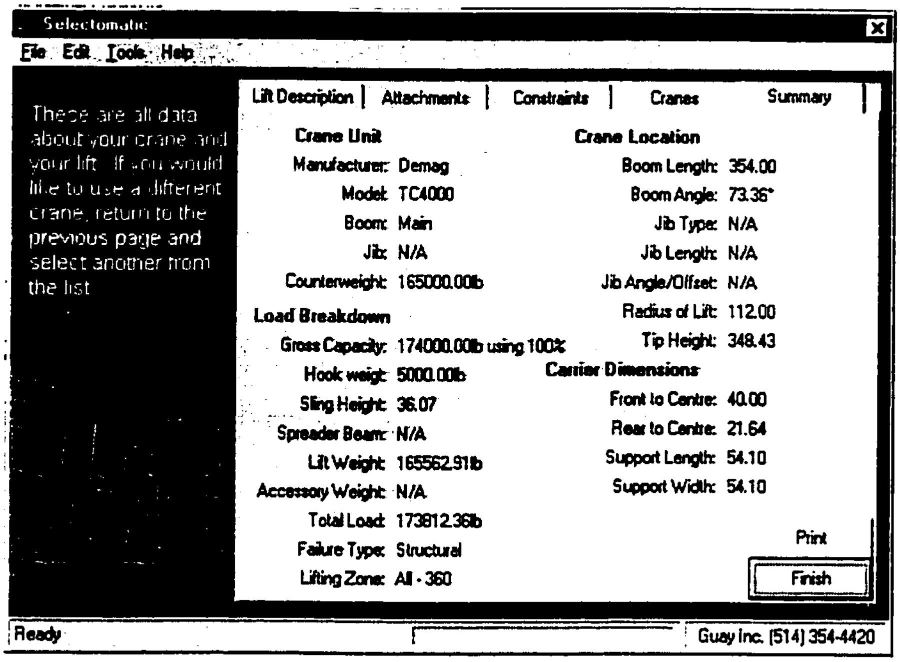


Figure 4-30 Crane Selection Module Crane Summary Tap-Form

Lift Plan Details

Building Information			
H1:	ft	D1:	ft
H2:	151ft	D2:	26ft
H3:	197ft	D3:	72ft
Max Radius:	ft		
Min Boom Clearance:	N/A		

Contact	Alain Dubuc
Company	Concordia University HVAC System
Address	1255 rue St-Amour
Address	
City	Ville St-Laurent
Province:	Qc
Post Code	H4S 1T4
Telephone	(514) 336-5717
Fax	(514) 336-8757

GUAY

Branch: Montreal
Sale's Rep.: Gaston
Date: 8/26/99

Lift Dimensions

Length:	23ft
Width:	23ft
Height:	10ft

Capacity Information

Lift Weight:	40000lb
Sheave Block	4938lb
Slings	1201lb
Spreader Beam	N/A
Total lift weight	**46139lb**
Gross Capacity	**49800lb**

Crane Unit

Manufacturer:	Demag
Model:	TC2000
Boom:	Main
Accessory:	Jib
Counterweight:	lb

Carrier Dimensions

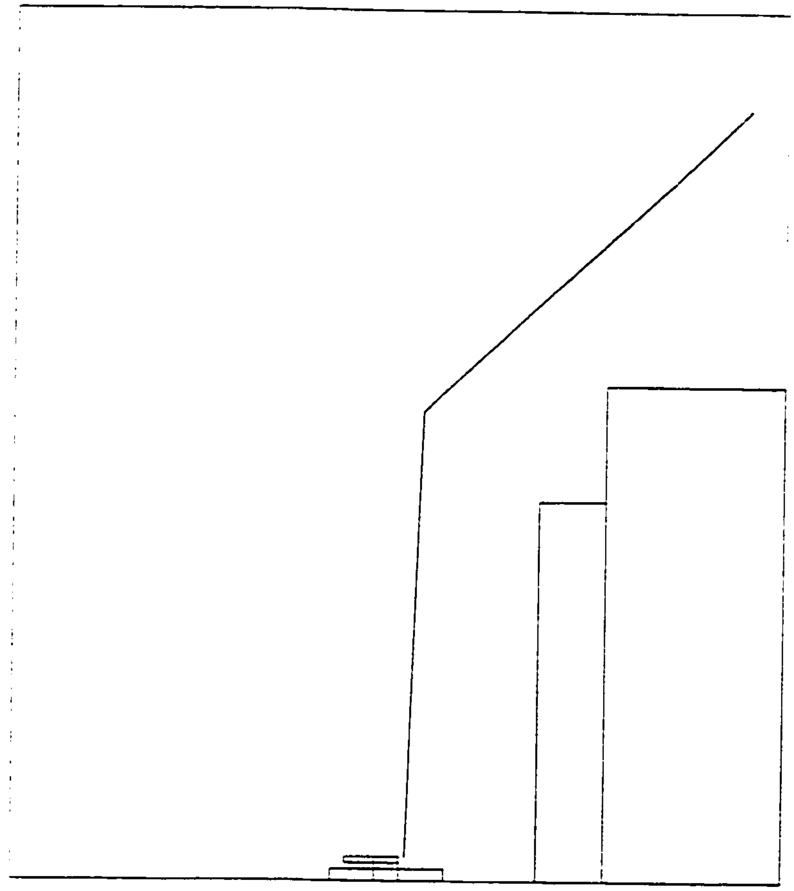
Front to Centre:	32
Rear to Centre:	22
Support Length:	46
Support Width:	46

Crane Location

Boom Length:	177
Boom Angle:	88°
Jib Type:	Luffing Jib
Jib Length:	177
Jib Angle/Offset:	45.26°
Lift Radius:	151
Tip Height:	308
Failure Type:	Structural
Lifting Zone:	All - 360

Equipment/Attachment

Sling Height:	10



Notes

1)Capacities do not exceed 85% / 75% of tipping load. 2)Maximum wind pressure: 15 kg/m2: approx. 15.5 m/s (85%) and 25 kg/m2: approx. 20 m/s (75%). 3)Crane operation up to a wind force of 5 degrees Beaufort scale (5 kg/m2: approx. 9 m/s) permissible. 4)The weights of all load-handling devices are considered part of the load, and suitable allowance should be made for them 5)The 75% crane ratings furthermore comply with DIN 150 19,2 (test load = 1.25 x lifting load + 0.1 x dead weight of boom reduced to the boom point). 6)Based on a main boom angle of 88 degrees.

Gross Capacity: *The maximum weight of the load to be lifted including hook block, slings, lifting beams, etc.*
Working Radius: *Maximum distance from the centre of rotation to the hook block.*

Figure 4-31 Crane Selection Module Lift Plan Report

Project Database: The purposes of the project database are:

1) To store data about the project on hand (i.e. information about the lift, the client, and the site),
2) To store information, that could be retrieved for further evaluation and/or modification.
3) To be used as a reference book for the users (sales representatives), were client information (company name, contact names and methods of communications, addresses, and telephone numbers), which can be used for other projects.
4) To be used at the management level for evaluation of resources performance and client satisfaction.
5) To reduce the manual effort involved in data-transaction for the sales representative to the office.

This database is a transactional database i.e. it is filled with information any time it is used. Figure 4-32, shows the screen for data-retrieval used in the crane selection module and Figure 4-33, shows the form used for data-entry. Numerical data is stored in metric units and retrieved as metric, but could be modified on screen should the user choose the imperial unit option.

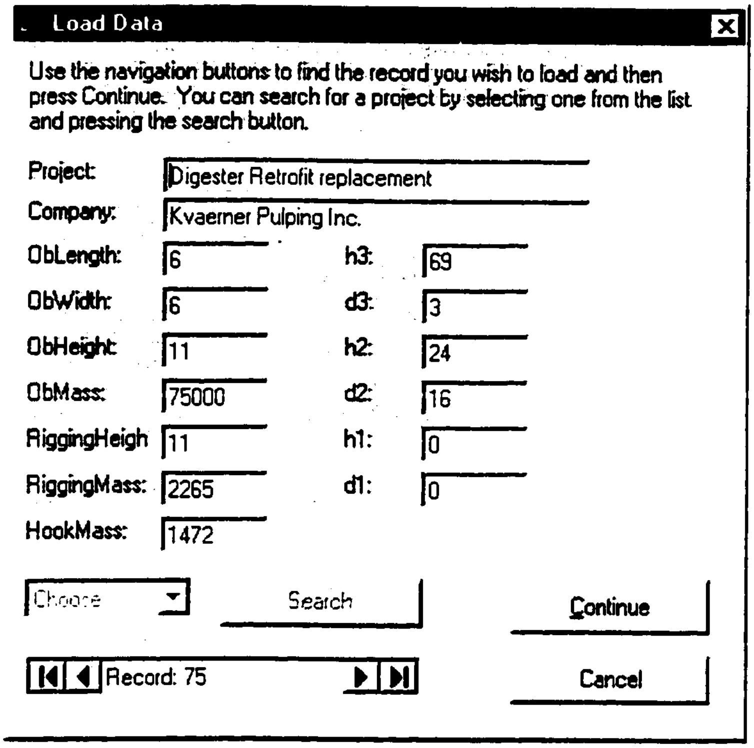


Figure 4-32 Projects Database "Project Selection Form"

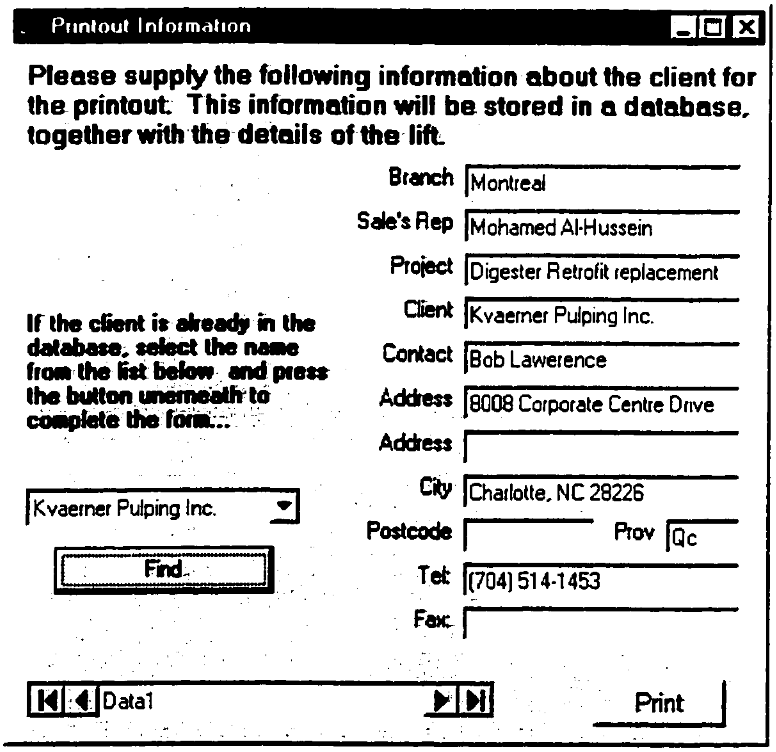


Figure 4-33 Projects Database "Project Data Entry Form"

4.3 OPTIMISATION MODULE IMPLEMENTATION

The optimization module was developed using Ms-Solver incorporated within Ms-Excel. In the spreadsheet shown in Figure 4-34, the module was designed in nine (9) different panels to distinguish between the crane and the site elements. The first two describe the heights needed of the buildings, the load, the slings, and the spreader beams. The cable length is calculated to give the user the option of evaluating the clearances and the allowable height of the lift. The third panel describes the widths (i.e. the load, the spreader beam, and the buildings). The forth panel represents the constraints imposed by the lift, the site, and the crane. These constraints are evaluated to calculate the clearances shown under the picture of the crane shown in Figure 4-34. The other set of constraints are in the seventh panel, which represents the constraints regarding the specific information about the crane, namely the minimum and maximum boom length and angle and the lifting radius. The eighth panel provides the calculated values for distance of the carrier of the crane to the building, the cable length excluding the minimum clearance and the boom length and angle to ground. The final, the ninth panel, is the objective function to provide the minimum or maximum lifting working radius.

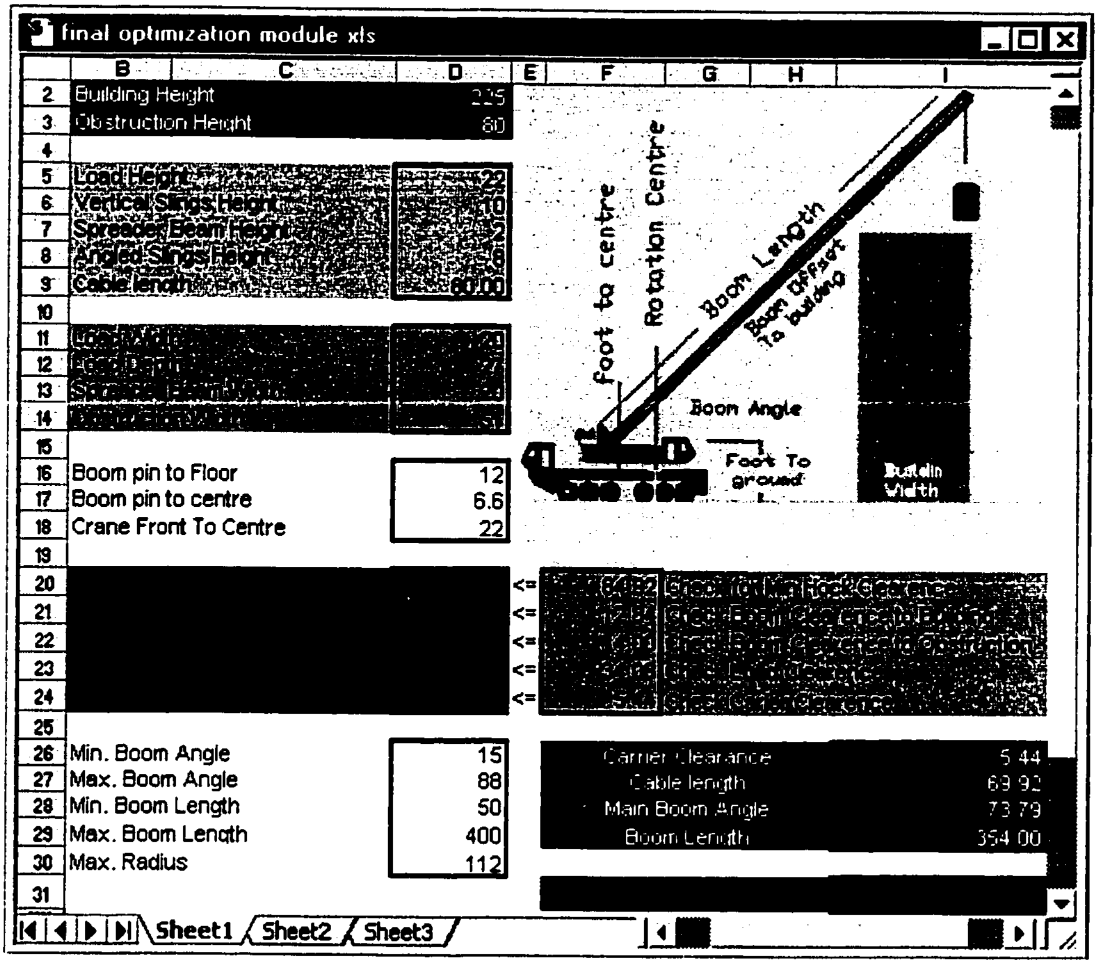


Figure 4-34 Ms-Excel Version of the Optimization Module

To avoid potential errors, MS-Visual basic was used to facilitate the user interface in a menu driven application supported by graphics. Two main forms were designed. The first, as shown in Figure 4-35, allows the user to input the main parameters about the crane and the building, while the second provides the results, as shown in Figure 4-36. The values shown in the figures are from the crane and the site in the case study. Alternatively, the cranes and rigging database could be linked to the optimization module to provide the information needed about the crane and the rigging equipment. The results are derived using an SQL statement, which calls Ms-Solver, defines the constraints, and the objective function. Ms-Solver is called twice to set the objective function to calculate the minimum radius and the maximum radius. In addition, each radius (minimum or maximum) is calculated along with its reference clearances (i.e. clearance of the crane and its boom to the building and the clearance of the lift to the boom).

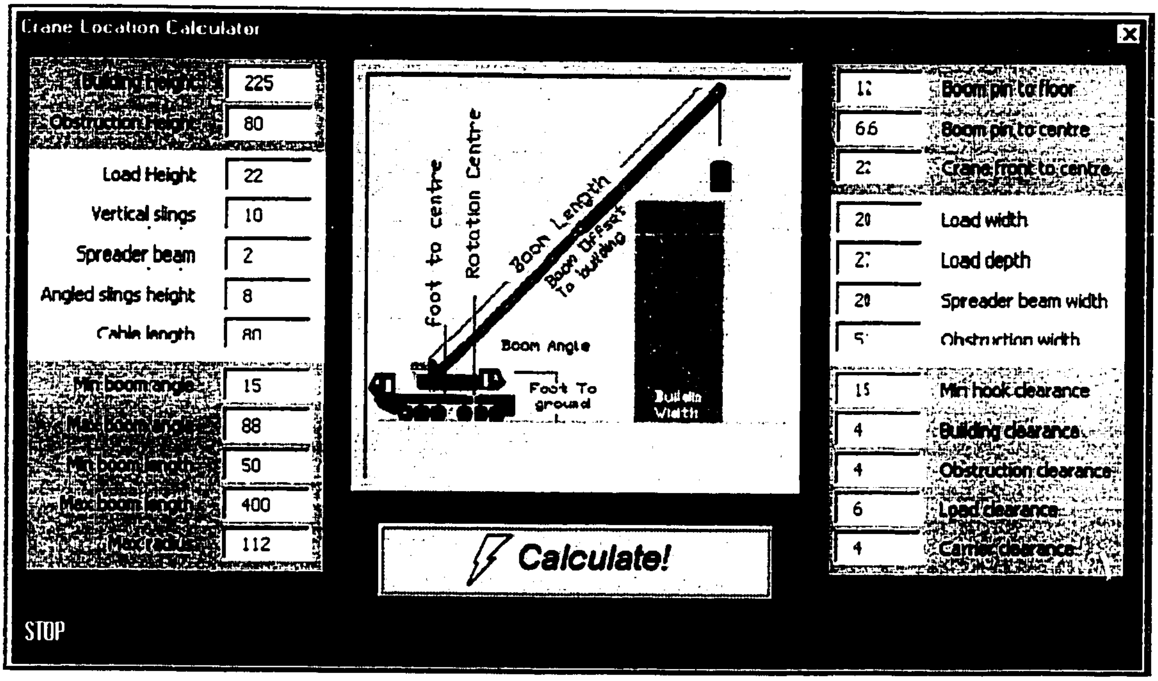


Figure 4-35 Ms-Solver Optimization Module Data Entry Form

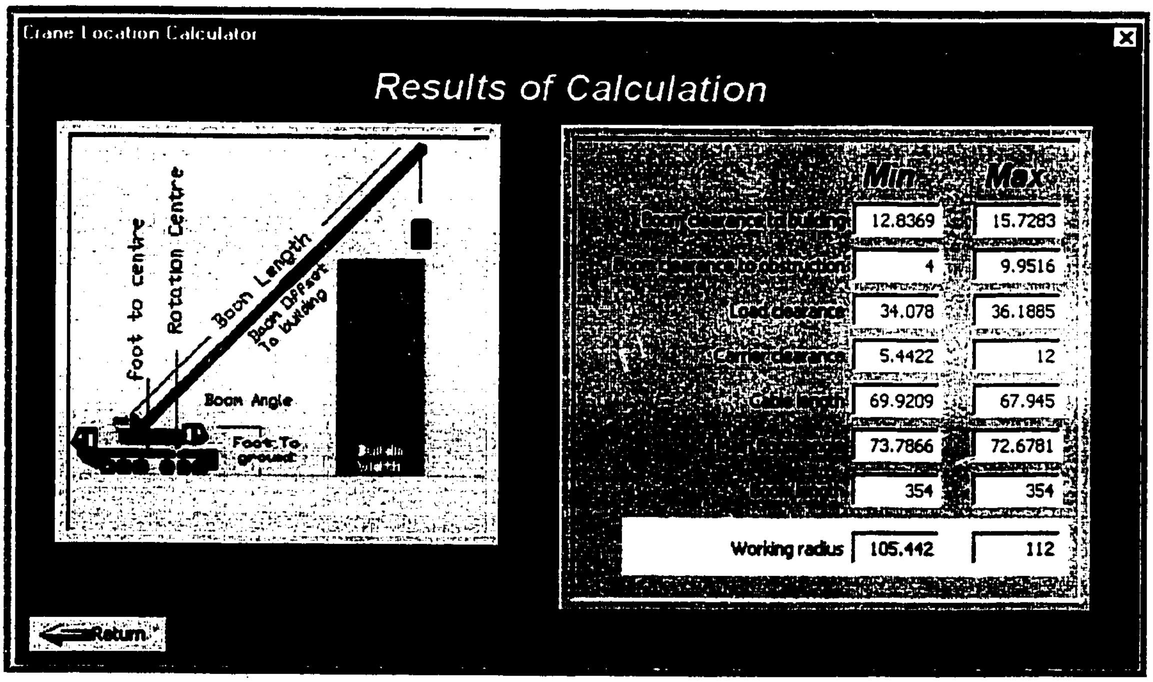


Figure 4-36 Ms-Solver Optimization Module Output

4.4 3D-Graphics Modules Implementation

Virtual simulation proves to be an effective tool to aid engineers and practitioners in visualizing and "walking through" the whole operation at a marginal cost, compared to the costs involved in cases of error and/or bad judgement. The use of 3D graphics for selecting and locating cranes is not common in the crane industry. Except for some limited cases 3D is not used, at least on a full scale. This section described the development and implementation of a 3D graphics module, using AutoCAD 3D-Solids and the 3D module using 3D Studio. These two modules are designed to represent the geometrical characteristics of the crane, lift, rigging, and site.

4.4.1 3D Graphics Module

This module is developed to aid practitioner in producing lifting plans using AutoCAD as a drafting tool. AutoCAD 3D-Solids were utilized to represent the physical site layout and crane components. The developed system currently has 12 different crane models drawn in AutoCAD-3D-Solids. The geometry of these cranes is stored in of 3-D module library database. These cranes vary in capacities from 140 tons to 880 tons (five (5) conventional, five (5) hydraulic, and two (2) crawler cranes). This set of cranes provides 76 options of different crane lift configurations. To reduce the AutoCAD operators' time in assembling the cranes' components for a new job, these crane configurations were further assembled and joined together to match the configuration required for different lift settings. These assemblies are defined to represent different boom lengths for lattice boom (conventional boom) configurations and different jibs/extensions lengths as well.

The developed 3D graphics module can best be described through a case example, where one can also demonstrate its advantages.

The same case cited above is used again, due to the considered site constraints a number of special arrangements had to be made:

1) The crane's outriggers had to be set between existing reservoirs and nearby facilities, and their mats (steel plates used to distribute the total load of the crane and the lift to the ground) had to be rotated to fit the crane's outriggers on site. This necessitated engineering analyses, evaluation, and approval prior to the execution of the lift.

2) The plan was to swing the crane 300° degrees in order for it to carry the lift to its final position, and due to the site accessibility problem, the initial lift pick-up was limited to that planned location.

3) The boom clearance to the obstruction is only 2ft (0.61m), which is a small distance for such a crane with a 354ft (107.89m) long main boom configuration at a 112ft (34.14m) radius, operating in its full capacity. This crane uses a conventional (lattice) boom, which allows for deflection, which is not considered in the calculations of the crane selection module.

The AutoCAD-3D-Solids module was used to assist in solving these problems and to produce lifting plans for the approval of the engineers and safety officers. The selection module cited above advises on selecting the Demag TC4000 with a boom length of 345ft (107.89m) at a working radius of 112ft (34.14m). The 3D graphics module shows that the crane's mats (located at locations A and B in Figure 4-38) have to be rotated in order to fit its outriggers on site.

The 3D module also shows that the tail swing of the crane will collide with the nearby building. As a result, the site has to be cleared and the lift delivered to a new location within the allowable swing of 150°, not 300° degrees as shown in Figure 4-37. The elevation view shown in Figure 4-39 also demonstrates that the main boom of the crane, without accounting for its elastic deflection, passes at a very small distance, i.e. 2ft (0.61m), from the wall of the nearby building (see point A in Figure 4-39).

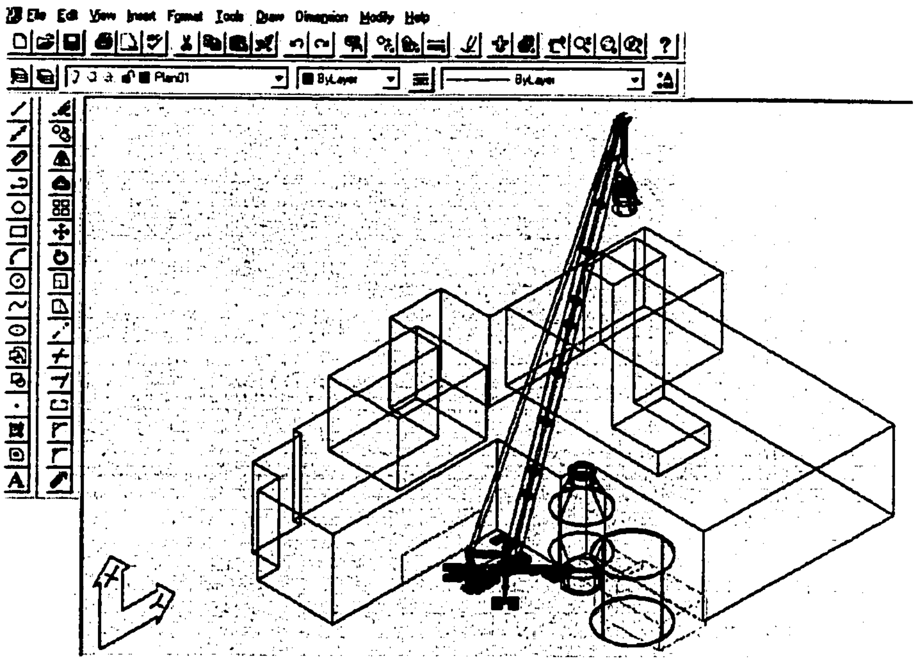


Figure 4-37 View of Case 1

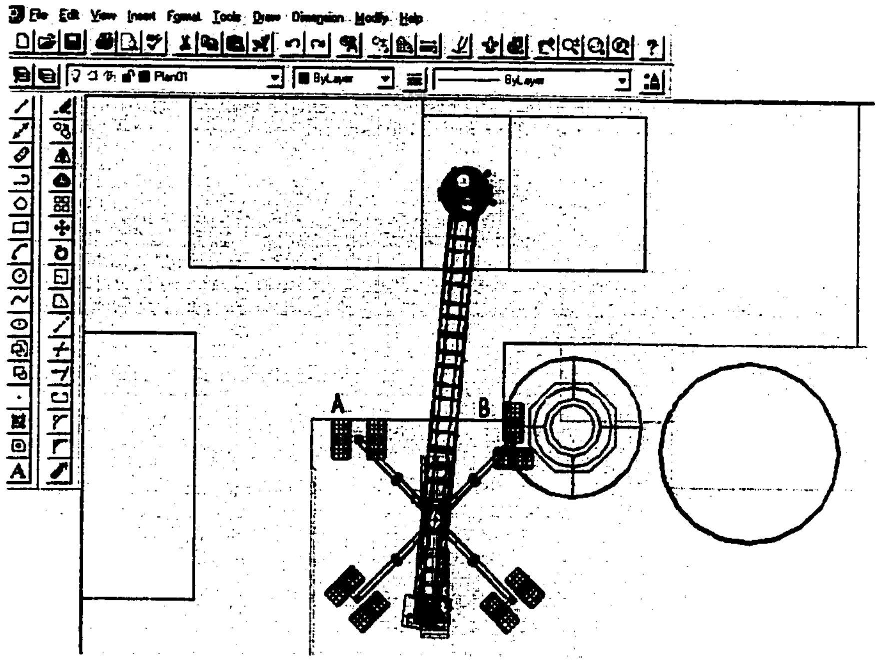


Figure 4-38 Plan View of Case 1

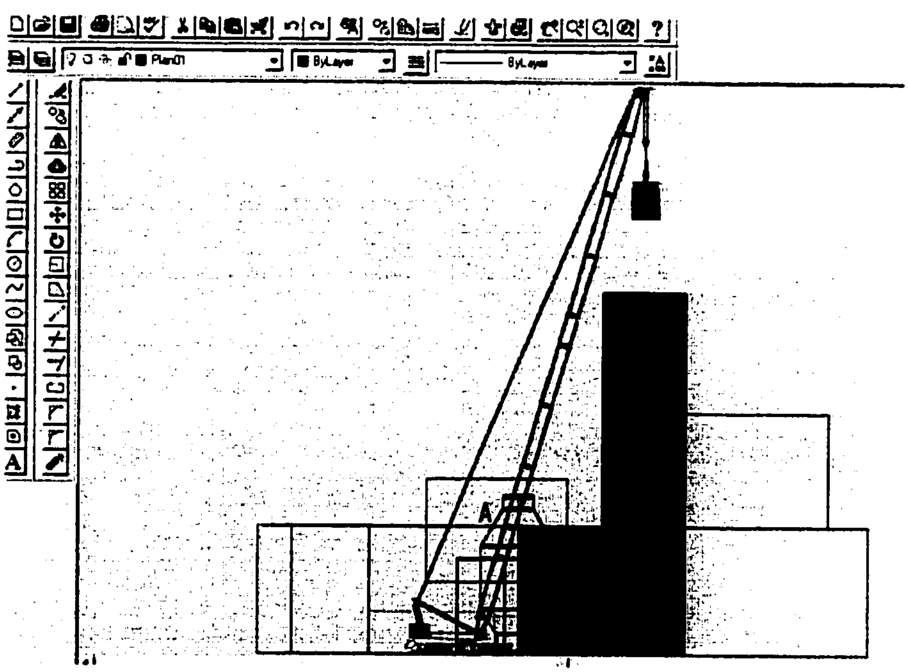


Figure 4-39 Elevation View of Case 1

4.4.2 3D- Animation Module

This module is designed to aid planning engineers and safety representatives to visualize the lift operations on screen. AutoCAD-3D-Solids drawing were transferred to the virtual simulation software 3D-Studio, to allow for on screen visualization of the entire operation, depicting the crane's relative position and its components to the nearby facilities. The same case example used in the previous section is used heir to allow for comparison and reduce the text involving project description. The 3D- animation module supported the same findings, i.e. the crane's mats, which have to be rotated to fit the crane's outriggers on site between the existing reservoirs and nearby facilities, as shown in Figure 4-40.

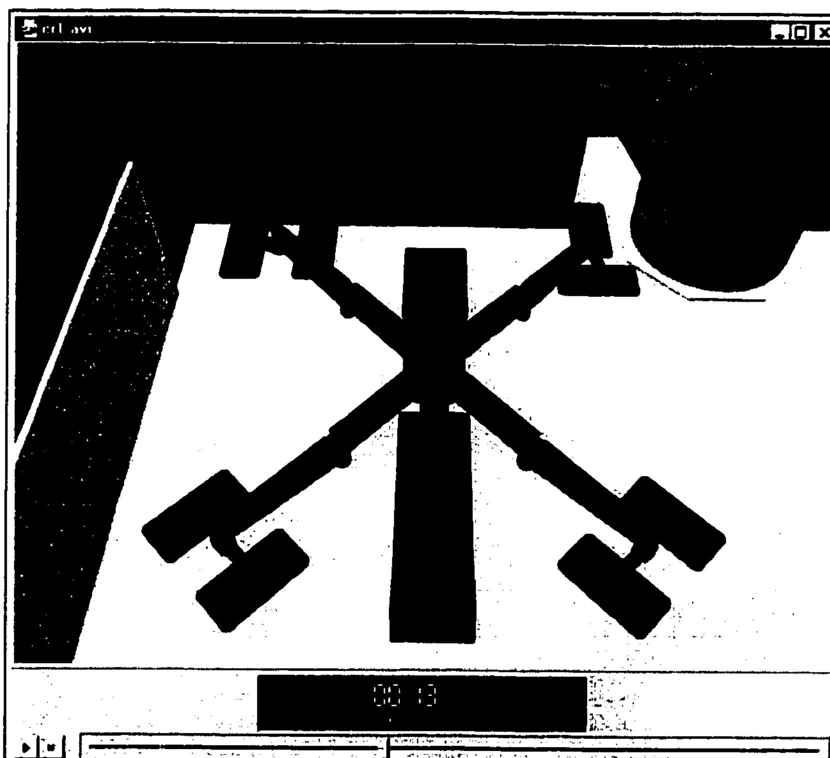


Figure 4-40 Animated Plan View of Case 1

The 3-D animation module also shows that the tail swing of the crane will collide with the nearby building as shown in Figure 4-41. As a result, the site has to be cleared and the lift has been delivered to a new location within the allowable radius of 150°, not 300° degrees as originally planned.

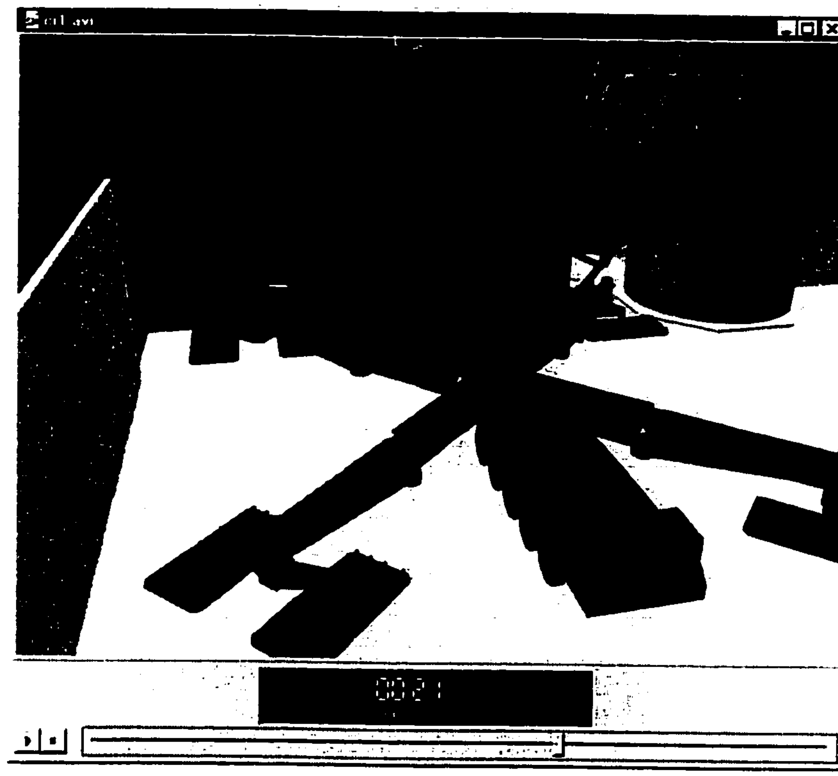


Figure 4-41 Animated 3D View Case 1

The view shown in Figure 4-42 also demonstrates that the main boom of the crane passes at a very small distance, from the wall of the adjacent facility. The 3-D animation model provided a robust visualization tool, helping to reveal the fact that the cladding of the building had to be removed to prevent a potential collision between the deflected main boom and the wall. As a result, the wall was stripped down prior to the crane's arrival, as shown in Figure 4-43.

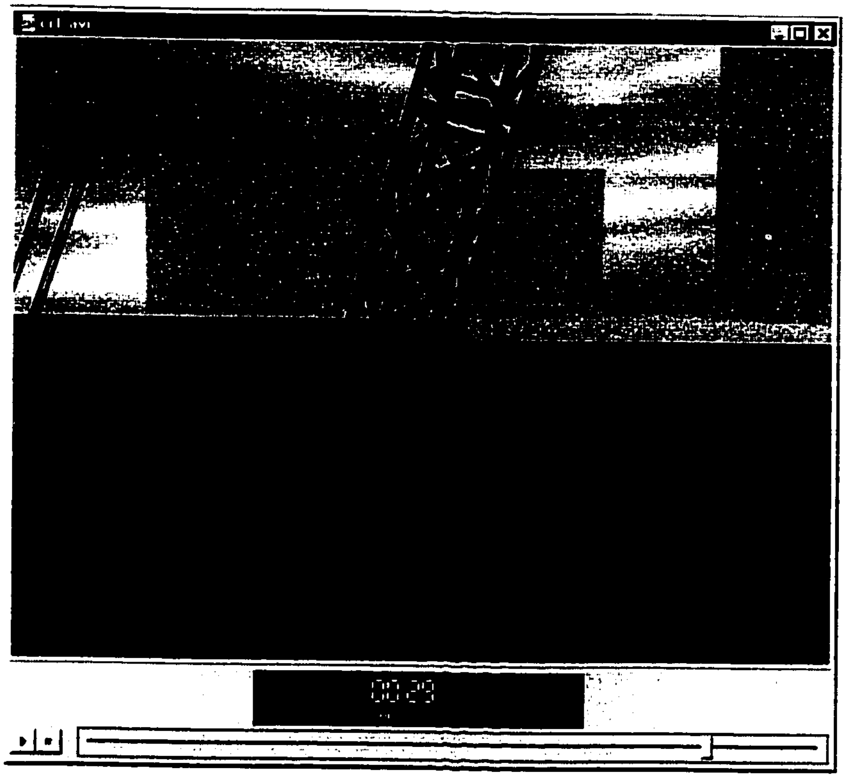


Figure 4-42 Animated Elevation View of Case 1

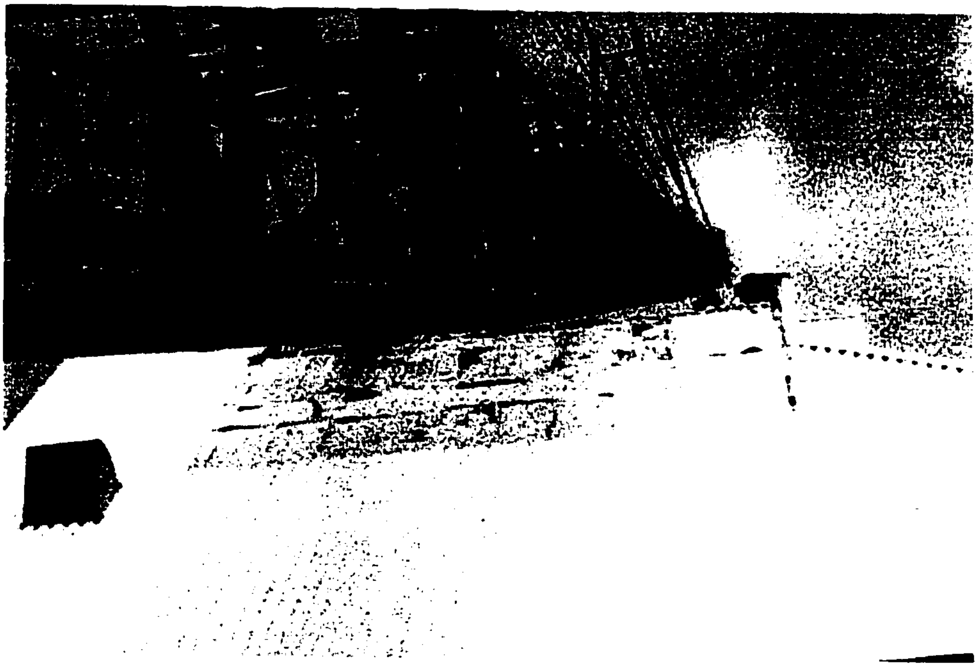


Figure 4-43 Picture Boom Deflection & Removed Cladding (Case 1)

Failure to identify these necessary on-site changes would have clearly resulted in cost over-runs and unsafe crane operation. The crane would have been sitting idle while waiting for the claddings to be removed and lift plans to be approved. Guesswork was reduced and unsafe and time consuming on site testing was eliminated. The cost savings in this particular case were compounded in view of the unexpected four-day (4) delay in the delivery of the cranes' carrier (The crane body, engine, and tires) to the job site. A crew of four (4) operators, all crane components (i.e. Boom elements, mats, outriggers, counterweights, and rigging equipment) and two (2) assisted cranes (a 100 tons conventional and a 34 tons all terrain), which will eventually erect the selected TC 4000 crane and its components, were, however on the site. The developed system allowed the planers to assemble and position the crane and particularly its support structure (i.e. outriggers and mats) circumventing the negative impact of the delay.

The concept of 3-D modeling and animation has also increased the efficiency of designers and planers. Once the site is drawn in 3-D and the crane and lift are placed, the planner can easily generate any number of views for evaluation and assessment prior to the approval of the planes for executing the lift. The clients' engineers and safety representatives received the report along with nine (9) different 2-D and 3-D drawings (see Appendix E) of the lift operation, along with the 3-D animation file to show the entire crane operation similar to the view shown in Figure 4-44. This expedites the work of safety officers in order to facilitate approval of the lifting plans.

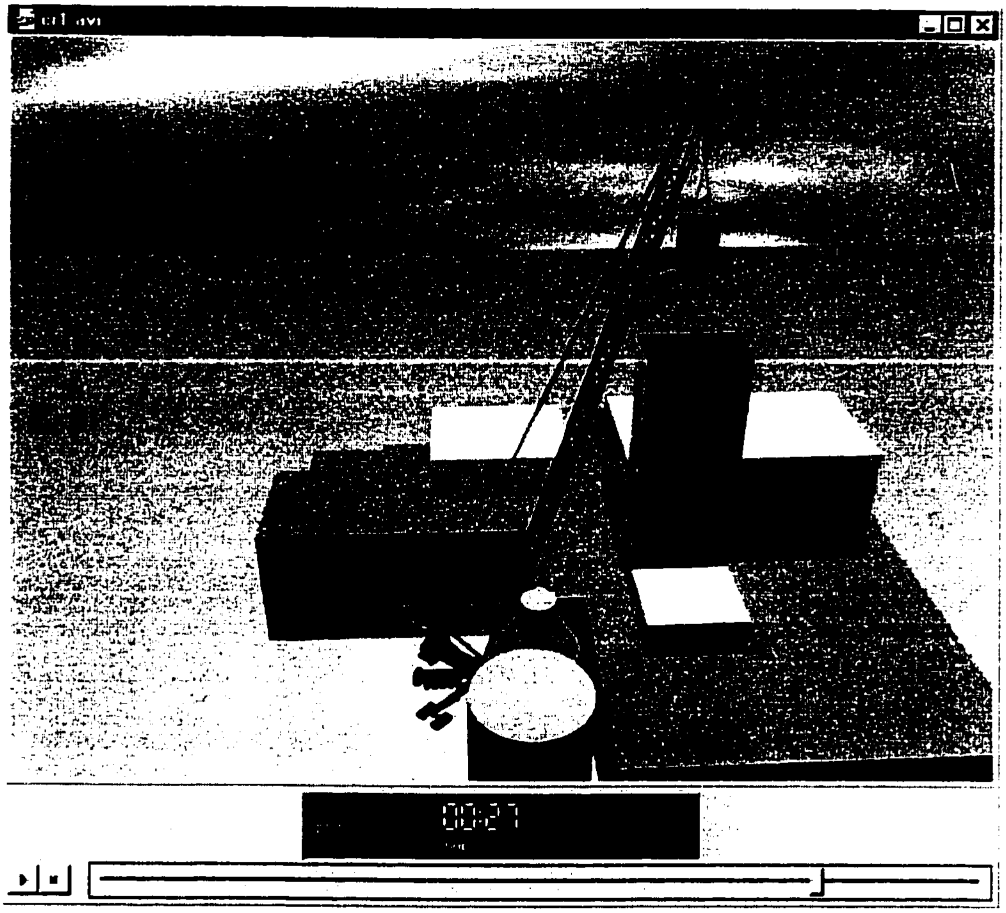


Figure 4-44 Animated Full View of Case1

4.5 UNIT ISSUES

All the data in the database are metric. This is essential for the calculations used both within the database application and in external models to work properly. Unifying the data also makes model development easier, as calculations do not have to be updated for either metric or imperial format. Forcing the user to enter only metric values, however, is counter-productive, as many North American cranes have data available in imperial format only.

The routine *Unit-Change* is self-contained. The *On-Exit* event for each control that takes dimensional data calls the Unit-Change function with two arguments: 1) the data from the control and 2) the type of data required using numeric codes. The function analyses the data string in an attempt to determine the unit type. If successful, it then checks that the type is consistent with that required. For example, if a length is required, units should all be linear. If there is a mismatch, the length of a boom is entered as 56kg, for example, the user is notified (the value entered is not liner) and the value is deleted. If no units are found, the user is also warned. Assuming the values entered pass the tests, any imperial values are converted to their metric equivalents and the units are stripped from the string. The units are always displayed next to the control to avoid any confusion.

This implementation of the metrification system thus allows any units to be entered in any control: for example 5.5ft, 5.5pi, 5'6 and 5'6" are all valid. Where metrification is not required (for example on dimensionless data) the call function for the routine is omitted from the programming to allow data to be entered normally. Positive feedback is provided to the user in that the results of the conversion are seen immediately.

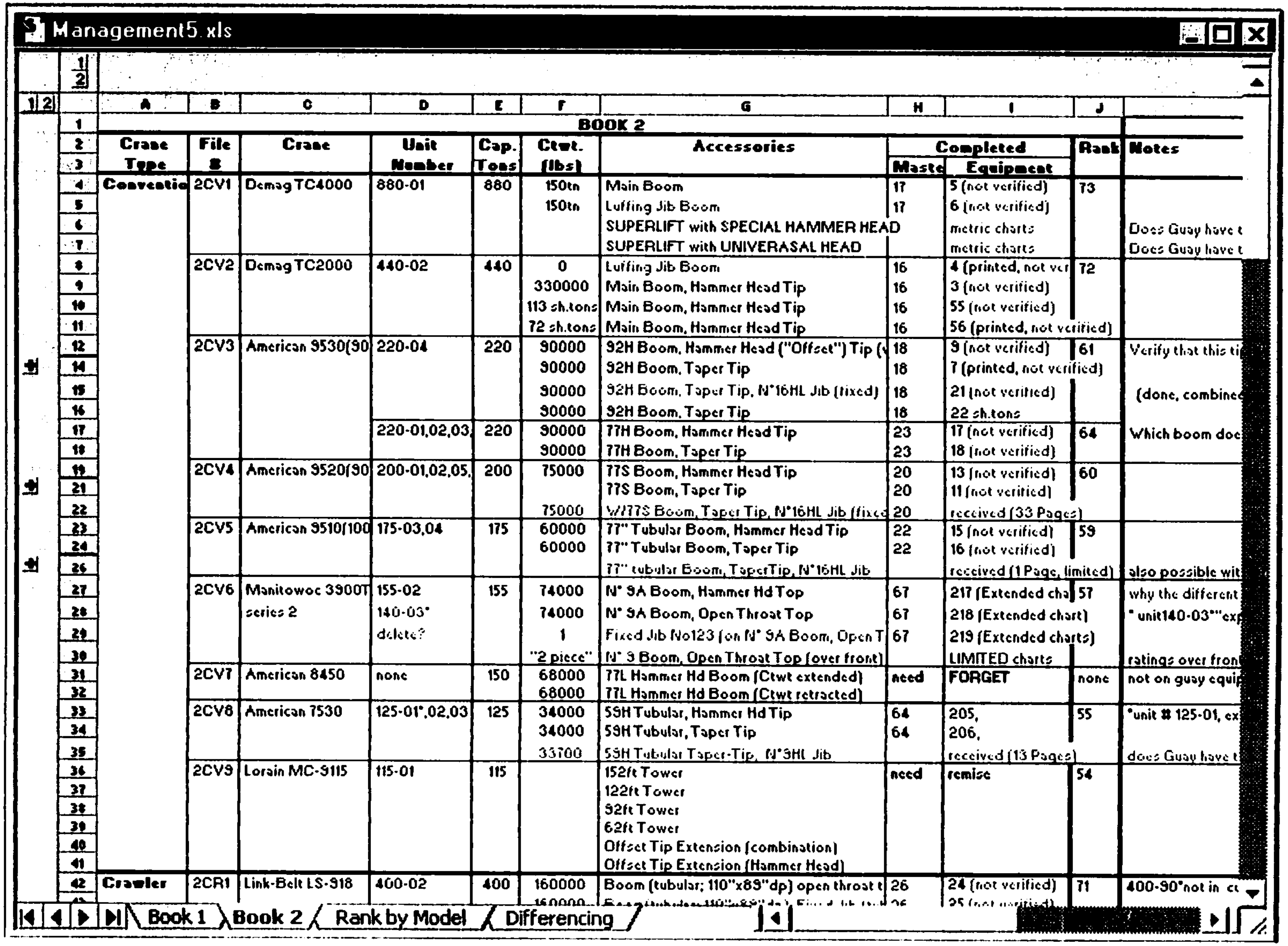
Chapter 5 SYSTEM PERFORMANCE

5.1 MANAGING THE DATA ENTRY

Entering the data in the database is a one-time process. which should be as simple as possible for the user (operator) and ensure few (if any) errors in the database. This task was achieved at two different stages: 1) operators training on the use of the software Ms-Access and on the feature of the developed database system, 2) establishing a methodology for the management of the data-entry and control system.

1) **Operators training:** The operators were given the opportunity to explore the software housing the developed Cranes Database in a classroom and they were given a handout explaining how to use both the database and the software. An example of these handouts is presented in Appendix A:

2) **Data-Entry Methodology:** Cranes in the sponsoring company are divided. based on their lifting capacities, into two main categories: 1) cranes with a lifting capacity of less than one hundred tones: 2) cranes with a lifting capacity of more than one hundred tones. Furthermore, they are sub-divided based on their type into the following six groups: Lattice Boom Cranes, Truck Cranes. Hydraulic Cranes. Crawler Mounted Cranes, Rough Terrain Cranes, and All Terrain Cranes). Cranes with a lifting capacity of less then one hundred tones also include Boom Trucks. This configuration was adapted during the data-entry process and two book sheets were structured in Ms-Excel, as shown in Figure 5-1. For a complete list refer to Appendix C.



	A	B	C	D	E	F	G	H	I	J	
1						BOOK 2					
2	Crane	File	Crane	Unit	Cap.	Ctwt.	Accessories	Completed		Rank	Notes
3	Type	#		Number	Tons	(lbs)		Maste	Equipment		
4	Conventio	2CV1	Demag TC4000	880-01	880	150tn	Main Boom	17	5 (not verified)	73	
5						150tn	Luffing Jib Boom	17	6 (not verified)		
6							SUPERLIFT with SPECIAL HAMMER HEAD		metric charts		Does Guay have t
7							SUPERLIFT with UNIVERASAL HEAD		metric charts		Does Guay have t
8		2CV2	Demag TC2000	440-02	440	0	Luffing Jib Boom	16	4 (printed, not ver	72	
9						330000	Main Boom, Hammer Head Tip	16	3 (not verified)		
10						113 sh.tons	Main Boom, Hammer Head Tip	16	55 (not verified)		
11						72 sh.tons	Main Boom, Hammer Head Tip	16	56 (printed, not verified)		
12		2CV3	American 9530(90	220-04	220	90000	92H Boom, Hammer Head ("Offset") Tip (v	18	9 (not verified)	61	Verify that this ti
14						90000	92H Boom, Taper Tip	18	7 (printed, not verified)		
15						90000	92H Boom, Taper Tip, N°16HL Jib (fixed)	18	21 (not verified)		(done, combine
16						90000	92H Boom, Taper Tip	18	22 sh.tons		
17				220-01,02,03,	220	90000	77H Boom, Hammer Head Tip	23	17 (not verified)	64	Which boom doe
18						90000	77H Boom, Taper Tip	23	18 (not verified)		
19		2CV4	American 9520(90	200-01,02,05,	200	75000	77S Boom, Hammer Head Tip	20	13 (not verified)	60	
21							77S Boom, Taper Tip	20	11 (not verified)		
22						75000	W/77S Boom, Taper Tip, N°16HL Jib (fixe	20	received (33 Pages)		
23		2CV5	American 9510(100	175-03,04	175	60000	77" Tubular Boom, Hammer Head Tip	22	15 (not verified)	59	
24						60000	77" Tubular Boom, Taper Tip	22	16 (not verified)		
26							77" tubular Boom, TaperTip, N°16HL Jib		received (1 Page, limited)		also possible wit
27		2CV6	Manitowoc 3900T	155-02	155	74000	N° 9A Boom, Hammer Hd Top	67	217 (Extended cha	57	why the different
28			series 2	140-03*		74000	N° 9A Boom, Open Throat Top	67	218 (Extended chart)		* unit140-03**exp
29				delete?		1	Fixed Jib No123 (on N° 9A Boom, Open T	67	219 (Extended charts)		
30						"2 piece"	N° 9 Boom, Open Throat Top (over front)		LIMITED charts		ratings over fron
31		2CV7	American 8450	none	150	68000	77L Hammer Hd Boom (Ctwt extended)	need	FORGET	none	not on guay equip
32						68000	77L Hammer Hd Boom (Ctwt retracted)				
33		2CV8	American 7530	125-01*,02,03	125	34000	59H Tubular, Hammer Hd Tip	64	205,	55	*unit # 125-01, ex
34						34000	59H Tubular, Taper Tip	64	206,		
35						33700	59H Tubular Taper-Tip, N°3HL Jib		received (13 Pages)		does Guay have t
36		2CV9	Lorain MC-9115	115-01	115		152ft Tower	need	remise	54	
37							122ft Tower				
38							92ft Tower				
39							62ft Tower				
40							Offset Tip Extension (combination)				
41							Offset Tip Extension (Hammer Head)				
42	Crawler	2CR1	Link-Belt LS-918	400-02	400	160000	Boom (tubular; 110"x89"dp) open throat t	26	24 (not verified)	71	400-90*not in cu

Figure 5-1 Sample Spreadsheet used in Crane Data-Entry

These sheets contain the following information:

1) The first column represents the crane type.

2) The second column contains the filing structure for the paper format information, it is collected and structured for reference.

3) The crane column represents the crane model.

4) The unit number column represents the crane ID for the company, in the event that the company owns more than one crane from the same model.

5) The rank column represents the ranking list of the cranes based on their rental cost. *"The values in this column have been removed"*.

6) The capacity column is used for the maximum capacity of the crane model.

7) The CTWT column, determine the counterweights weight or type.

8) The accessories column subdivide the crane model into its lift configurations.

9) The rest of the columns are used to control the lift settings, their indexing, ID^s, and their total number in the database.

This process becomes an effective strategy in revealing all types of equipment available in the company and setting up priorities for cranes or lift configurations time of entries. Book one contains information about cranes with a capacity of less then hundred tones, book two contains information about the cranes with a capacity higher than one hundred tons.

In addition, information about the cranes needed to be gathered in a systematic way. To make this possible and consistent to ensure that users, entering data, use the same terminology, special forms were designed, which will be filled in by the database operator (the personnel involved in the data entry). Refer to Appendix B for samples of these forms.

5.2 Data Verification

Different methods of verification and validations were used including:

1) Changing the data-type, for example the lift capacities are stored as text to allow for different units. this data-type was converted to numeric at later stage. This kind of check traps human data-entry errors such as using a spacebar.

2) Specially designed queries to trap empty or null values.

3) The mathematical equations used in the five scenarios mentioned in the methodology chapter (Chapter 3). were programmed in excel (Figure 5-2 show part of these scenarios). the same data was entered in the database and the spreadsheet. To speed the process of verifying operators error. in entering wrong values. two computers were used at the same time. one using the database and the other using the Excel file, to compare the results.

4) Specially designed queries to print tables as shown Figure 5-3. which are used by the operators involved in the data-entry process, they could print and check the values manually (see Appendix F for sample of these printed reports). Due to the large number of pages, which could exceed 200 pages for one lift configuration. the operators divided the page using supporters lines of up to 10 rows at a time. This allows them to scan a small sector of a page (sector A, B, C, ...etc. in Figure 5-3)

5) During the process of data entry the operators involved in the process compare the calculated data entered or generated in the database with the given data by the

manufacturer. For example for lift on the main boom in addition to the main boom length and lifting radius the tip height and/or boom angle to ground may be given, the operator leave the database to calculate these values and then compare the results.

6) Duplicate or wrong data report as shown in Table 5.1, is generated and filed in the repository system, for reference and record.

Table 5.1 Duplicated or Wrong Data Table

Equipment	Settings Affected	Duplicate	Incorrect	Responsible	Fixed

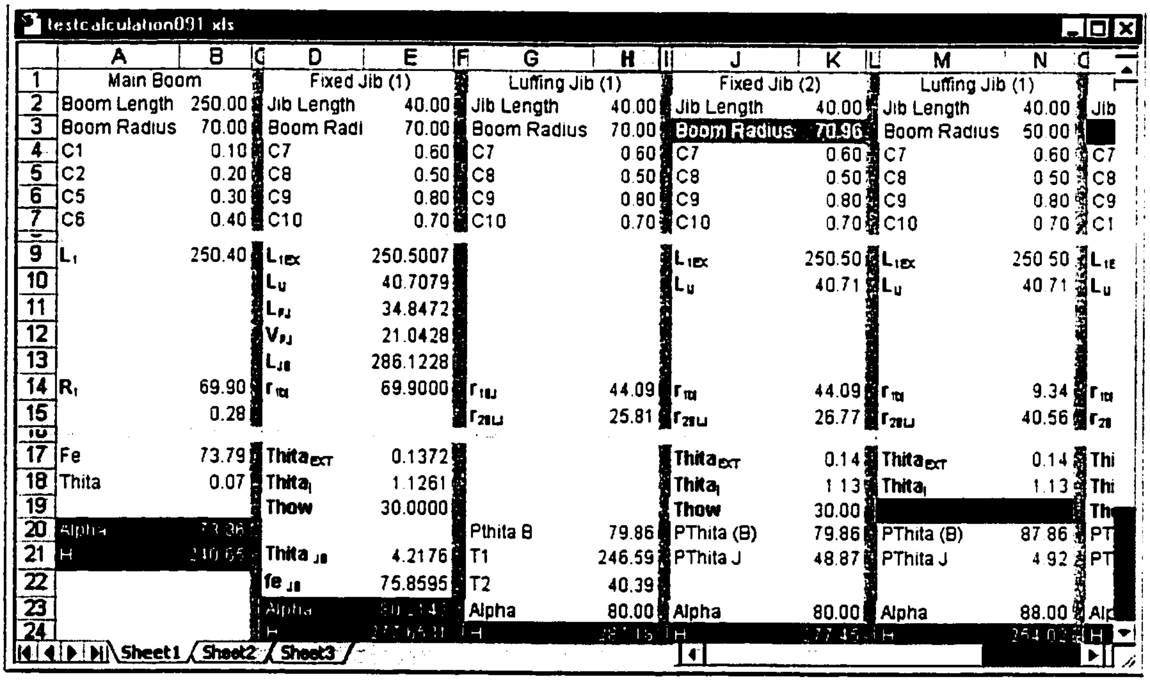
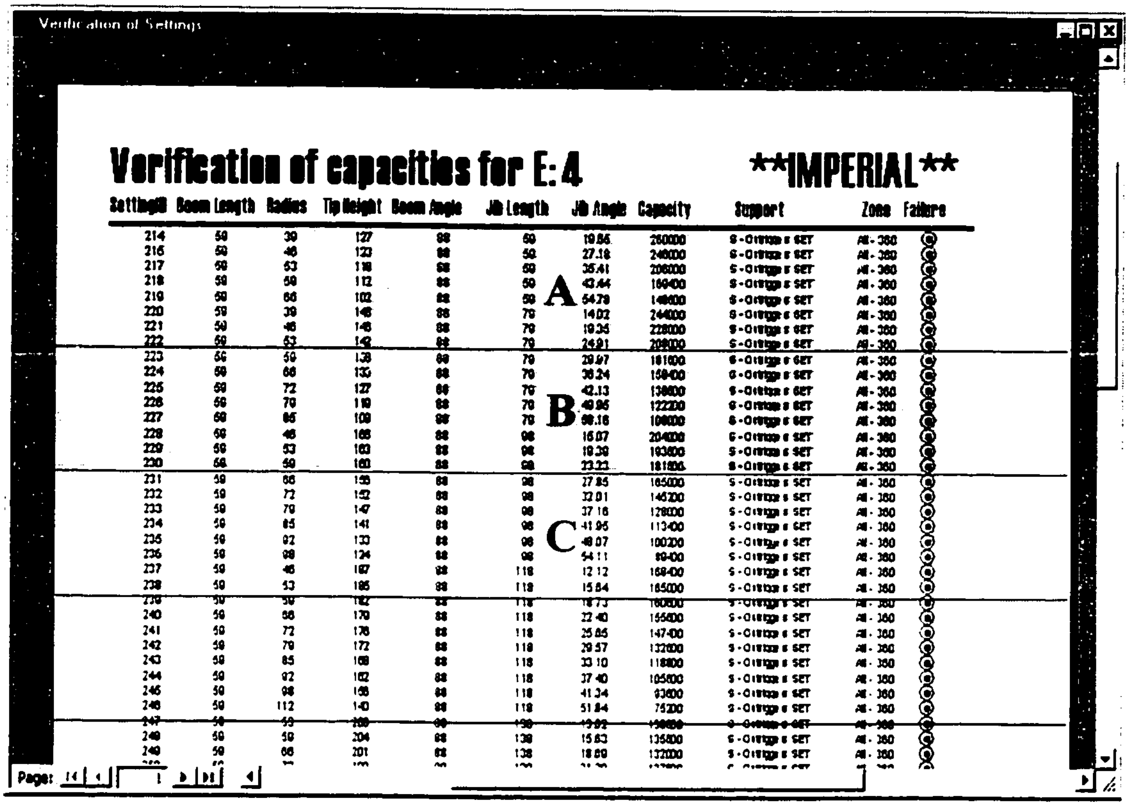


Figure 5-2 Calculation Scenarios in Ms-Excel



Verification of capacities for E:4 ****IMPERIAL****

Setting#	Boom Length	Radius	Tip Height	Boom Angle	Jib Length	Jib Angle	Capacity	Support	Zone	Failure
214	59	39	127	88	59	19.86	260000	S - Outriggers SET	All - 360	◉
216	59	46	123	88	59	27.18	240000	S - Outriggers SET	All - 360	◉
217	59	53	118	88	59	35.41	206000	S - Outriggers SET	All - 360	◉
218	59	59	112	88	59	43.44	169400	S - Outriggers SET	All - 360	◉
219	59	66	102	88	59	54.79	148400	S - Outriggers SET	All - 360	◉
220	59	39	148	88	79	14.02	244000	S - Outriggers SET	All - 360	◉
221	59	46	145	88	79	19.35	228000	S - Outriggers SET	All - 360	◉
222	59	53	142	88	79	24.91	209000	S - Outriggers SET	All - 360	◉
223	59	59	138	88	79	29.97	181600	S - Outriggers SET	All - 360	◉
224	59	66	135	88	79	36.24	159400	S - Outriggers SET	All - 360	◉
225	59	72	127	88	79	42.13	138800	S - Outriggers SET	All - 360	◉
226	59	79	119	88	79	49.86	122200	S - Outriggers SET	All - 360	◉
227	59	85	109	88	79	58.16	106000	S - Outriggers SET	All - 360	◉
228	59	46	165	88	98	16.07	204400	S - Outriggers SET	All - 360	◉
229	59	53	163	88	98	19.39	193600	S - Outriggers SET	All - 360	◉
230	59	59	160	88	98	23.23	181800	S - Outriggers SET	All - 360	◉
231	59	66	155	88	98	27.85	165000	S - Outriggers SET	All - 360	◉
232	59	72	152	88	98	32.01	146200	S - Outriggers SET	All - 360	◉
233	59	79	147	88	98	37.16	128000	S - Outriggers SET	All - 360	◉
234	59	85	141	88	98	41.95	113400	S - Outriggers SET	All - 360	◉
235	59	92	133	88	98	48.07	100200	S - Outriggers SET	All - 360	◉
236	59	98	124	88	98	54.11	89400	S - Outriggers SET	All - 360	◉
237	59	46	187	88	118	12.12	168400	S - Outriggers SET	All - 360	◉
238	59	53	185	88	118	15.84	165000	S - Outriggers SET	All - 360	◉
239	59	59	182	88	118	18.73	160800	S - Outriggers SET	All - 360	◉
240	59	66	179	88	118	22.40	155600	S - Outriggers SET	All - 360	◉
241	59	72	176	88	118	25.85	147400	S - Outriggers SET	All - 360	◉
242	59	79	172	88	118	29.57	132000	S - Outriggers SET	All - 360	◉
243	59	85	168	88	118	33.10	118800	S - Outriggers SET	All - 360	◉
244	59	92	162	88	118	37.40	105800	S - Outriggers SET	All - 360	◉
245	59	98	155	88	118	41.34	93600	S - Outriggers SET	All - 360	◉
246	59	112	140	88	118	51.84	75200	S - Outriggers SET	All - 360	◉
247	59	53	[illegible]	88	138	[illegible]	[illegible]	S - Outriggers SET	All - 360	◉
248	59	59	204	88	138	15.63	135800	S - Outriggers SET	All - 360	◉
249	59	66	201	88	138	18.89	132000	S - Outriggers SET	All - 360	◉

Figure 5-3 Database Verifications Printed Report

5.3 ALGORITHMIC VALIDATIONS

5.3.1 Database code Verification and Validation

The programmed Excel file with the mathematical equations used in the five scenarios mentioned in the methodology chapter (Chapter 3), was used also to validate the code of these equations in the database. The same concept used to speed the process of the code and algorithm validations, two computers were used at the same time, one using the database and the other using the Excel file, to compare the results.

5.3.2 Selection Module Code Verification and Validation

The selection module was validated at five different stages:

1) At the implementation stage: An optimization module was developed with similar functions i.e. optimization of the crane, lift, and site geometry and constraints. This optimization module was described in the methodology and implementation chapters. The optimization module was implemented using MS-Solver. Both the crane selection and the optimization modules were initialized at the same time using two computers to test the system on 75 hypothetical cases and 12 actual cases (from past projects) to evaluate the results of the selection module.

2) At the prototyping stage: Practitioners at the engineering staff level validated the module using 60 hypothetical cases and 20 actual cases (from past and new projects).

3) At the system submission stages: During the five milestone meetings with executives, an average of 10 cases per meeting, hypothetical and actual cases, were used to validate and demonstrate the module capabilities and train potential users.

4) At the first draft of the full version submission: The selection module and the database were installed on the computers of the most experienced sales representatives to use it in their daily operations in actual cases, while validating the selection module results and the data retrieved from the database.

5) After the final submission: Due to the structured format of the modules' output and its storing capabilities for information about each project, the sponsoring company's past projects are in the process of being entered using the selection module. This will expose the module to a wider range of validations.

5.4 Performance Evaluations

Two actual cases are used in this chapter to demonstrate the application of the crane selection module for heavy and critical lifts and its dynamic linkage to the databases. The first case is used for comparison between the traditional way of the crane selection and that using the crane selection module. The second case demonstrates the accuracy used in the algorithm in the crane selection module and the cranes database. In addition to the actual case three scenarios representing added site constraints, which limit the search for cranes are also described.

Case 1: The case considered involved the replacement of the heating system for the Hall Building of Concordia University, located downtown the city of Montreal. The heating system is located in a service area on the roof of the building as shown in Figure 5-4. The old heating system has been dismantled into parts, the largest of which had a weight of 40,000lb (18,144kg). The most suitable crane had to be selected, one that could carry the total lift weight and reach a total height of 198-ft (60.35m), and a total width of 97ft (29m), measured from the ground level to the roof of the service area and from the edge of the roof of the main building to the center of the opening, respectively.

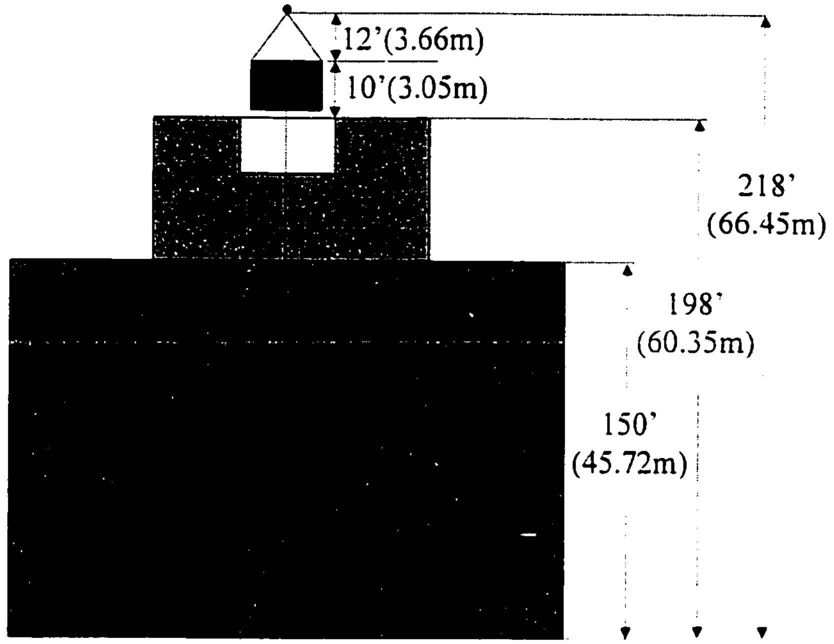


Figure 5-4 Elevation View of Case 2

The lift weight and its key dimensions are entered in the selection module, "Lift Description" screen, first. The lift weight and size limit the search for the rigging type and size. The user has the option of selecting the rigging equipment from the rigging database, or alternatively, can enter the height and weight of rigging of his/her choice. For this particular case, four slings 10ft (3m) long each are selected in the "Attachment" screen, which weigh a total of 1200lb (544.32kg). The shape of the building, the final lifts' location, and the site constraints are entered next in the "Constraints" Screen.

The search for technically feasible crane configurations and their lift settings starts by choosing the "list cranes" option from the "Cranes" screen, shown in the Figure 5-5. A list of technically feasible crane configurations and their lift settings is then deployed, ranked in a descending order based on their rental costs.

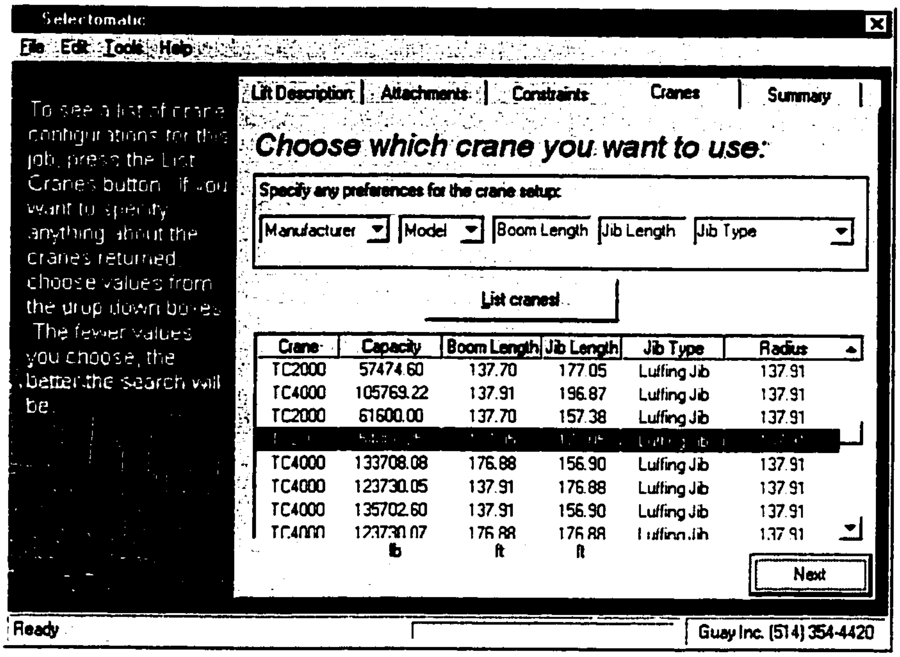


Figure 5-5 Selection Module List of Technically Feasible Cranes (Case 2)

Upon choosing a particular crane configuration and lift setting from the list, more information and details about this particular configuration and lift setting are displayed on the summary screen. The summary screen includes the type of crane, lifting radius, tip height, boom and jib lengths, boom and jib angles, clearances, and crane capacity. A report is then produced, including a summary of relevant information about the project, crane configuration, lift capacity, along with a 2D-elevation view of the crane (see Appendix E). The report contents are stored in a separate transactional ***project database.***

A manual selection was carried out by the cranes' supplier earlier and is used here for comparison. The configuration and lift setting selected manually is the highlighted option in Figure 5-5 (i.e. Dimag TC 2000, main boom length 177ft (53.95m) and a luffing jib length of 177ft (53.95m), the crane is operating at a radius of 138ft (42.06m). In this configuration, the crane operates on 84% of its capacity, in view of its 55,000lb

(24,948kg) gross capacity and the total lift weight of 46,138lb (20.93kg) (40,000lb lift, 4,938lb hook block, and 1,200lb slings).

In contrast to the manual-based selection, which provides only one configuration and lift setting, the selection module, upon evaluation of the company's entire fleet of cranes, provides the users with a list of technically feasible crane configurations and lift settings, ranked in a descending order based on their rental costs. In the case being considered, the alternative configurations and lift settings include the Dimag TC 2000, but with a number of technically feasible lift settings. Five alternatives, in particular, as shown in Table 5.2, use shorter boom and/or shorter jib configurations, resulting in reduced costs and increased lifting capacities. In addition to cost reduction, the developed database significantly reduces the time and effort involved in the selection process, and provides the user with alternatives, supported by detailed reports and drawings. Figure 5-6, presents a picture of the actual case as the lift is performed.

Table 5.2 Comparison between Manual and Automated Selection

No	Crane Model	Main Boom Length (ft/m)	Luffing Jib Length (ft/m)	Lifting Radius (ft/m)	Lifting Capacity (lb/kg)	Selection Type
1	**TC-2000**	**(177 / 53.95)**	**(177 / 53.95)**	**(138 / 42.06)**	**(54880.25/24893.68)**	**Manual**
2	TC-2000	(138 / 42.06)	(157 / 47.85)	(138 / 42.06)	(61600.00/27971.76)	Selection Module
3	TC-2000	(138 / 42.06)	(177 / 53.95)	(125 / 38.10)	(61800 / 28032.48)	Selection Module
4	TC-2000	(138 / 42.06)	(177 / 53.95)	(138 / 42.06)	(57474.60/26070.48)	Selection Module
5	TC-2000	(157 / 47.85)	(138 / 42.06)	(125 / 38.10)	(68600 / 31116.96)	Selection Module
6	TC-2000	(157 / 47.85)	(138 / 42.06)	(138 / 42.06)	(59400 / 26943.84)	Selection Module

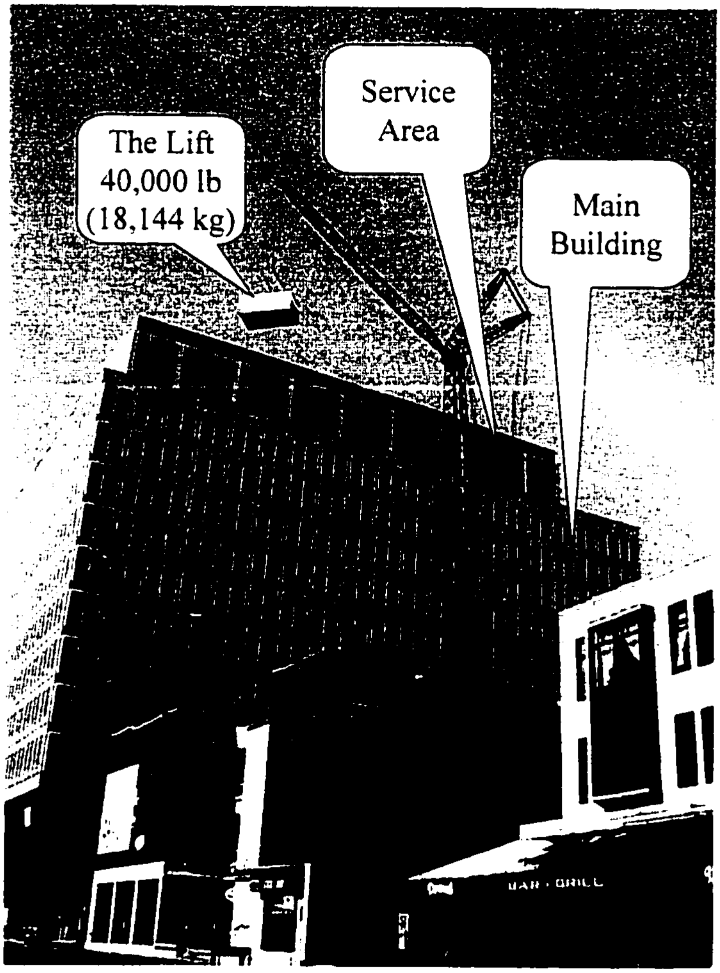


Figure 5-6 Lift Characteristic Case 2

Case 2: This case demonstrates the use of the system in evaluating critical lifts, in particular, the effect of the horizontal reach (lifting radius) and the limited spaces on sites for the outriggers, on selecting cranes. Practitioners (seals representatives) used this case during the validation and testing period. An actual case is presented along with two hypothetical scenarios of the case assuming changes in the site constraints (i.e. one scenario increases lifting radius and the other limes the space on the site). The actual case involved the replacement of three electrical transformers located in a hydro station in East-Montreal. The site is congested with buildings and high voltage power cables. Each transformer weigh 57,750lb (26,195.4kg), and has a width, length, and height of 6ft

(1.83m), 6ft (1.83m), and 10ft (3.048m) respectively. The transformers were to be placed 10ft (3.048m) behind a 14ft (4.267m) high and 20ft (6.096m) wide building as shown in Figure 5-7. It is required to select the most suitable crane, i.e. a technically feasible and a cost effective one.

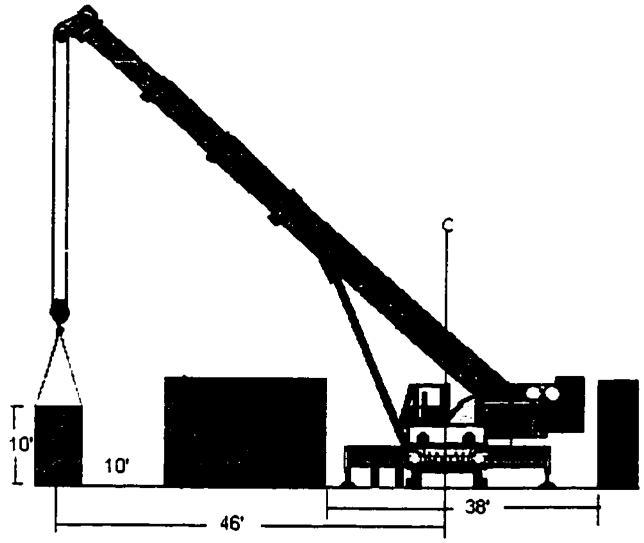


Figure 5-7 Elevation View of Case 3

The search for technically feasible crane configurations and their lifts settings starts by choosing the "***Search for crane***" option, shown in Figure 5-8. The described in previous chapter limited search options were used heir. The search was limited to hydraulic cranes and lift settings in the margin of the total lift weight and the first 20% of the total lift weight. The list shown contains 2,235 different lift settings of hydraulic cranes, their lifting capacities are within the range of [60,297lb (27351kg) to 72,357lb (32,821kg)], which represents the total load and the first added 20 %, these are also technically feasible, capable of carrying the lift safely. The highlighted, the first configuration in Figure 5-8, was recommended because it is from the 165 tones maximum capacity Demag AC 335 crane, which has the least rental cost of all the other cranes in the list.

This lift configuration has a boom length of 103ft (31.4m), a radius of 46ft (14.37m), and a lifting capacity of 67,000lb (30,351kg). The list of technically feasible crane configurations was doubled when adding a 60% option to the capacity. In addition, the lift plans were produced using the 3D-CAD module as shown in Figure 5-9.

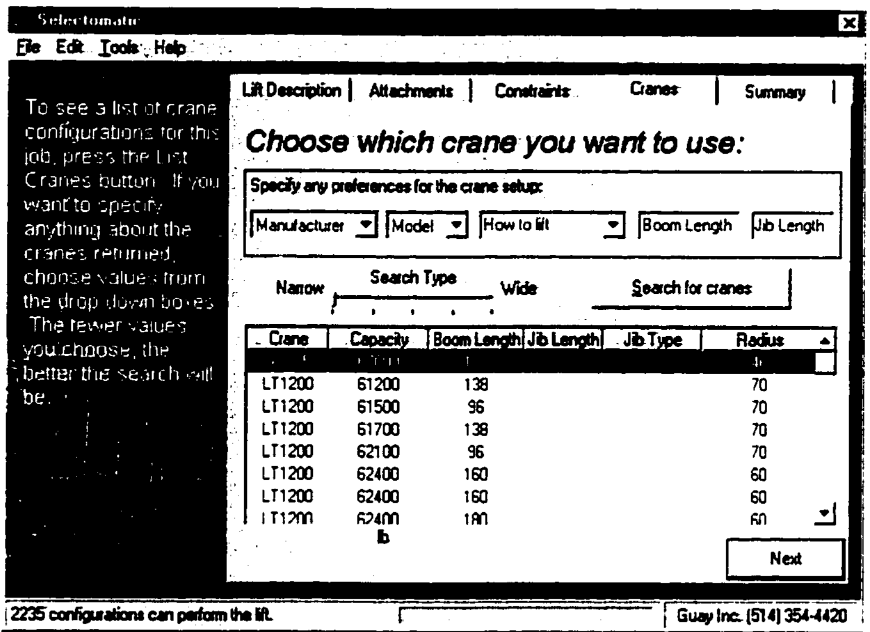


Figure 5-8 List of Technically Feasible Cranes Screen Case 3

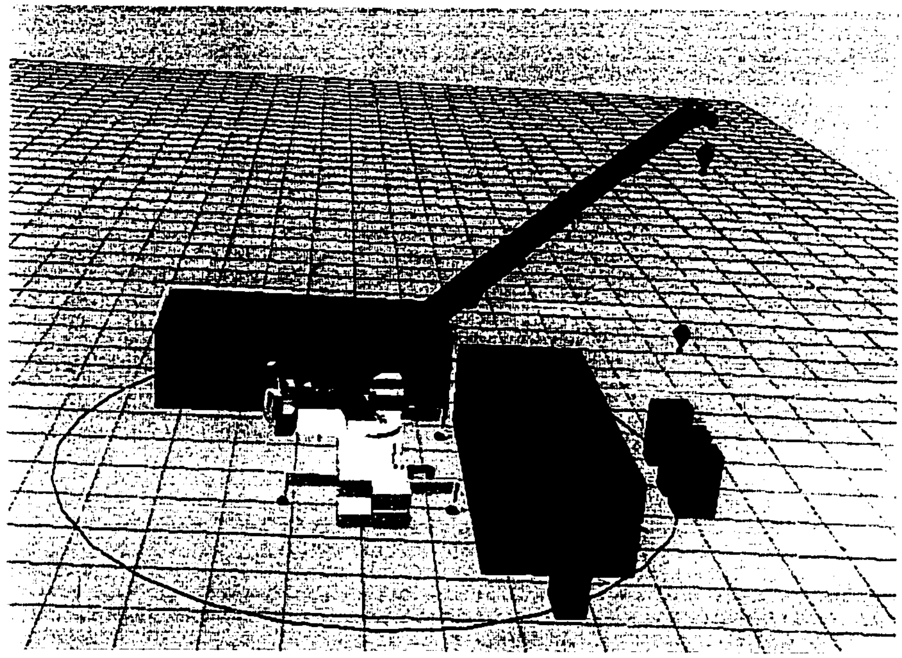


Figure 5-9 3D-Veiw of Case 3

<u>Scenario 1:</u> in an effort to challenge the developed system practitioners (seals representatives) used the actual case cited above, with different site constraints, which limit the choice of cranes. It was assumed that an obstruction was added to limit the tail-swing of the crane at a distance of 38ft (11.58m), as shown in Figure 5-10the sales representative also assumed the use of a hydraulic crane. The system was challenged by the fact that the sales representative expected the system to show limited number (if any) of configurations from more than a hundred thousand configurations and lift settings stored in the database. The site constraints in this case were modified; an obstruction was added, limiting the maximum radius and a value of 38-ft was assigned to the maximum radius, as shown in Figure 5-11. The search was activated choosing the hydraulic option. The system only listed one crane lift setting: the Demag AC335 crane, as shown in Figure 5-12.

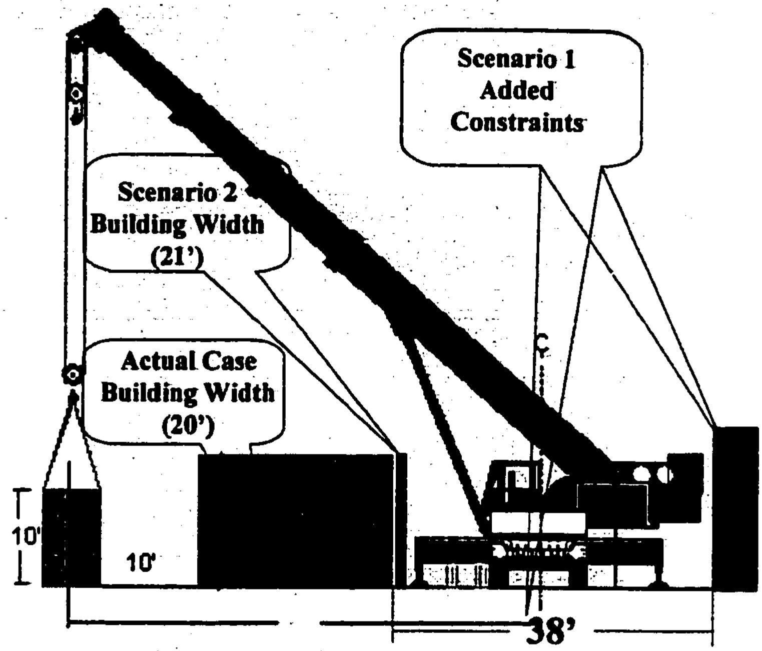


Figure 5-10 Added Site Constraints Case 3

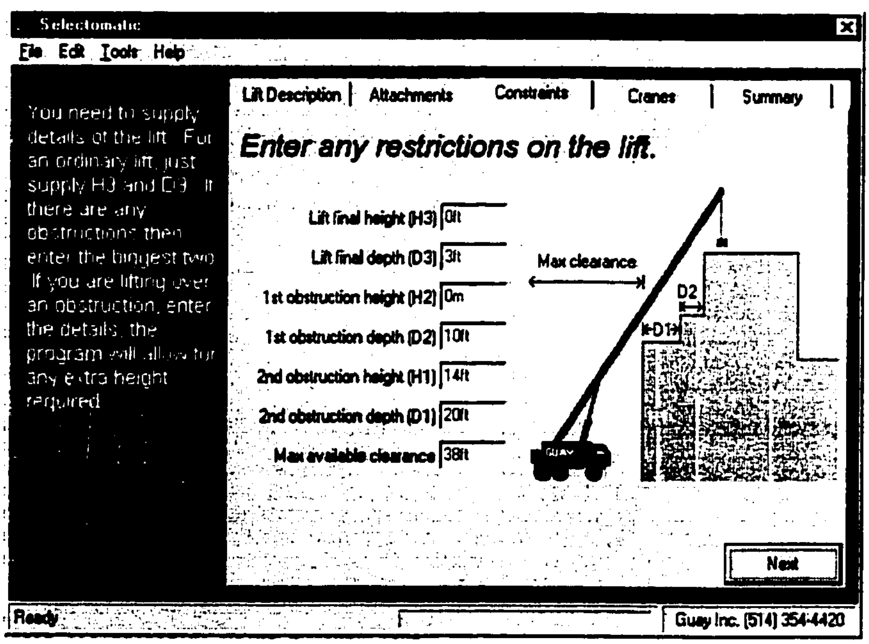


Figure 5-11 Site Constraints Evaluation View Screen (Case 3 Scenario 1)

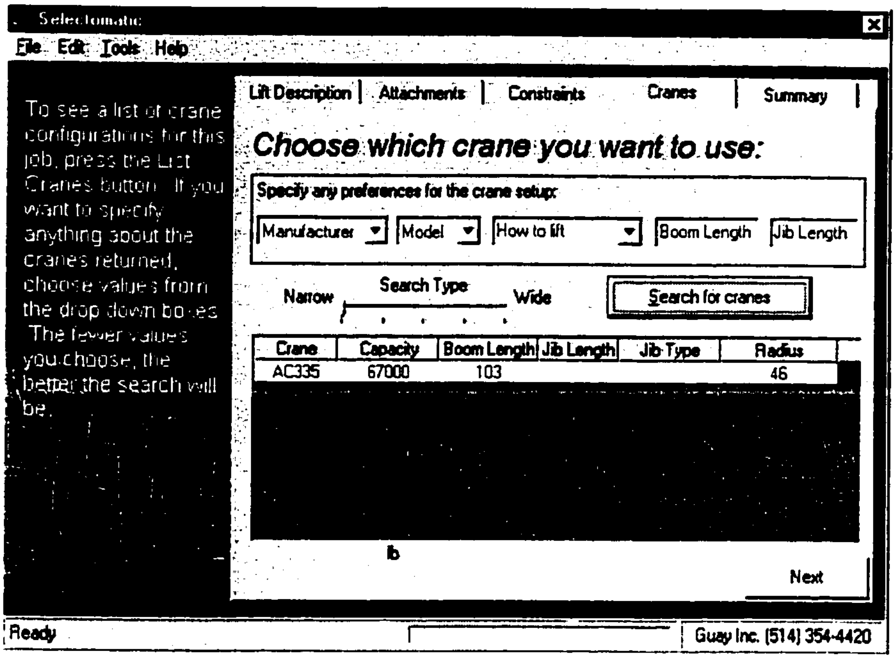


Figure 5-12 List of Technically Feasible Crane of (Case 3 Scenario 1)

Scenario 2: When the system shows the 165-tone crane, for the original case (no tail-swing constraints) the sales and the engineering staff did not expected, that the crane will reach horizontally. Therefore, the actual case cited above with different site constraints, which also limit the choice of cranes. The building obstructing the lift was assumed to be wider. One (1') ft (.30m) was added to the obstruction width i.e. increased from 20ft (6.09m) to 21ft (6.40). The search was activated choosing from all cranes within the 20% margin of the lift capacity. This results in a list of 2,210 lift settings, those technically feasible. As shown in Figure 5-13, the Demag AC 335 was not part of the list. The first crane on the list was the LT1200, a 450-tons capacity crane. In addition, different values were used to test the system's level of accuracy. When a 20.6ft (6.28m) wide building was used the lift setting from the Demag AC 335 crane appeared on the list. When a 20.7ft (6.31m) wide building was used, the lift setting from the Demag AC 335 crane was excluded from the list.

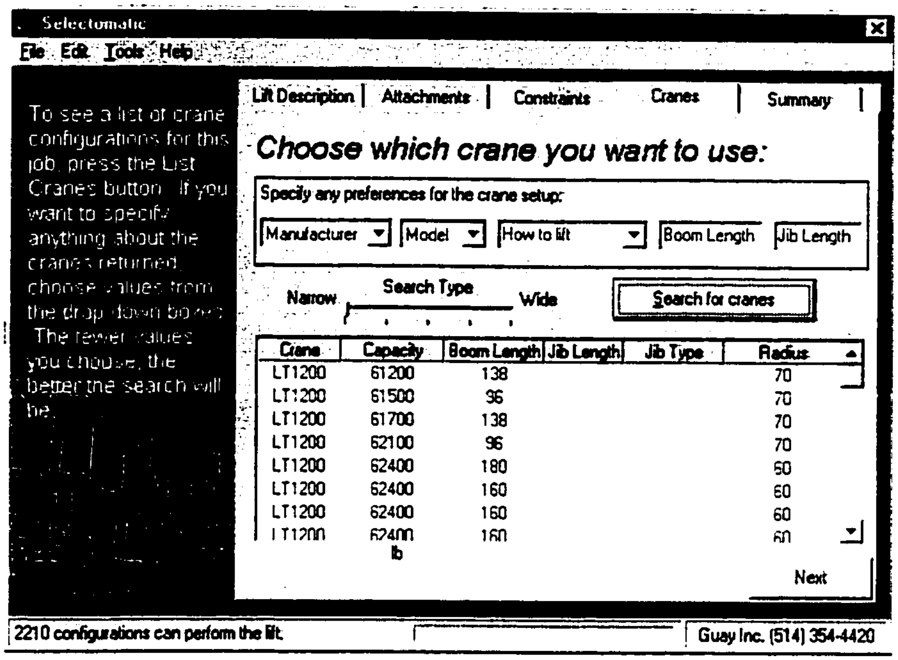


Figure 5-13 List of Technically Feasible Cranes (Case 3 Scenario 2)

Case 3: This case demonstrates the use of the 3D module and 3D-animation in locating the crane and lift utilisation. The case considered involves the replacement of large peas from a paper pulp manufacturer (gooseneck) located in New Richmond, New Brunswick. The case considered imposed the following constraints:

1) The final location of the load is surrounded by facilities from all its sides

2) The root to its final location must overpass a new steel structure designed for permanent support to the load.

3) The use of an available crane (300-tons M-250 Crawler crane from Manitowoc) near the site in the province of New Brunswick would result in considerable savings; the alternative involving the transportation of a larger crane from Montreal to New Richmond.

The crane selection module was effective in selecting the crane, but it was limited in evaluating the utilisation of the lift path. The 3D-CAD module was used to overcome this limitation. The crane is available in 3D-CAD cranes library. Furthermore. the lift and the site were drawn in 3D using AutoCAD, and the crane was inserted as shown in the 3D View in Figure 5-14, and the elevation and the plan views shown in Figure 5-15. The 3D-animation module shows that the selected crane is just adduct to perform the lift, its tracks have to be blocked on the position shown in Figure 5-17. Two possible options for the placement of the lift are subject to evaluation. The first option, lift to be swung over the steel structure used to support the gooseneck, as shown in Figure 5-14 or alternatively the crane to swing the lift over the building (Building B). The 3D-animation module illustrates that choosing the first option the object (the gooseneck) will hit the steel structure . This was evident despite the fact that the gooseneck was rotated on the screen to go around the steel structure. The second option (i.e. swing over the building as shown Figure 5-18) required the removal of objects from the roof of building (B). The 3D-virtual animation module shows that the lower part of the gooseneck, as shown in Figure 5-19, is moving just above the roof of the building. The final location of the lift is shown in Figure 5-20.

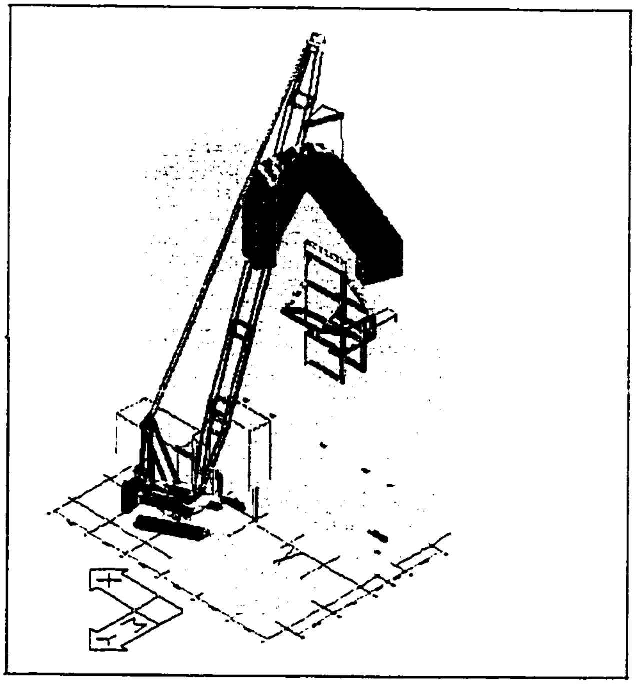


Figure 5-14 3D View of Case 4 (object above Steel structure)

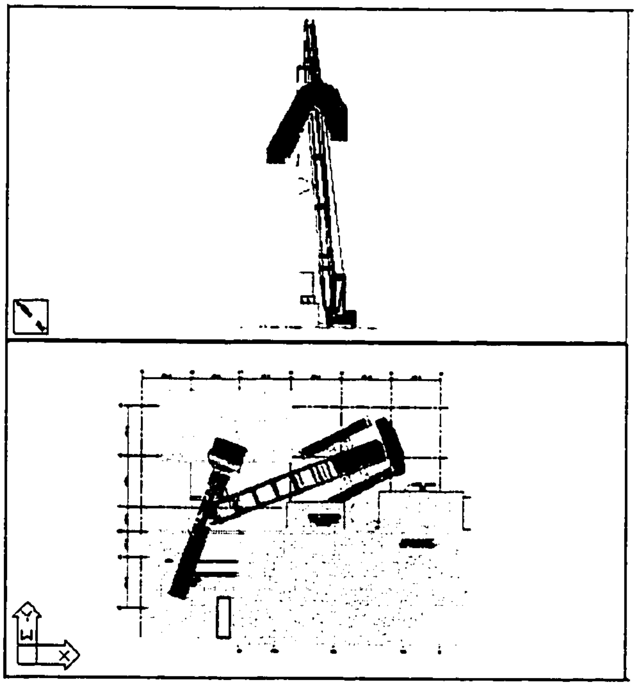


Figure 5-15 Elevation View and Plan View of Case 4

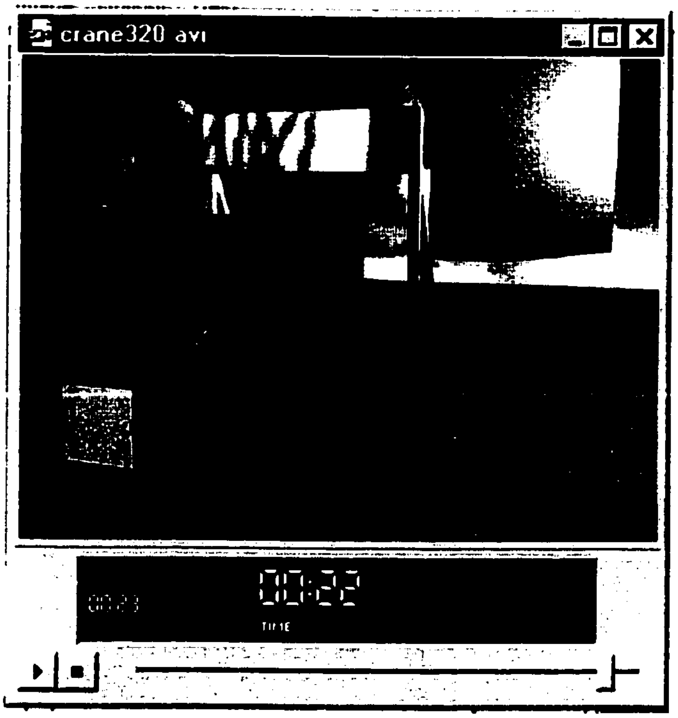


Figure 5-16 Animated View Case 4 (Lift in Collusion With Steel Structure)

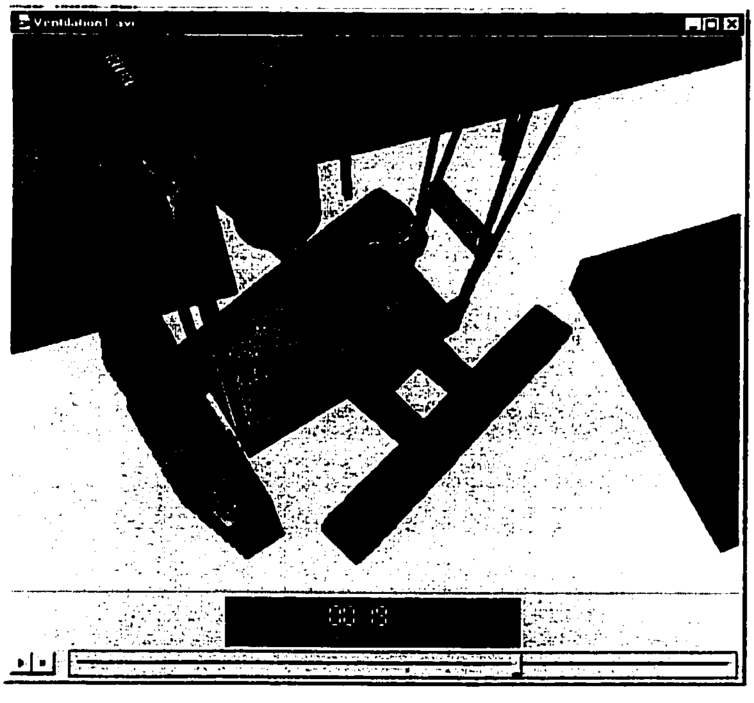


Figure 5-17 Animated View Crane Tracks on Site Case 4

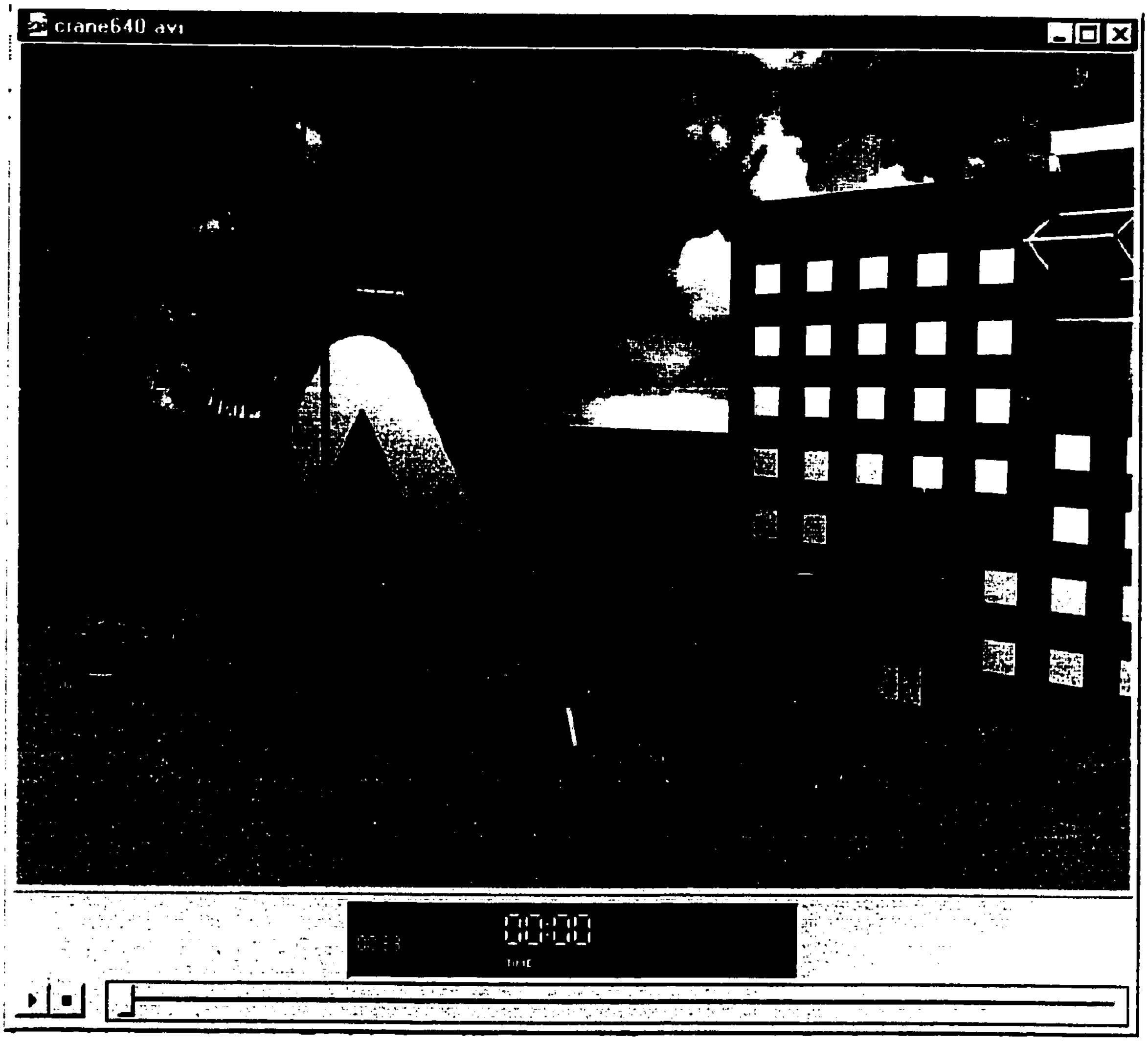


Figure 5-18 Animated 3D View of Case 4 (object above the Building)

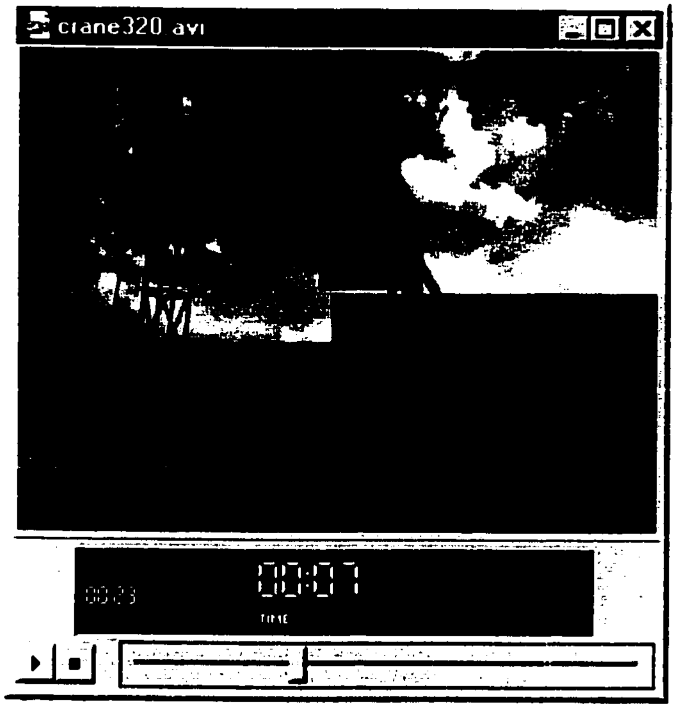


Figure 5-19 Animated 3D Close View Case 4 (object above the Building)

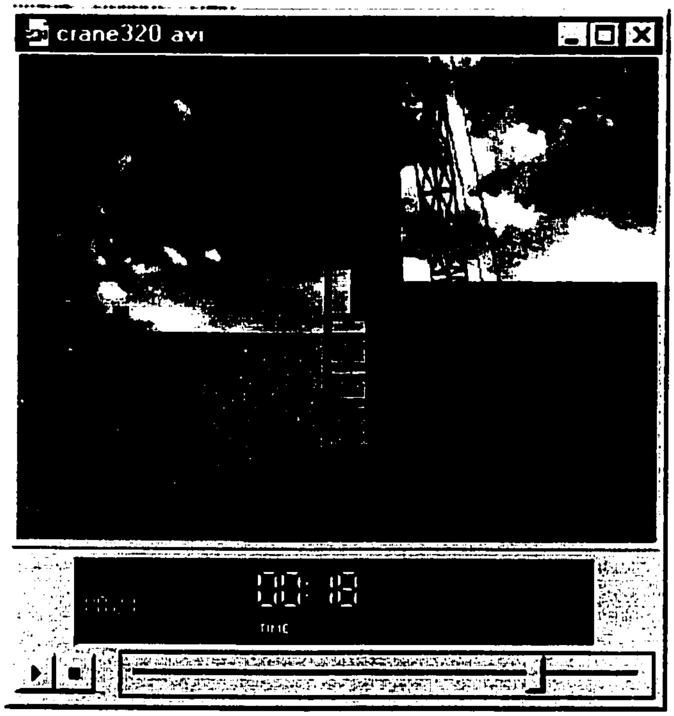


Figure 5-20 Animated View Case 4 (Near Final Lift Placement)

Chapter 6 SUMMARY AND CONCLUDING REMARKS

6.1 CONCLUDING REMARKS

Lifts employing cranes need careful planning in order to ensure safety and economy. This involves selecting technically feasible and cost effective crane configurations for any given lift conditions and site constraints. It also requires a search and evaluation of a large number of crane configurations. a process that is time consuming and can lead to costly mistakes. The need for developing an efficient system that can process data associated with crane configurations. lift capacity settings. and rigging equipment cannot be ignored. The primary advantage of such a system lies essentially in the speed with which search through and evaluation of large amount of data can be done.

A computer integrated system for crane selection and on site utilization has been developed and presented in this thesis. The system consists of crane selection and on sites location module. a database system. an optimization module. a 3D CAD module. and a 3D-animation module. The database design grew on a well-defined and structured problem and presented a pragmatic solution to data management useful for planning crane operations. Later in the implementation. the database became an integral part of the selection system. formulating a wide Management Information System. as well as it can be used with any Decision Support System. related to crane operations. The developed database has a number of interesting features including its' capability of accommodating different types of cranes using different units of measurements. The database is also powerful in its storing and querying capabilities. It has a practical user-friendly interface. supported by graphics in a multimedia environment. The developed database is a relational database designed using Entity Relation diagram (ER) and is implemented using MS-Access DBMS.

3-D CAD is not currently amongst the premiere tools in the crane selection and crane operation domain. Except for some limited cases, 3-D is not used, at least on a full scale. This research identified this shortcoming and implemented a 3-D model to assist in the crane selection and planning process. The developed model utilizes 3D-CAD to represent the physical site layout and crane geometry to support selection and planning of crane operations.

Animation proved to be an effective tool, which aids engineers and practitioners alike in envisioning problems and walking through the whole operation at a marginal cost, compared with what would have to be paid in case of an error. Animation is not currently used in planning crane operations. This research implemented a 3D-animation module using 3D-Studio to assist practitioners in planning heavy and critical lifts operations.

Optimization techniques are also used and presented in this thesis. Optimization is mainly used to optimize geometry related to cranes such as the crane's working radius and booms/jibs reach and their angles to grounds.

Four actual cases and three scenario cases of building and industrial project have been considered in order to demonstrate the use of the proposed methodology and its system and illustrate its essential futures and capabilities.

6.2 Research Contributions

The contributions of this research can be summarized as follow:

- A new method for crane selection has been developed
- An operational integrated computer system has been implemented utilizing the newly developed methodology.

The newly developed and implemented methodology is designed to assist practitioners in crane selection, lifts planning, and selection optimization. It eliminates the guesswork and the consequences of poor judgement in the selection process. It can reduce cost and time spent on the selection process. It provides a range of feasible solutions and alternatives providing flexibility to the decision-maker. It enhanced the crane operations safety, by evaluating possible collusion between crane, lifts and site components. Through its 3D-CAD and 3D-Animations it accelerates the approval of lift plans by the safety authority. The developed system's modules have a number of interesting features including powerful graphics capabilities, featuring a multimedia environment and a practical user-friendly interface and flexibility in using metric and empirical units. The system incorporates a unique, comprehensive, and well-structured database, which can be adapted to other construction equipment.

6.3 Recommendations for Future Research

Although this research presents an operational system as a solution to an industry problem (crane selection an on site utilization), there is however, a potential for improvements. These may include:

- Developing a transportation strategy or module to assist practitioners in selecting appropriate procurement strategy for deployment of cranes.
- Developing a methodology that counts for boom deflections.
- Developing a systematic costs estimation methodology for crane's owing and operating costs.
- Applying Information Technology for automating the information flow from the inquiry for a crane to billing.
- Expanding the development made using 3D-CAD and 3D-Animations to modeling of the construction processes.
- Applying the methodology used in this research for other construction equipment

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APPENDIX (A)

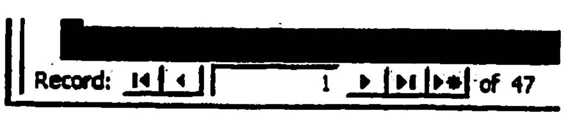
HANDOUT USED FOR OPERATORS TRAINING

Object of finished version: The database will contain all the data from the printed load charts. Giving certain criteria will allow the database to be used for the choice of a crane.

How far have we gotten? The data structures are in place. Data have to be entered in the database before they can be retrieved to. What you see at the moment is the most important part of the project the method of entering the data. There are two main forms: one is for adding details of the cranes and the other is for adding the lift capacities.

The cranes are entered first. This allows all the data about the crane to be stored including booms, jibs, dimensions and other information. When this is complete, the second form allows you to choose a combination of cranes, booms and jibs to define a setup. You then enter data for that set up. These two forms are accessed from the startup menu.

What you have to do? Simply enter some data about a crane and then add the lifting capacities. You do not need to enter all the data, the main thing is to see: how the program works so far; what the problems are and what improvements could be made. Please remember that all criticism, however small, are welcome.

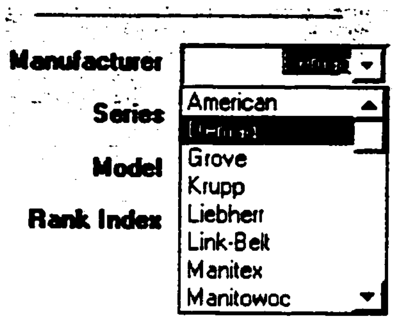


Instructions in using Access: When you open a form, you see several controls that are common to all forms. The main set of controls is the navigation buttons. These allow you to move around within the database. The buttons, in order, allow you to go to the first record, previous record, next record, last record or add a new record. The number in the box shows the current record.

At the top left of the window are record control icons. There are two main types, one shows an existing record. This means that the form is complete and is saved.

If you make any changes to the form or add a new record, you will see the other main icon, which is a pencil. This means that you are part way through entering or changing a record. To undo any changes yon have made, press Escape (Esc Key) until the first icon reappears.

You can move around the sections of a form by pressing the TAB key. Sometimes forms have different sections. The TAB key will move only within a section on a form. To move to the next section or page, press Ctrl+TAB. You can move backwards by using Shift+TAB or Shift+Ctrl+TAB. You may also use the mouse. If you see an error message, click the OK button to continue. You can usually press the ENTER key instead of clicking with the mouse. Please make a note of any errors and what you did to create them.



Many controls have drop down lists. To make data entry easier, the lists contain information already stored in the database. For example, if yon have cranes manufactured by Link-belt and American in the database, these names will be shown in the manufacturer list to save you typing them in. If the name you want is not on the list, simply type it in the box. Obviously, when the database is empty, there will be no data in the lists.

Instructions for adding a crane

Crane: When you open the crane form, the first page asks details about the crane. You can add a picture of the crane by following the on screen instructions. Some sample pictures have been provided with the database. The Crane ID section allows you to store a name for the cranes. For example, if you have three Grove TM1075 cranes, you might call them 100-1, 100-2 and 100-3. How you name them is your choice.

Boom Mount Data: These are measurements from the crane that will be used in calculations in the final version of the database.

Boom and Head Details: In the drop-down box, select a boom or type a new one in. Then choose which head can be fitted to this boom. If you have two heads for a boom, enter the boom twice, with a different head each time. If the crane is an hydraulic one, the boom and head are entered for you and you cannot change them. Enter other information about the head if you have it.

Jib Details: A crane can have more than one jib. The green section of the form shows one jib at a tune. Use the arrow buttons to move through the jibs. A message tells you how many jibs are stored for a crane. To add another jib, press the Next Jib button until the jib name and type boxes are blank. Choose a jib and specify its type. If you are entering a fixed jib, enter the fixed angles in the Jib Angles section. If you are entering a luffing jib, enter the fixed boom angle here instead. The message telling you how many jibs are stored doesn't update when you add another jib this is a known problem.

Dimensions: This page stores information about the size of the crane.

Manufacturer's Notes: Enter each note on the load chart - one note per box. These notes will be referred to when you enter the lift detail. The numbering is automatic and you cannot change it.

Instructions for adding lift data

How to set up the crane: Choose a crane/boom/tip combination from the first box. If you are using a jib, select one from the box. Only the jibs that can be used with this crane appear in the list. The values you enter on this page will stay for the next new record.

Lifting capacities: Fill in the six boxes at the top of the form first. Then choose which notes are important for this lift from the boxes on the left-hand side of the form. You may choose as many messages as you wish. Only the messages that apply to the current crane are displayed. Finally, enter the lift capacities in the correct place.

Notes about the crane setup: As there is no room to display all file messages on the previous page, this is a reminder of which messages you have chosen. You cannot change the data on this page.

APPENDIX (B)

Forms Used for Data-Collection

Conventional Crane Datasheet

Type of crane: ☐ Conventional Truck ☐ Crawler

Unit Details:

Manufacturer:	Series:	Model:

Unit Numbers:					

Carrier Dimensions:

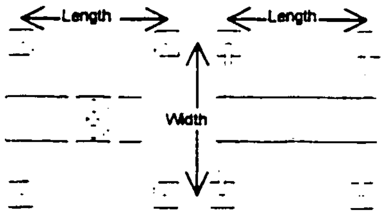
Width (in/mm)	Front to Centre (in/mm)	Rear to Centre (in/mm)	Max Cab height (in/mm)

Counterweight Dimensions:

Lower Ctwt Height (in/mm)	Upper Ctwt Height (in/mm)	Outer Ctwt to centre (in/mm)	Ctwt width (in/mm)

Outrigger Dimensions:

Layout: ☐X ☐H	Length (in/mm)	Width (in/mm)
Fully Set:		
Partly Set:		



Boom Mount Position:

Foot to Centre (in/mm)	Foot to Ground (in/mm)	Mast Length (in/mm)	Mast Pin to Centre (in/mm)	Mast Pin to Ground (in/mm)

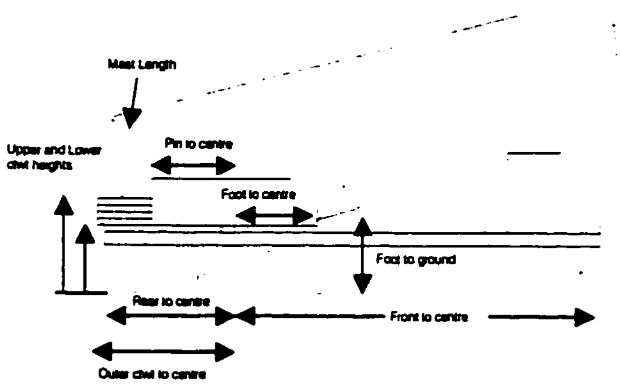
Distances are negative when pin is to the rear of the centre

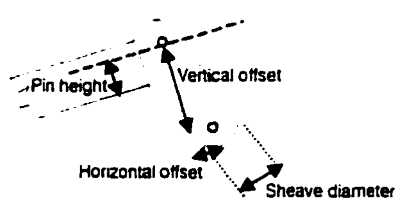
Types of boom to use with this crane:

Boom type:																				
Heads for this boom:																				
Tick which Heads apply for each boom	Standard	Taper Tip	Hammer Head	High Head	Super Lift	Standard	Taper Tip	Hammer Head	High Head	Super Lift	Standard	Taper Tip	Hammer Head	High Head	Super Lift	Standard	Taper Tip	Hammer Head	High Head	Super Lift

Head Details:

Name:					
No Sheaves:					
Sheave Dia: (in/mm)					
Pin Height: (in/mm)					
Vertical Offset: (in/mm)					
Horiz. Offset: (in/mm)					
Rope Diameter. (in/mm)					





Telescopic Crane Datasheet

Type of crane: ☐ Telescopic Truck ☐ All Terrain ☐ Rough Terrain

Unit Details:

Manufacturer:	Series:	Model:

Unit Numbers:					

Carrier Dimensions:

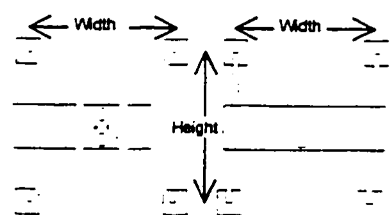
Width (in/mm)	Front to Centre (in/mm)	Rear to Centre (in/mm)	Max Cab height (in/mm)

Counterweight Dimensions:

Lower Ctwt Height (in/mm)	Upper Ctwt Height (in/mm)	Outer Ctwt to centre (in/mm)	Ctwt width (in/mm)

Outrigger Dimensions:

Layout: ☐X ☐H	Length (in/mm)	Width (in/mm)
Fully Set:		
Partly Set:		



Telescopic Boom Mount Position:

Foot to Centre (in/mm)	Foot to Ground (in/mm)	Distance A (in/mm)	Distance B (in/mm)	Distance C (in/mm)

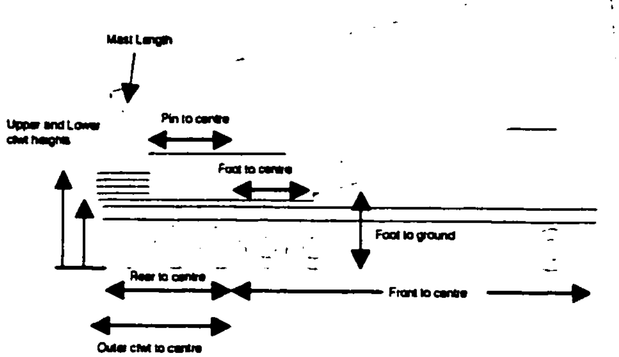
Distances are negative when pin is to the rear of the centre

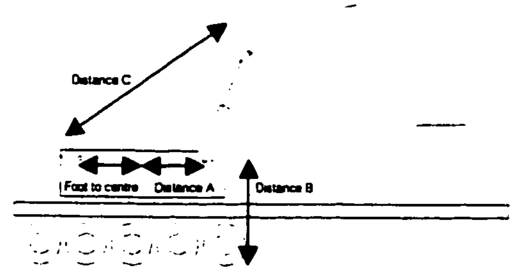
Head Details:

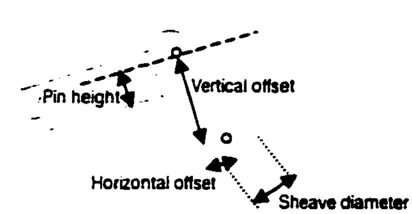
Name:	
No Sheaves:	
Sheave Dia: (in/mm)	
Pin Height: (in/mm)	
Vertical Offset: (in/mm)	
Horiz. Offset: (in/mm)	
Rope Diameter. (in/mm)	

Boom Details:

Component	
Length (in/mm)	
Name	
Type	
Length (in/mm)	
Width (in/mm)	
Height (in/mm)	
Weight (lb/kg)	







APPENDIX (C)

EXCEL SHEETS FOR MANAGING CRANES DATA-ENTRY

BOOK 1

(CRANES WITH MAXIMOM LIFTING CAPACITY LESS THAN ONEHONDRED TONES)

"Book 1"								Data Base References							
Crane Type	File #	Crane	Unit Number	Cap. (Tons)	Ctwt. (lbs)	Accessories	Cost Rank	Model Master	Configuration Equipment	Index #	Settings First	Settings Last	Capacities Aprx. Qty.	# Full Pages	Last Page
Conventional	1CV1	American 7510	100-01,02,05,06,09,11	100	30900(?)	Hammer Head Tip	53	47	128	115	27941	28074	397	4	73
					30900(?)	Tapered Tip		47	129	116	28075	28271	541	6	53
					30900(?)	Tapered (Tip&) Hanger Block		47	130	117	28272	28464	543	6	55
					31000	59H Tubular Boom Taper-Tip Jib No 9HL		47	received (1 Page)						
	1CV2	Link-Belt HC-218	82-02,03	82	21000+1080	Hi-Lite Boom (open throat top section)	51	48	131	118	28465	28680	769	9	35
					21000+1080	Fixed Jib (need extended charts)		48	134	119	29005	31715	615	2	455
	1CV3	American 7450	80-02,03	80	19500	59S Boom w/ Tapered Tip	50		Later						
	1CV4	American 5530	75-02		25600	47H Boom		[redacted]							
					16700	47 Heavy Duty Boom									
					26000	47 Hvy. Boom									
						47 HD Boom w/ 7HL Jib									
	1CV5	American 5510	65-06 (outa order)	65	25000 (?)	Boom	49								
Crawler	1CR1	Link-Belt LS-418	100-07	100	"A"	Hi-Lite Boom (Gantry,No Gantry)	52	51	138	127	30289	30497	283	3	41
					"AB"	Hi-Lite Boom (With Gantry)		51	139	125	30499	30707	209	2	49
					"AB"	Jib		51	140	126	30711	31602	891	10	75
	1CR2*	American 999C (?)	90-01	90				[redacted]							
	1CR3*	Link-Belt LS-318	(not in Guay file)	73(?)	25000	Boom (with boom live mast)									
					32000	Boom (with boom live mast)									
					25000	Boom (without boom live mast)									
					32000	Boom (without boom live mast)									
					32000	Jib									
	1CR4	American 7250	60-02	60	33700	59S Boom w/ Hammer Head Tip	48	49	132	120	28682	28817	246	3	4
					33700	59S Boom w/ Tapered Tip		49	133	121	28818	29004	348	4	24
					34000	W/59S Hamr-Hd Boom, No 9HL Jib		49	received (3 Pages)						
					34000	W/59S Taper-Tip Boom, No 9HL Jib		49	received (4 Pages)						
	1CR5	Link-Belt LS-118	60-04	60	12200(A)	Boom (side frames: ext, ret)	47	50	135	122	29424	29508	164	2	4
					46000(AB)	Boom (side frames extended)		50	136	123	29509	29684	140	1	62
					46000(AB)	Fixed Jib		50	137	124	29649	30288	640	7	70
	1CR6	P&H 550	50-13 ("remise")	50	20000	Boom	46	[redacted]							
					20000	Jib									
Telescopic Truck	1TT1	Grove TM1075	100-04,03	100	13350	Boom	38	37	81	70	20288	20372	170	2	10
					13350	Boom (108ft) & P P Fly		37	82	71	20488	20512	28	0	28
					13350	Boom (140ft) & 32ft Ext		37	83	72	20517	20573	28	0	28
					13350	Jib		37	84	73	20595	20718	124	1	46
	1TT2	Grove TM800 (same as TM 850 ?)	80-01,17,22,23	80	12975	Boom (36'-114')	37	40	96	85	26058	26122	134	1	56
					12975	Boom (114') & 32' Fly		40	97	86	26123	26142	40	0	40
					12975	Jib (36' - 146')		40	98	87	26143	26268	126	1	48
	1TT4	Grove TMS475LP (same as TMS475)	45-09 (50-18,22)	50	(?)	Boom	29	63	200	185	33989	34052	102	1	24
					(?)	Boom(85') & PPFly		63	201	186	34053	34069	25	0	25
					(?)	Boom(85') & 32' Extension (PPFly Retracted)		63	202	187	34070	34087	27	0	27
					(?)	Boom (110') & 32' Extension		63	203	188	34088	34105	23	0	23
					(?)	24' Fixed Jib		63	204	189	34106	34120	15	0	15
	1TT6	Grove TMS 745B	45-11,12	45	7800	Boom (over Rear)	26	41	99 (re-verify) printed	88					
					7800	Boom (360 degrees)		41	100 (re-verify) printed	89					
		(Grove TMS 700) (same as 700B)	(45-10)		7800	Boom (on rubber: 0mph & 3 mph)		41	101,	90	26461	27502	34	0	34
					7800	32ft Extension		41	110,	94	26826	26873	84	1	8
					7800	32-56ft Tele-Extension		41	111,	95	26874	27012	139	1	61
					3900	Boom		41	102 (re-verify) printed	91					
					3900	Boom (on rubber: 0mph & 3 mph)		41	109,	93	26824	27532	28	0	28
					3900	32ft Extension		41	112 (re-verify) printed	96					
					3900	32-56ft Tele-Extension (outrig fully-set)		41	113,	97	27061	27204	133	1	55
					3900	32-56ft Tele-Extension (outrig part-set)		41	120	99	27557	27632	76	0	76
					0	Boom		41	108 (re-verify) printed	92					
					0	Boom (on rubber: 0mph & 3 mph)		41	119,	98	27541	27558	24	0	24
					0	32ft Extension		41	121,	100	27633	27674	42	0	42
					0	32-56ft Tele-Extension		41	122,	101	27675	27786	112	1	34
	1TT7	Grove TMS300B	40-05	40		got boom charts & jib chart	23	Measure	Later						
	1TT8	P&H T-400XL	40-06	40		(no charts)	24	[redacted]							
	1TT9	Manitex C35100	34-40 (Renamed? 35 ton according to Pascal)	35		Boom	21	Have	Later						
						Fixed Jib									
						Tele-Jib									
	1TT10	Grove TMS375LP same carrier as 300B	45-05,06,07,08	34?	(?)	Boom	22.5	62	197	182	33892	33939	63	1	5
					(?)	Boom (89ft) & 32 Fly		62	198	183	33940	33957	30	0	30
					(?)	Jib (60ft)		62	199	184	33958	33988	39	0	39
	1TT10	Grove TMS300LP	34-08		(?)	Jib (60ft)	27	[redacted]							

"Book 1"

Data Base References

Crane Type	File #	Crane	Unit Number	Cap. (Tons)	Ctwt. (lbs)	Accessories	Cost Rank	Model Master	Configuration Equipment	Index #	Settings First	Settings Last	Capacities Aprx. Qty.	# Full Pages	Last Page
Telescopic Truck Cont'd	1TT11	Grove TMS300	34-12,23,24,25,26,27,28 32,33,38	34	(?)	Boom	17	46	123	110	27791	27873	133	1	55
					(?)	Boom (81ft) & Fly		46	124	111	27875	27890	26	0	26
					(?)	Boom (81ft) & Extension (32ft)		46	125	112	27891	27907	26	0	26
					(?)	Boom (104ft) & Extension (32ft)		46	126	113	27908	27925	26	0	26
					(?)	Jib (24ft) & Extension (32ft)		46	127	114	27926	27940	15	0	15
	1TT12	Link-Belt HTC-35	34-11	34		Boom	18	[redacted]							
	1TT13	P&H T-300	30-24 (34-37?)	30		Boom	14								
	1TT14	National Series 900	25-13,18,19,20,21	25		Boom	9	Need	Later						
						48ft Jib									
	1TT15	Clark 720-OS	22-01	22	4000	Boom	7	Have	Later						
						Jib									
						Manual Extension									
	1TT16	RO Stinger TC-250-76	22-03,04,05,06,07,08,09	22		Boom	5	[redacted]							
						25ft Jib									
						2 stage Jib									
	1TT17	Manitex 2284	22-10,11,12,13,14,15,16,17, ..18,19,20,21,22,23,24	22		Boom (26' - 84')	6	42	104	102	26620	26671	52	0	52
						Fixed Jib (26' & 46')		42	105	105	26673	26697	25	0	25
	1TT18	National Series 800 (875B)	17-05,08,09,10,11,14,15,17, ..18,19,22,24,27,28,29,32, ..34,35,36,38,39,40,41,42, ..43,46,52	17		Boom (22' - 75')	3	44	106	104	26698	26721	24	0	24
						Jib (21' & 35')		44	107	105	26722	26730	8	0	8
	1TT19	National Series 600 (not666-A?) (not666-B?)	(12-14 ?) (14-01 ?)	12.5			2	[redacted]							
	1TT20	RO Stinger TC-120-4		10	2000	Boom	1								
All Terrain	1AT1	Krupp 70 GMT-AT(Renam	80-13,14,15	80	24200	Boom	34	31	33 (verify) printed	45					
					15400	Boom		31	34 (verify) printed	46					
					2200	Boom		31	35 (verify) printed	47					
					0	Boom (on Rubber)		31	37 (verify) printed	48					
					24250	33'-52.6' Swing Away Extension		31	38 (verify) printed	49					
	1AT2	Grove AT880	80-24	80	26900	Boom	35	52	141	128	31603	31695	114	1	36
						Boom & P P Fly		52	142	129	31716	31727	12	0	12
						Boom, PPFly &Fixed Jib		52	143	130	31728	31855	126	1	50
					23800	Boom		52	144	131	31856	31914	103	1	25
						Boom & P P Fly		52	145	132	31915	31926	12	0	12
						Boom, PPFly &Fixed Jib		52	146	133	31927	32046	120	1	42
					14330	Boom		52	147	134	32047	32103	97	1	19
						Boom & P P Fly		52	148	135	32104	32115	12	0	12
						Boom, PPFly &Fixed Jib		52	149	136	32116	32223	106	1	30
					"No Ctwt"	Boom		52	150	137	32225	32291	60	1	2
					(~7000)	Boom & P P Fly		52	151	138	32293	32302	10	0	10
						Boom, PPFly &Fixed Jib		52	152	139	32306	32396	91	1	13
	1AT3	Krupp KMK 2035	34-19,20,21,22	34	11700	Boom	16	32	39 (verify) printed	50					
					4000	Boom		32	41 (verify) printed	51					
					11700	26'-43' Swing Away Extension		32	42 (verify) printed	52					
	1AT4	Grove AT745-34	34-14,15	34	11000	Boom	15	[redacted]							
					11000	Boom (on rubber)									
					11000	Boom & Telescopic swingaway (30ft - 54ft)									
					2200	Boom									
					2200	Boom (on rubber)									
					2200	Boom & Telescopic swingaway (30ft - 54ft)									

"Book 1"								Data Base References							
Crane Type	File #	Crane	Unit Number	Cap. (Tons)	Cwt. (lbs)	Accessories	Cost Rank	Model Master	Configuration Equipment	Index #	Settings First	Settings Last	Capacities Aprx. Qty.	# Full Pages	Last Page
Rough Terrain	1RT1	Grove RT980	80-04,05,06,07,08,09,... ...,10,12,18,19,20	80	(?)	Boom (with 3 rubber configs.)	36	45	114	106	27165	27294	197	2	37
					(?)	Boom (114ft) & Extension (32ft)		45	115	107	27295	27308	28	0	28
					(?)	Jib (28ft) & Extension (32ft)		45	117	108	27309	27339	30	0	30
					(?)	Boom & Fixed Jib		45	118	109	27340	27463	124	1	46
	1RT2	P&H Omega 65	65-07	65	9000	Boom	33	[redacted]							
					9000	Boom (on rubber)									
					9000	Jib									
	1RT3	Grove RT865	65-05	65	(?)	Boom (includes 6 rubber configs)	32	53	153	140	32397	32469	165	2	5
					(?)	Boom (88ft) & P.P. Fly Ext		53	154	141	32470	32481	17	0	17
					(?)	32' Extension (PPFly Retracted)		53	156	142	32482	32494	17	0	17
					(?)	"A" Frame Jib		53	157	143	32510	32533	24	0	24
					(?)	32' Extension (PPFly Extended)		53	159	144	32534	32547	14	0	14
	1RT4	Grove RT760	60-06,07,08	60	(?)	32'-56'Tele-Extension (PPFly Extended)	31	54	160	145	32548	32610	63	0	63
					(?)	32'-56'Tele-Extension (PPFly Retracted)		54	161	146	32611	32673	63	0	63
					(?)	32'Offsettable Extension (PPFly Extended)		54	162	147	32674	32694	21	0	21
					(?)	32'Offsettable Extension (PPFly Retracted)		54	163	148	32695	32715	21	0	21
					(?)	Boom (includes 6 rubber configs.)		54	164	149	32716	57188	133	1	55
					(?)	Boom (85ft) & P. P. Fly Ext		54	165	150	32774	32789	16	0	16
	1RT5	Grove RT755	55-02,03,04,05,06,07,08,11,12	55	(?)	Boom	30	55	166	151	32790	32848	60	0	60
					(?)	Boom (6 rubber configs.)		55	167	152	32850	32864	75	0	75
					(?)	Boom (85ft) & PPFly		55	168	153	32865	32880	16	0	16
					(?)	Boom (85') & 32' Extension (PPFly Retracted)		55	169	154	32881	32898	18	0	18
					(?)	Boom (110ft) & Extension (32ft)		55	170	155	32899	32919	21	0	21
					(?)	24ft "A" Frame Jib		55	171	156	32920	32937	18	0	18
	1RT6	Grove RT75S	50-05,06,07,08,10,15,23,24,25,26	50	(?)	Boom	28	56	172	157	32938	32996	91	1	13
					(?)	Boom (3 rubber configs.)		56	173	158	32997	33008	26	0	26
					(?)	Boom(85') & PPFly		56	174	159	33009	33024	24	0	24
					(?)	Boom(85') & 32' Extension (PPFly Retracted)		56	175	160	33025	33042	27	0	27
					(?)	Boom (110') & 32' Extension		56	176	161	33043	33061	25	0	25
					(?)	24' Fixed Jib		56	177	162	33062	33076	15	0	15
	1RT7	Grove RT740B	40-01,02	40	(?)	Boom	22	57	178	163	33077	33170	94	1	16
					(?)	Boom (with 3 rubber configs.)		57	179	164	33171	33239	166	2	6
					(?)	Offsettable Extension (32ft)		57	180	165	33240	33403	42	0	42
					(?)	32-52ft Offesttable Tele-Extension		57	181	166	33261	33399	119	1	41
	1RT8	Pettibone 70	35-02	35			20	[redacted]							
	1RT9	Grove RT65S	35-06,07,10,11,12,13	35	(?)	Boom	19	58	182	167	33404	33479	103	1	25
					(?)	Boom (with 3 rubber cofigs.)		58	183	168	33480	33491	26	0	26
					(?)	23 ft PPFly		58	184	169	33492	33506	22	0	22
					(?)	32 ft Extension (on PPFly)		58	185	170	33507	33526	23	0	23
	1RT10	Grove RT63S (Grove RT630)	30-03 (30-13,30-19)	30	(?)	Boom	13	60	189	174	33676	33722	47	0	47
					(?)	Boom (with 2 rubber configs.)		60	190	175	33723	33769	83	1	5
					(?)	Boom & Manual Fly		60	191	176	33770	33777	8	0	8
					(?)	24' Fixed Jib		60	192	177	33778	33799	22	0	22
	1RT12	Koehring Lorain LRT 275D	27-01	27.5		30-72ft Boom	10	[redacted]							
						30-72ft Boom with Jib									
						30-92ft Boom									
						30-92ft Boom with Jib									
	1RT13	Grove RT62S	25-10,12	25	(?)	Boom	8	59	186	171	33526	33587	62	0	62
					(?)	Boom (2 rubber configs.)		59	187	172	33588	33653	120	1	42
					(?)	Boom (80ft) & 24 ft Jib		59	188	173	33654	33675	22	0	22
					(?)	Boom (24-60ft) & Jib (20ft)		[redacted]							
	1RT14	Grove RT620S	20-05,08,12	20	(?)	Boom	4	61	193	178	33800	33845	46	0	46
					(?)	Boom (on rubber)		61	194	179	33846	33858	18	0	18
					(?)	Maual Fly (18ft on 60m ft Boom)		61	195	180	33859	33869	11	0	11
					(?)	Jib (fixed)		61	196	181	33870	33891	22	0	22
	1RT15*	Grove AP308 (in book1)	8-13,14	8.5	(?)	Boom	None	[redacted]							
					(?)	Tele Extension (fixed)									
											SUM		11065		
											AVERAGE		103		

BOOK 2

(CRANES WITH MAXIMUM LIFTING CAPACITY GREATER THAN ONE HUNDRED TONES)

			BOOK 2					Data Base References							
Crane Type	File #	Crane	Unit Number	Cap. (Tons)	Ctwt. (lbs)	Accessories	Cost Rank	Master (Model)	Equipment (Configuration)	Index #	Settings First	Settings Last	Capacities Aprx. Qty.	# Full Pages	Last Page
Conventional	2CV1	Demag TC4000	880-01	880	300000	Main Boom	73	17	5.	2	828	1105	284	3	22
					300000	Luffing Jib Boom		17	6.	3	828	2376	723	8	71
						SUPERLIFT with SPECIAL HAMMER HEAD ("Heavy Duty"?)			metric charts						
						SUPERLIFT with UNIVERSAL HEAD			metric charts						
						Partially Spread Outriggers			No Charts						
	2CV2	Demag TC2000	440 02	440	0	Luffing Jib Boom	72	18	4.	1	214	1778	1151	14	7
					330000	Main Boom, Hammer Head Tip		18	3.	4	1	213	213	2	53
					113 sh tons	Main Boom, Hammer Head Tip		18	55.	5	14870	15124	112	1	34
					72 sh tons	Main Boom, Hammer Head Tip		18	56.	6	15140	15282	175	2	15
						Partially Spread Outriggers			No Charts						
	2CV3 1	American 9530 (900 Series)	220 04	220	90000	92H Boom, Hammer Head ("Offset") Tip (with Rubber)	61	18	9.	7	2378	2848	855	10	39
					90000	92H Boom, Taper Tip		18	7.	19	2552	3035	577	7	7
					90000	92H Boom, Taper Tip, N°16HL Jib (fixed)		18	21.	20	4995	11404	3610	44	6
	2CV3 2	American 9530 (900 Series)	220-01,02,03,05,06	220	90000	77H Boom, Hammer Head Tip	64	23	17.	13	3038	3361	648	7	78
					90000	77H Boom, Taper Tip		23	18.	14	3363	3721	718	8	68
	2CV4	American 9520 (900 Series)	200-01,02,05,06	200	75000	77S Boom, Hammer Head Tip	60	20	13.	8	3722	4002	748	9	14
					75000	77S Boom, Taper Tip		20	11.	9	4003	4361	847	10	31
					75000	W/77S Boom, Taper Tip, N°16HL Jib (fixed)		20	222.	10	47346	51378	4028	49	14
	2CV5	American 9510 (100 Series)	175 03,04	175	60000	77" Tubular Boom, Hammer Head Tip	59	22	15.	13	4707	4989	1047	12	67
					60000	77" Tubular Boom, Taper Tip		22	16.	11	4362	4706	1296	15	70
						77" tubular Boom, TaperTip, N°16HL Jib		22	226.	12	53380	57189	5192	63	30
	2CV6	Manitowoc 3900T (series 2)	155-02	155	74000	N° 9A Boom, Hammer Hd Top	57	67	217.	202	41784	42292	509	8	21
			140-03*		74000	N° 9A Boom, Open Throat Top		67	218.	203	42293	42766	472	5	66
			delete?NO		1	Fixed Jib No123 (on N° 9A Boom, Open Throat Top)		67	219.	204	42769	44968	2204	25	158
	2CV7	American 8450	none	150	68000	77L Hammer Hd Boom (Ctwt extended)	[redacted]								
					68000	77L Hammer Hd Boom (Ctwt retracted)									
	2CV8	American 7530	125 01*,02,03	125	34000	59H Tubular, Hammer Hd Tip	55	64	205.	190	34121	34272	456	5	50
					34000	59H Tubular, Taper Tip		64	206.	191	24273	34513	603	7	33
					33700	59H Tubular Taper-Tip, N°9HL Jib		64	221.	192	45309	46857	1547	16	75
	2CV9	Lorain MC-9115	115-01	115		152ft Tower	[redacted]								
						122ft Tower									
						92ft Tower									
						62ft Tower									
						Offset Tip Extension (combination)									
						Offset Tip Extension (Hammer Head)									
Crawler	2CR1	Link-Belt LS-918	400-02	400	160000	Boom (tubular; 110"x89"dp) open throat top (80'-340')	71	26	24 (not verified) printed	22	7002	7518	518	8	28
					160000	Boom (150'-270')OpnThrt, Fixed Jib(tubular; 48"x39"dp)(40'-100')		26	25 (not verified) printed	23	7519	14033	1514	18	42
					140000	144'-244' Towers (tub., 110"x89"dp), Boom (100"x85"dp) Opn Thr Top		26	215.	200	40660	47306	658	7	66
					160000	254' Tower, Boom (100"x85"dp)			216.	201	41422	47339	213	2	53
	2CR2	Link-Belt LS-718HL	none	360	134.5+415	Boom (tubular, 110"x89"dp) open throat top	[redacted]								
					?	Jib (tubular,48"x39"dp)									
	2CR3	Manitowoc M 250	300 01	300	207k+60k	N°44 Boom, Long Reach Top	70	34	51.	59					
					167k	N°44 Boom, Long Reach Top		34	52.	60					
					207k+60k	N°44 Boom, Long Reach Top, Fixed Jib N°132		34	54.	61					
					167k	N°44 Boom, Heavy Lift Top		34	80.	62					
					167k	N°44 Boom, Heavy Lift Top, Fixed Jib N°132		34	88.	63					
					207k+60k	N°44 Boom, Heavy Lift Top (360°, Over-Front/Blocked)			GOT						
					207k+60k	N°44 Boom, Heavy Lift Top, Fixed Jib N°132			GOT						
	2CR4	Link-Belt LS-718	250-01,03	250	"A": 60k	Hvy Duty Boom (tubular,100"x85"dp), Open Throat Top	68	35	93.	81	22596	23539	267	3	25
					"AB": 134.5k	Hvy Duty Boom		35	94.	82	23822	24440	368	4	44
					"AB": 134.5k	Hvy Duty Boom (over ends)*		35	95.	83	24702	25490	366	4	42
					"AB": 134.5k	Hvy Duty Boom, Fixed Jib (tubular, 48"x39"dp)(50'-120')		35	211.	84	36471	47345	3918	47	68
					"AB": 134.5k	Tower(tubular,100"X85"dp), HvyDuty Boom		35	212.	188	40048	40782	735	9	1
					"AB": 134.5k	Tower, HvyDuty Boom, 30' Jib (tubular, 36"x30"dp)		35	214.	189	40783	40858	77	0	77
					"A": 60k	long range boom (Same specs. Why?)		[redacted]							
					"AB": 134.5k	long range boom									
						long range boom, jib tubular 36"x30"deep									
	2CR5	American 9310	225-01	225	"SS": 135k	77H tubular Hammer Hd Boom	65	66	208	185					
					"SS": 135k	77H tubular Taper Tip Boom		66	209	186					
					"SS": 135k	77H Hammer Hd Boom, No16HL Jib			have extended charts						
					"SS": 135k	77H Taper Tip Boom, No16HL Jib		66	210	187					
					"SS": 135k	92HT tubular-chord Boom		[redacted]							
						92HT , 16HL Jib									
						92HT , 30H Jib									
	2CR6	Link-Belt LS-518	150-03,05,06,07,08,11,12	150	"A": 20.5k	Boom, tubular (62"x70"dp) open throat	56	68	223.	204	51380	51553	174	2	14
					"AB": 90k	Boom, tubular (62"x70"dp) open throat		68	224.	205	51554	51843	290	3	48
					"AB": 90k	Jib, tubular (30"x36"dp)		68	225.	206	51844	53379	1526	18	54
	2CR7	American 9299	165-02,03,04	165	"P-P": 105k	77S tubular, Hammer Hd Boom	58	65	207.	193					
					"P-P": 105k	77S tubular, Taper Tip Boom		65	220.	194					
						77S tubular, Taper Tip Boom, No16HL Jib			(Possible) no charts ORDER						

BOOK 2								Data Base References							
Crane Type	File #	Crane	Unit Number	Cap. (Tons)	Ctwt. (lbs)	Accessories	Cost Rank	Master (Model)	Equipment (Configuration)	Index #	Settings First	Settings Last	Capacities Aprx Qty.	# Full Pages	Last Page
Telescopic	2T1	Krupp KMK 8350	450-01	450	132280	Boom (55'-171')	45	25	19 (not verified) PRINTED	16					
					132280	Boom Extension (on 184' Boom)		25	20 (not verified)PRINTED	17					
					66140	Boom		25	26 (not verified)PRINTED	18					
					132280	Power Luffing Jib (on 98' - 169' Booms)		25	27 (not verified)PRINTED	19					
	2T2	Liebherr LT1200	272-01	272	72730	Boom (54'-180')	44	29	53 (not verified)PRINTED	29					
					32000	Boom (54'-180')		29	57 (not verified) PRINTED	30					
					57300	Boom (54'-180')		29	58 (not verified) PRINTED	31					
					57300	Luffing Fly Jib(36'-124') (on 96'-180' Booms)		29	59,	32					
					57300(or7275	Fixed Fly Jib (138'-180') (on 65'&95' Booms)		29	62,	33					
					57300	Folding Fly Jib (49'&75') (on 160'&180' Booms)	44	29	63,	34					
	2T3	Grove TM1500	150-13	150	15700	Boom (46'-141') PPFly Retracted	42	36	73,	67					
					15700	P P Fly Extended (32', on 141' Boom)		36	74,	68					
					15700	Tele-Extension (33'-58') (on173' Boom, P P Fly Extended)		36	75,	69					
	2T4	Grove TM1400	140-01,02*,05,08	140	15700	Boom (46' - 141')	40	28	28,	24					
					15700	P P Fly (32') (on 141' Boom)		28	29,	25					
					15700	P P Fly (32') & 32 ft Extension (on 141' Boom)		28	30,	26					
					15700	Luffing Jib (on 173' boom, PPFly extended)		28	78,	27					
					15700	Fixed Jib (46'-88') (on 173' boom, PPFly extended)		28	79,	28					
	2T5	Grove TM1275	None	125			None	[illegible]	[illegible]	None [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
All Terrain	2AT1	Demag AC335	165-01	165	88000	Boom (42'-164')	43	30	32,	34	7849	8077	126	1	48
					60000	Boom (42'-164')		30	36,	35	8133	8406	143	1	65
					24000	Boom (42'-164')		30	40,	36	8408	53368	133	1	55
					0	Boom (42'-164')		30	43,	37	8615	8794	114	1	36
					60000	Tele-Extension (33' & 56')		30	44,	38	9075	9190	115	1	37
					88000	Tele-Extension (33' & 56')		30	45,	39	8949	9071	123	1	45
					24000	Tele-Extension (33' & 56')		30	47,	41	9203	9280	78	1	0
					24000	Luffing Fly Jib (59',79',98',118')		30	46,	40	8795	8947	152	1	74
					24000	Fixed Jib (39',59',79',98') (3°, 20° offsets)		30	49,	42	9282	9364	82	1	4
					60000	Fixed Jib (39',59',79',98') (3°, 20° offsets)		30	50,	43	9366	9475	99	1	21
	2AT2	Grove AT1500	150-14	150	77200	Boom (45'-140') 4-Section, Telescoping (Includes Fly Extended)	41	33	64,	53					
					77200	Boom (45'-140') 4-Section, Pinned		33	65,	64					
					77200	33'-58' Tele-Extension (on 140' Boom)		33	66,	54					
					32850	Boom (45'-140') 4-Section, Telescoping (Includes Fly Extended)		33	67,	55					
					32850	Boom (45'-140') 4-Section, Pinned		33	68,	65					
					32850	33'-58' Tele-Extension (on 140' Boom)		33	69,	56					
					0	Boom (45'-140') 4-Section, Telescoping (Includes Fly Extended)		33	70,	57					
					0	Boom (45'-140') 4-Section, Pinned		33	71,	66					
					32850(or7720	Fixed Offset Jib (48'-88') (on 140' Boom)		33	72,	58					
	2AT3	Grove AT1400	140-06,07	140	14110	Boom (44'8"-140'4") (Includes P P Ext'd)	39	38	85,	74					
					32850	Boom (44'8"-140'4") (Includes P P Ext'd)		38	86,	75					
					0	Boom (44'8"-140'4") (Includes P P Ext'd)		38	87,	76					
					14110	33' Fixed Swingaway		38	89,	77					
					14110	33'-58' Telescopic Swingaway		38	90,	78					
					32850	33' Fixed Swingaway		38	91,	79					
					32850	33'-58' Telescopic Swingaway		38	92,	80					
											SUM		39782		
											AVERAGE		865		

APPENDIX (D)

SAMPLE OF DATABASE CODE

(CRANES TABLE AND ITS RELATIONSHIP TO OTHER TABLES)

Properties

Date Created:	9/18/97 11:03:43 AM	Def. Updatable:	True
Description:	List of cranes and crane attributes.	Last Updated:	8/17/98 9:22:30 AM
OrderByOn:	False	RecordCount:	46

Columns

Name		Type	Size
MasterID		Number (Long)	4
	AllowZeroLength:	False	
	Attributes:	Fixed Size, Auto-Increment	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	975	
	Description:	Database serial number	
	Ordinal Position:	1	
	Required:	False	
	Source Field:	MasterID	
	Source Table:	Cranes	
Mfr		Text	25
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Caption:	Manufacturer	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	1410	
	Description:	Crane manufacturer	
	DisplayControl:	Text Box	
	Ordinal Position:	2	
	Required:	True	
	Source Field:	Mfr	
	Source Table:	Cranes	
Series		Text	10
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	750	
	Description:	Crane series number	
	DisplayControl:	Text Box	
	Ordinal Position:	3	
	Required:	False	
	Source Field:	Series	
	Source Table:	Cranes	

Model		Text	10
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Caption:	Model	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	735	
	Description:	Crane model number	
	DisplayControl:	Text Box	
	Ordinal Position:	4	
	Required:	True	
	Source Field:	Model	
	Source Table:	Cranes	
Type		Text	2
	AllowZeroLength:	True	
	Attributes:	Variable Length	
	Bound Column:	1	
	Caption:	Type	
	Collating Order:	General	
	Column Count:	1	
	Column Heads:	False	
	Column Widths:	1440	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	615	
	Description:	Crane type: 1-Conventional Truck; 2-Crawler; 3-Telescopic Truck; 4-Rough Terrain; 5-All Terrain. See CraneTypes table	
	DisplayControl:	Combo Box	
	Input Mask:	>L	
	Limit To List:	False	
	List Rows:	8	
	List Width:	1440twip	
	Ordinal Position:	5	
	Required:	True	
	Row Source Type:	Table/Query	
	Row Source:	SELECT DISTINCTROW [CraneTypes].[Crane Type] FROM [CraneTypes];	
	Source Field:	Type	
	Source Table:	Cranes	
bmf2c		Text	10
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	720	
	Description:	Locate the position of the boom mountings	
	DisplayControl:	Text Box	
	Ordinal Position:	6	
	Required:	False	
	Source Field:	bmf2c	

	Source Table:	Cranes	
bmf2f		Text	10
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	675	
	Description:	Locate the position of the boom mountings	
	DisplayControl:	Text Box	
	Ordinal Position:	7	
	Required:	False	
	Source Field:	bmf2f	
	Source Table:	Cranes	
hyddista		Text	10
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	945	
	Description:	Distance for hydraulic boom pin location	
	DisplayControl:	Text Box	
	Ordinal Position:	8	
	Required:	False	
	Source Field:	hyddista	
	Source Table:	Cranes	
hyddistb		Text	10
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	945	
	Description:	Distance for hydraulic boom pin location	
	DisplayControl:	Text Box	
	Ordinal Position:	9	
	Required:	False	
	Source Field:	hyddistb	
	Source Table:	Cranes	
hydsistc		Text	10
	AllowZeroLength:	False	
	Attributes:	Variable Length	
	Collating Order:	General	
	ColumnHidden:	False	
	ColumnOrder:	Default	
	ColumnWidth:	900	
	Description:	Distance for hydraulic boom pin location	
	DisplayControl:	Text Box	
	Ordinal Position:	10	

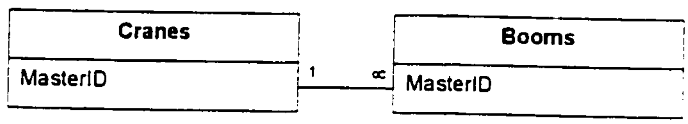
Required:	False	
Source Field:	hydsistc	
Source Table:	Cranes	
hydmaxboomlength	Text	50
AllowZeroLength:	False	
Attributes:	Variable Length	
Collating Order:	General	
ColumnHidden:	False	
ColumnOrder:	Default	
ColumnWidth:	2055	
Description:	Distance for hydraulic boom pin location	
DisplayControl:	Text Box	
Ordinal Position:	11	
Required:	False	
Source Field:	hydmaxboomlength	
Source Table:	Cranes	
Validation Text:	You cannot have negative numbers	
Picture	OLE Object	
AllowZeroLength:	False	
Attributes:	Variable Length	
Collating Order:	General	
ColumnHidden:	False	
ColumnOrder:	Default	
ColumnWidth:	Default	
Description:	Picture of this type of crane	
Ordinal Position:	12	
Required:	False	
Source Field:	Picture	
Source Table:	Cranes	
MiscData1	Text	10
AllowZeroLength:	False	
Attributes:	Variable Length	
Collating Order:	General	
ColumnHidden:	False	
ColumnOrder:	Default	
ColumnWidth:	Default	
Description:	Max Length	
DisplayControl:	Text Box	
Ordinal Position:	13	
Required:	False	
Source Field:	MiscData1	
Source Table:	Cranes	
MiscData2	Text	10
AllowZeroLength:	False	
Attributes:	Variable Length	
Collating Order:	General	
ColumnHidden:	False	
ColumnOrder:	Default	
ColumnWidth:	Default	
Description:	Width	

Rank	Number (Integer)	2

AllowZeroLength:	False
Attributes:	Fixed Size
Collating Order:	General
ColumnHidden:	False
ColumnOrder:	Default
ColumnWidth:	Default
Decimal Places:	0
Default Value:	0
Description:	Cost/Usability ranking
DisplayControl:	Text Box
Ordinal Position:	30
Required:	False
Source Field:	Rank
Source Table:	Cranes

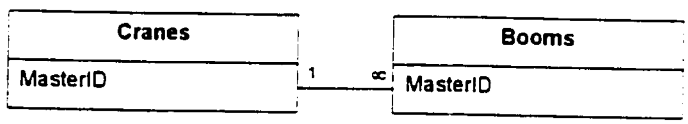
Relationships

CranesBooms



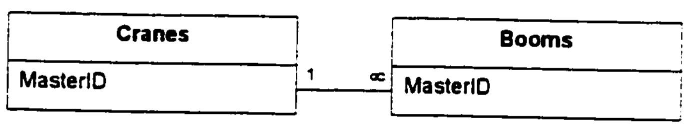
Attributes:	Enforced, Cascade Updates, Cascade Deletes
Attributes:	One-To-Many

CranesBooms1



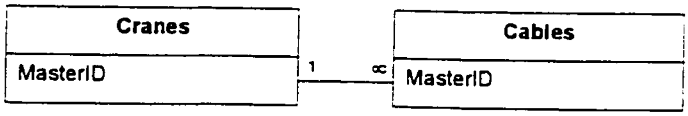
Attributes:	One-To-Many
Attributes:	Enforced, Cascade Updates, Cascade Deletes

CranesBooms2



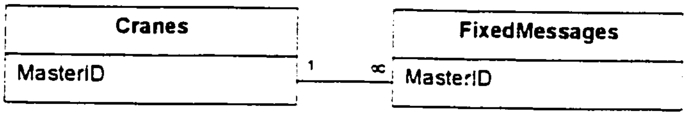
Attributes:	One-To-Many
Attributes:	Enforced, Cascade Updates, Cascade Deletes

CranesCables



Attributes: One-To-Many
Attributes: Enforced, Cascade Updates, Cascade Deletes

CranesFixedMessages

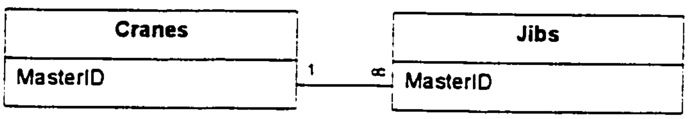


Attributes: Enforced, Cascade Updates, Cascade Deletes, Right Join
Attributes: One-To-Many

CranesHooks

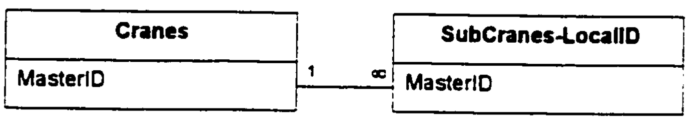
Attributes: Enforced, Cascade Updates, Cascade Deletes
Attributes: One-To-Many

CranesJibs



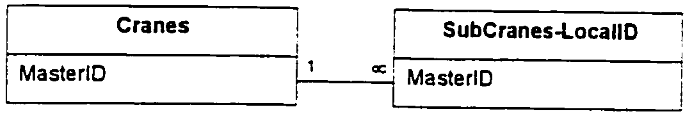
Attributes: One-To-Many
Attributes: Enforced, Cascade Updates, Cascade Deletes

CranesLocalCraneLookup1



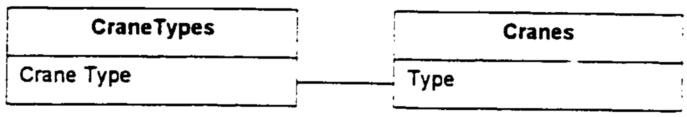
Attributes: One-To-Many
Attributes: Enforced, Cascade Updates, Cascade Deletes

CranesSubCranes-LocalID



Attributes:	One-To-Many
Attributes:	Enforced, Cascade Updates, Cascade Deletes, Right Join

CraneTypesCranes



Attributes:	Not Enforced
Attributes:	Indeterminate

Table Indexes

Name		Number of Fields
MasterID		1
	Clustered:	False
	Distinct Count:	40
	Foreign:	False
	Ignore Nulls:	False
	Name:	MasterID
	Primary:	False
	Required:	False
	Unique:	False
	Fields:	MasterID, Ascending
PrimaryKey		1
	Clustered:	False
	Distinct Count:	40
	Foreign:	False
	Ignore Nulls:	False
	Name:	PrimaryKey
	Primary:	True
	Required:	True
	Unique:	True
	Fields:	MasterID, Ascending
Type		1
	Clustered:	False
	Distinct Count:	7
	Foreign:	False
	Ignore Nulls:	False
	Name:	Type

APPENDIX (E)

SAMPLES OF SYSTEM OUTPUTS

CRANE SELECTION MODULE OUTPUTS

REPLACEMENT OF CONCORDIA UNIVERSITY HVAC SYSTEM

Lift Plan Details

GUAY

Branch: Montreal
Sale's Rep.: Gaston
Date: 7/5/99

Contact	Alain Dubuc
Company	Concordia University HVAC System
Address	1255 rue St-Amour
Address	
City	Ville St-Laurent
Province:	Qc
Post Code	H4S 1T4
Telephone	(514) 336-5717
Fax	(514) 336-8757

Building Information

H1:	ft	D1:	ft
H2:	151ft	D2:	26ft
H3:	197ft	D3:	72ft

Max Radius: ft
Min Boom Clearance: N/A

Lift Dimensions

Length:	23ft
Width:	23ft
Height:	10ft

Capacity Information

Lift Weight:	40000lb
Sheave Block	4938lb
Slings	1201lb
Spreader Beam	N/A
Total lift weight	**46139lb**
Gross Capacity	**55000lb**

Crane Unit

Manufacturer:	Demag
Model:	TC2000
Boom:	Main
Accessory:	Jib
Counterweight:	lb

Carrier Dimensions

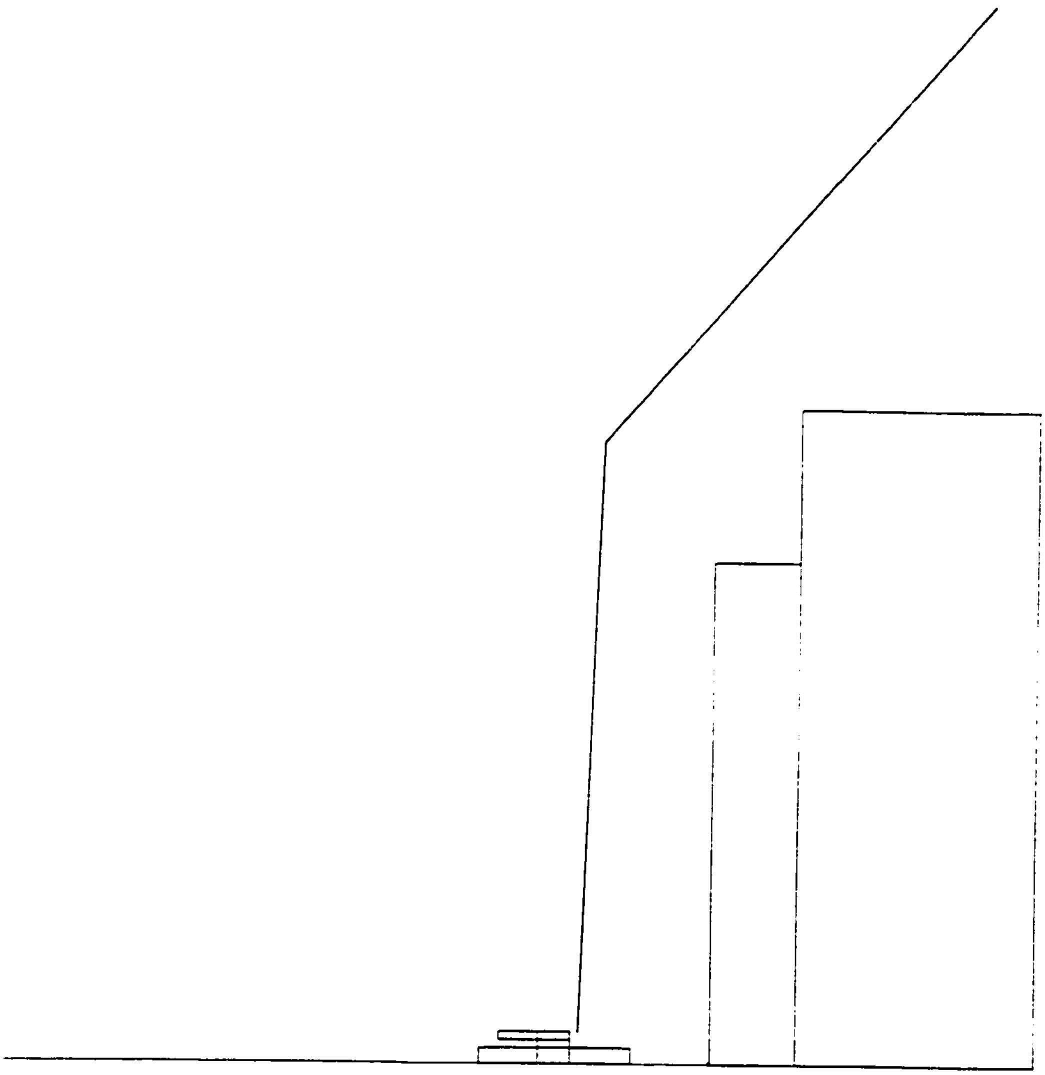
Front to Centre:	32
Rear to Centre:	22
Support Length:	46
Support Width:	46

Crane Location

Boom Length:	177
Boom Angle:	88°
Jib Type:	Luffing Jib
Jib Length:	177
Jib Angle/Offset:	39.31°
Lift Radius:	138
Tip Height:	322
Failure Type:	Structural
Lifting Zone:	All - 360

Equipment/Attachment

Sling Height:	10



Scale 1:700

Notes

1)Capacities do not exceed 85% / 75% of tipping load 2)Maximum wind pressure: 15 kg/m2, approx. 15.5 m/s (85%) and 25 kg/m2, approx. 20 m/s (75%). 3)Crane operation up to a wind force of 5 degrees Beaufort scale (5 kg/m2; approx. 9 m/s) permissible. 4)The weights of all load-handling devices are considered part of the load, and suitable allowance should be made for them 5)The 75% crane ratings furthermore comply with DIN 150 19,2 (test load = 1.25 x lifting load + 0.1 x dead weight of boom reduced to the boom point). 6)Based on a main boom angle of 88 degrees.

ross Capacity: *The maximum weight of the load to be lifted including hook block, slings, lifting beams, etc.*

orking Radius: *Maximum distance from the centre of rotation to the hook block.*

DIGESTER RETROFIT (INDUSTRIAL PLANT)

Lift Plan Details

Building Information			
H1:	ft	D1:	ft
H2:	79ft	D2:	52ft
H3:	226ft	D3:	10ft
Max Radius:	ft		
Min Boom Clearance:	N/A		

Contact	Bob Lawerence
Company	Digester Retrofit replacement
Address	8008 Corporate Centre Drive
Address	
City	Charlotte, NC 28226
Province:	Qc
Post Code	
Telephone	(704) 514-1453
Fax	

GUAY

Branch: Montreal
Sale's Rep.: Mohamed Al-Hussein
Date: 7/5/99

Lift Dimensions

Length:	20ft
Width:	20ft
Height:	36ft

Capacity Information

Lift Weight:	165563lb
Sheave Block	5000lb
Slings	3249lb
Spreader Beam	N/A
Total lift weight	**173812lb**
Gross Capacity	**174000lb**

Crane Unit

Manufacturer:	Demag
Model:	TC4000
Boom:	Main
Accessory:	N/A
Counterweight:	165000lb

Carrier Dimensions

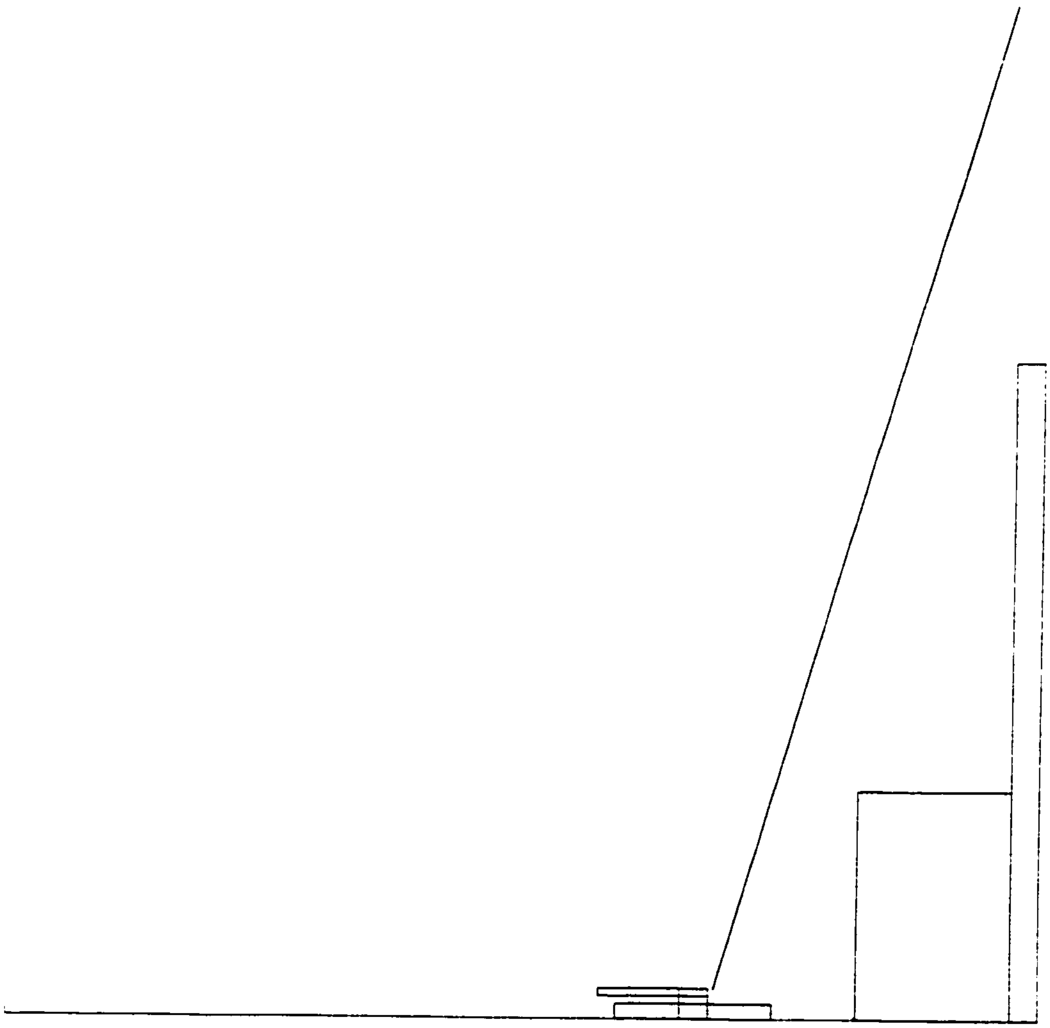
Front to Centre:	40
Rear to Centre:	22
Support Length:	54
Support Width:	54

Crane Location

Boom Length:	354
Boom Angle:	73.36°
Jib Type:	N/A
Jib Length:	N/A
Jib Angle/Offset:	N/A
Lift Radius:	112
Tip Height:	348
Failure Type:	Structural
Lifting Zone:	All - 360

Equipment/Attachment

Sling Height:	36



Scale 1:800

Notes

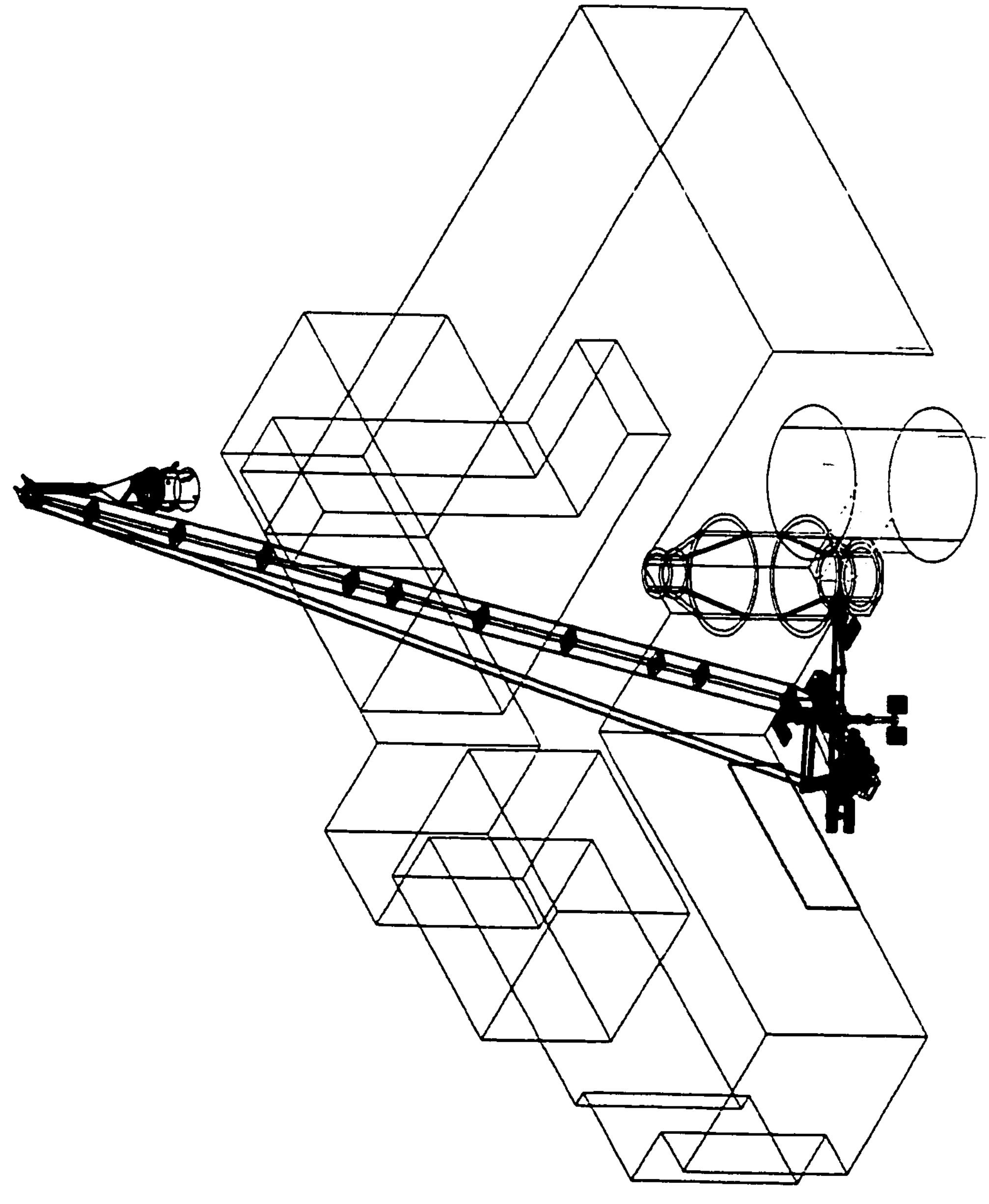
1)Capacities do not exceed 85% / 75% of tipping load. 2)Maximum wind pressure: 15 kg/m2; approx. 15.5 m/s (85%) and 25 kg/m2; approx. 20 m/s (75%). 3)Crane operation up to a wind force of 5 degrees Beaufort scale (5 kg/m2; approx. 9 m/s) permissible. 4)The weights of all load-handling devices are considered part of the load, and suitable allowance should be made for them. 5)The 75% crane ratings furthermore comply with DIN 150 19,2 (test load = 1.25 x lifting load + 0.1 x dead weight of boom reduced to the boom point). 6)Lifting capacities for a supporting base of 32' 10" (10m) are furnished upon request.

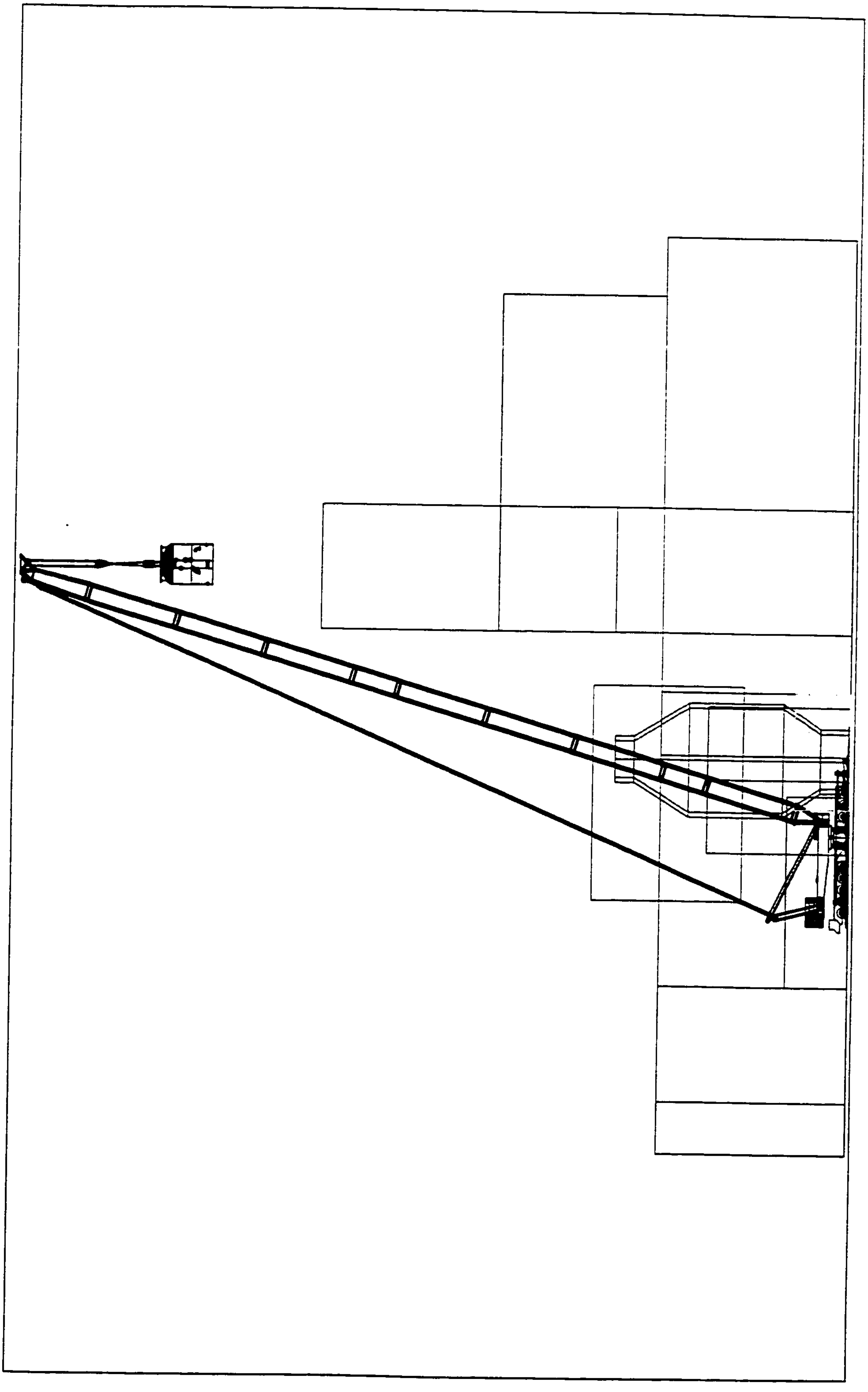
ross Capacity: *The maximum weight of the load to be lifted including hook block, slings, lifting beams, etc.*

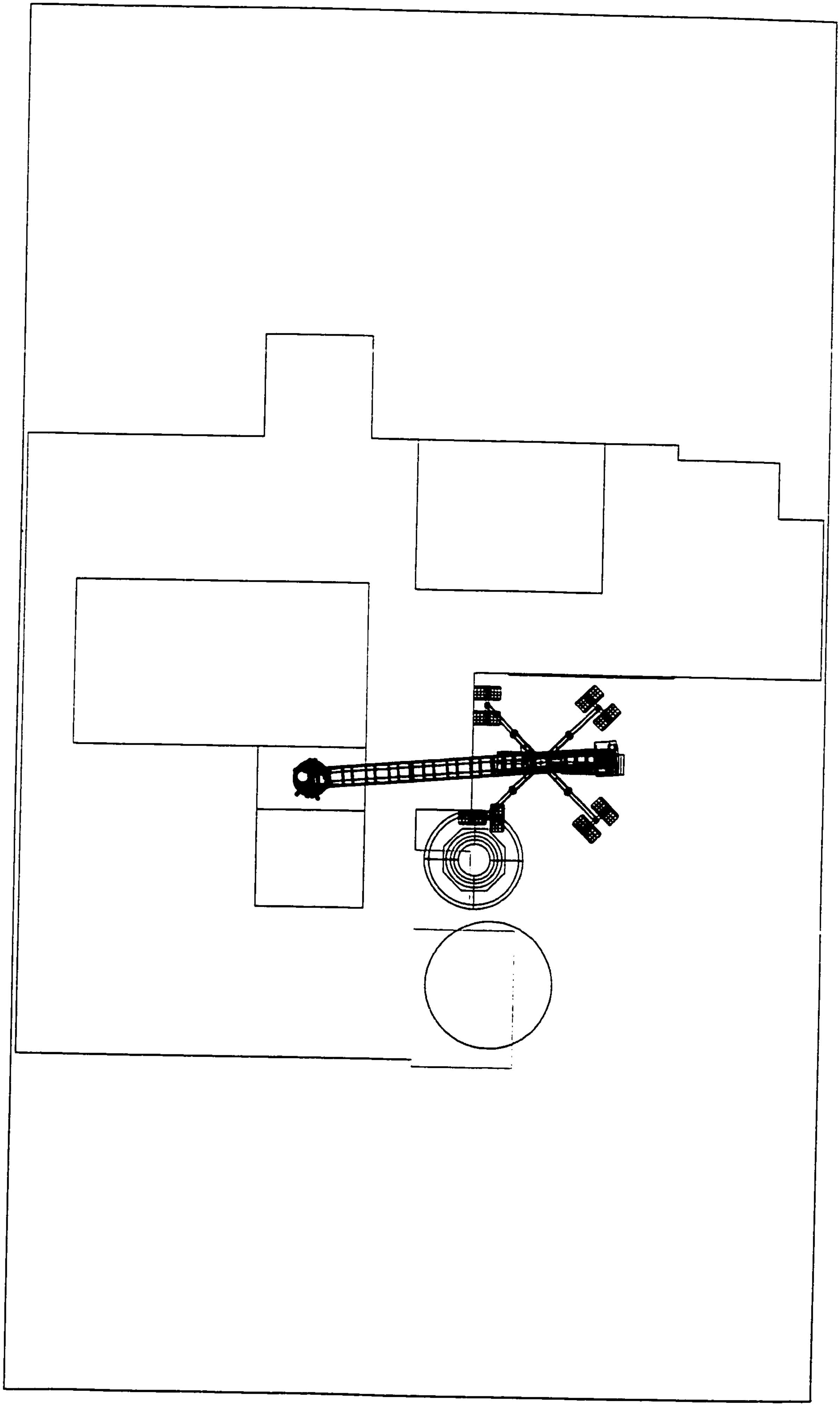
orking Radius: *Maximum distance from the centre of rotation to the hook block.*

3D MODULE OUTPUTS

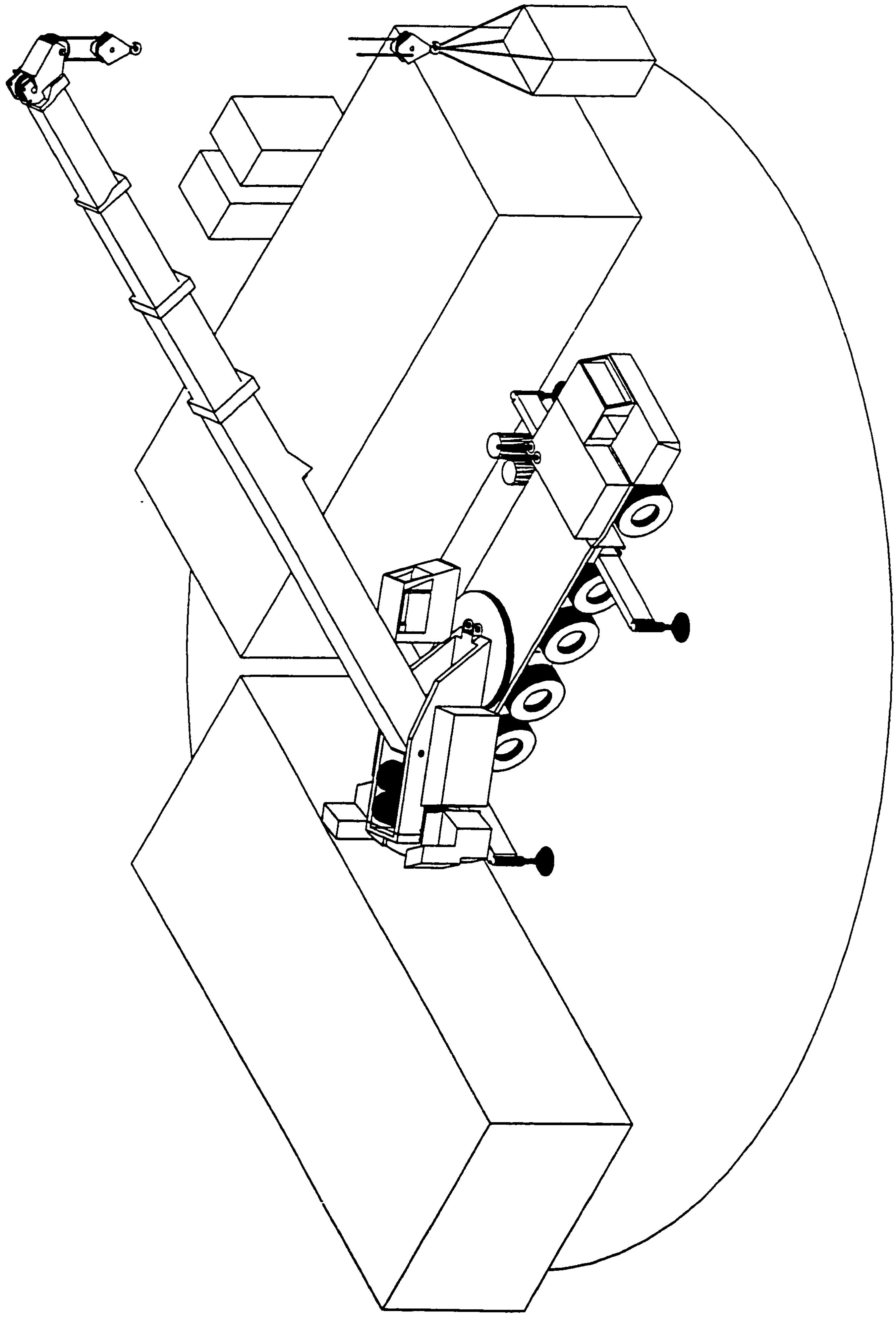
DIGESTER RETROFIT (INDUSTRIAL PLANT)

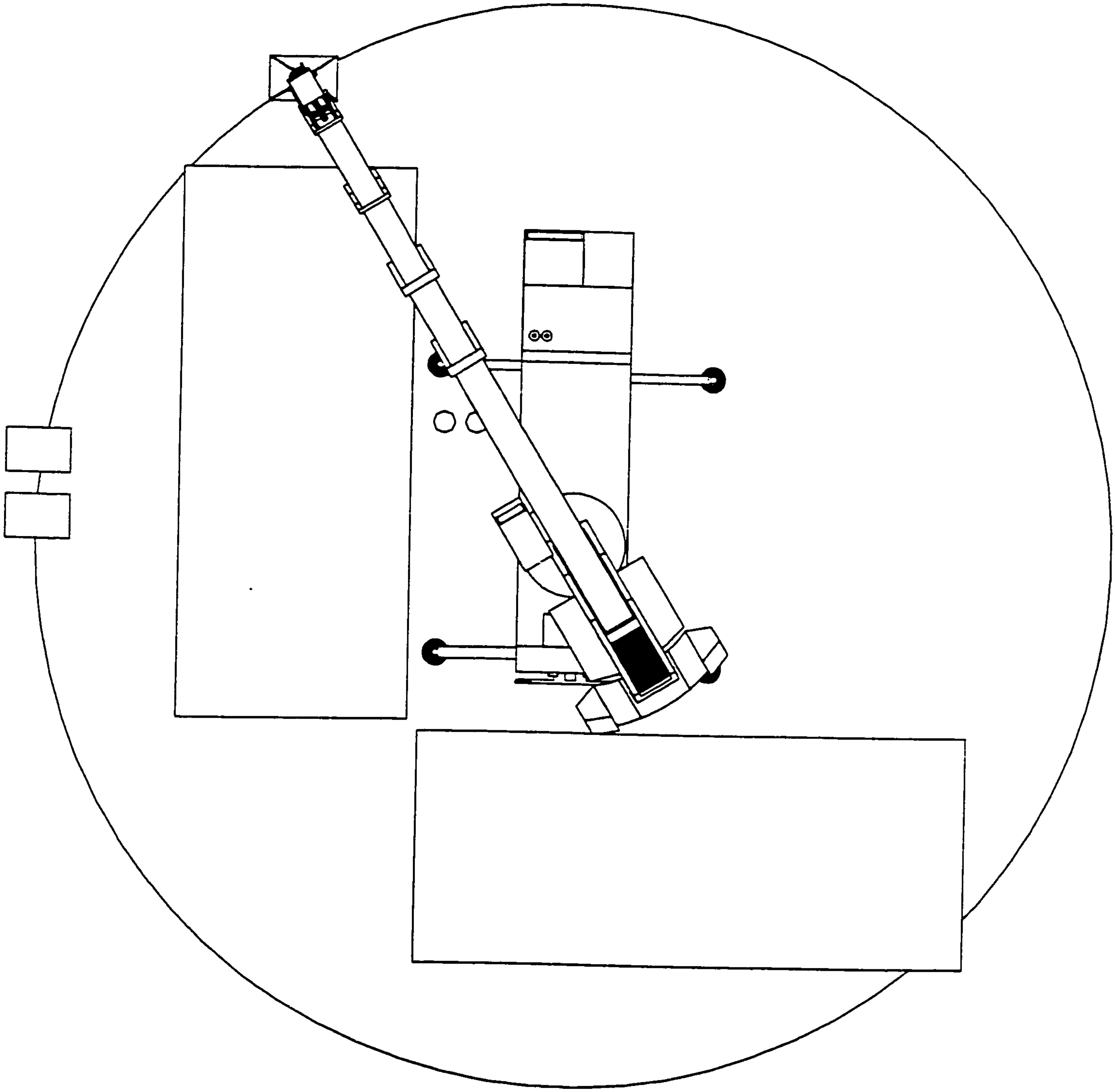


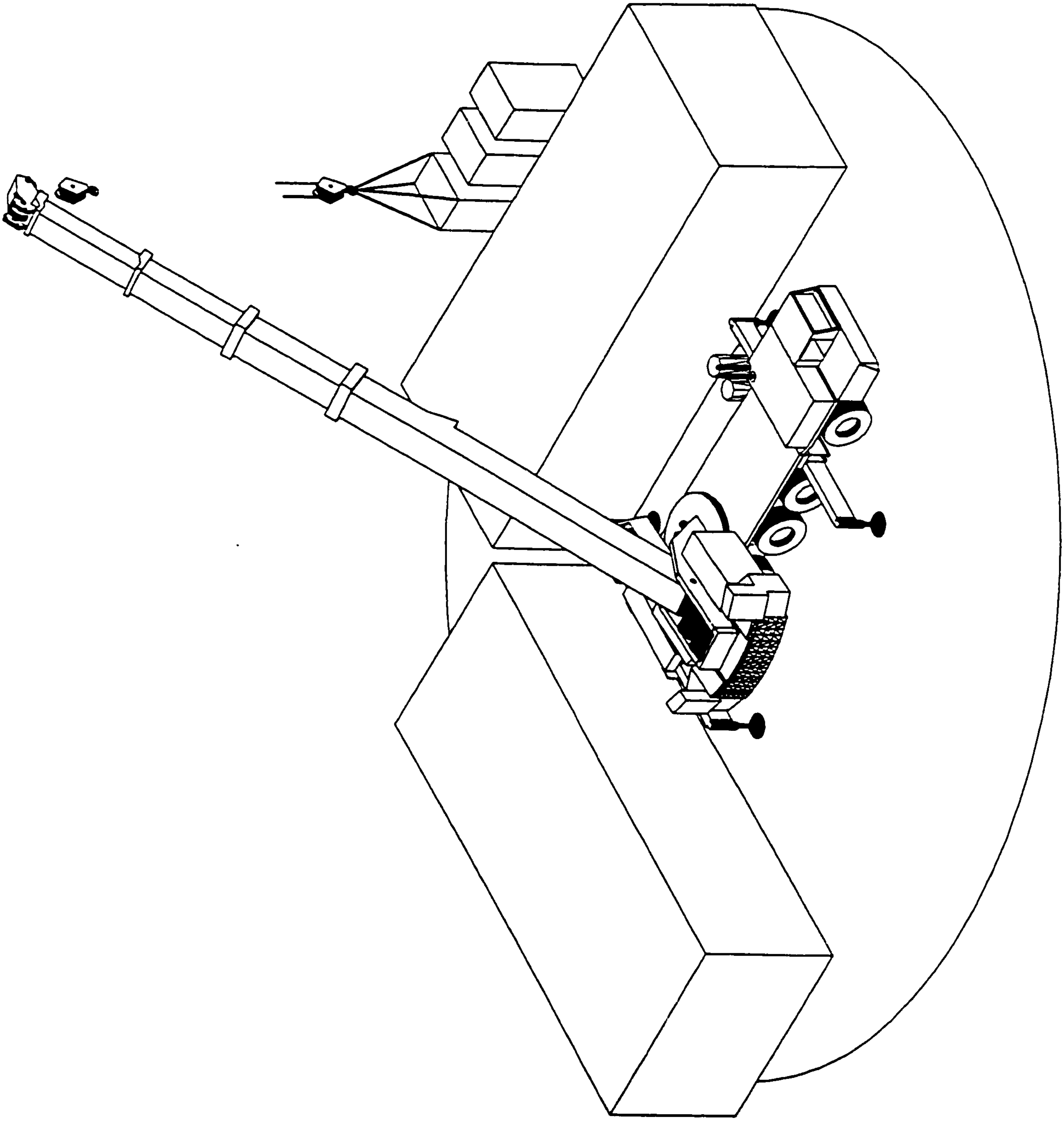


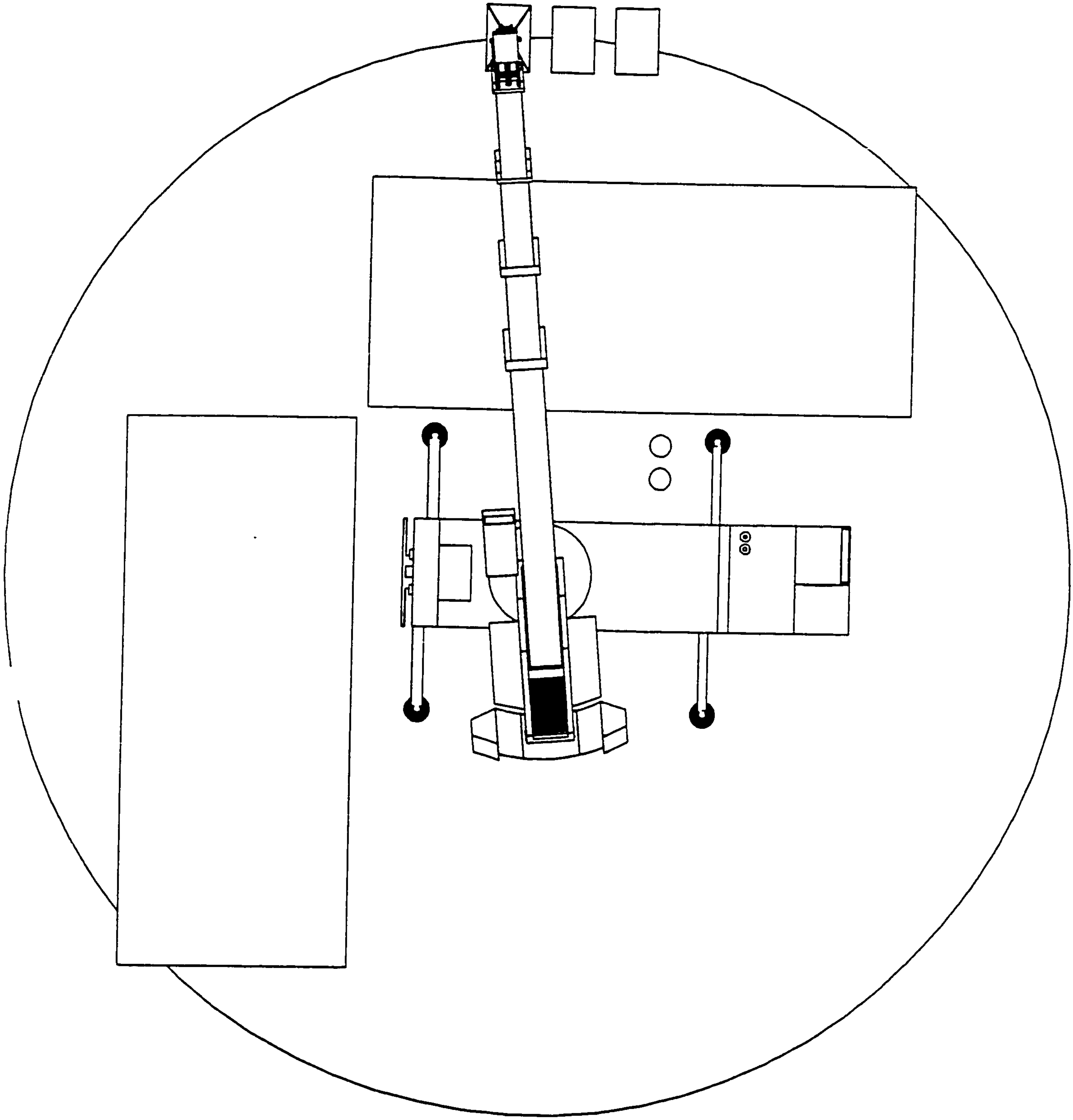


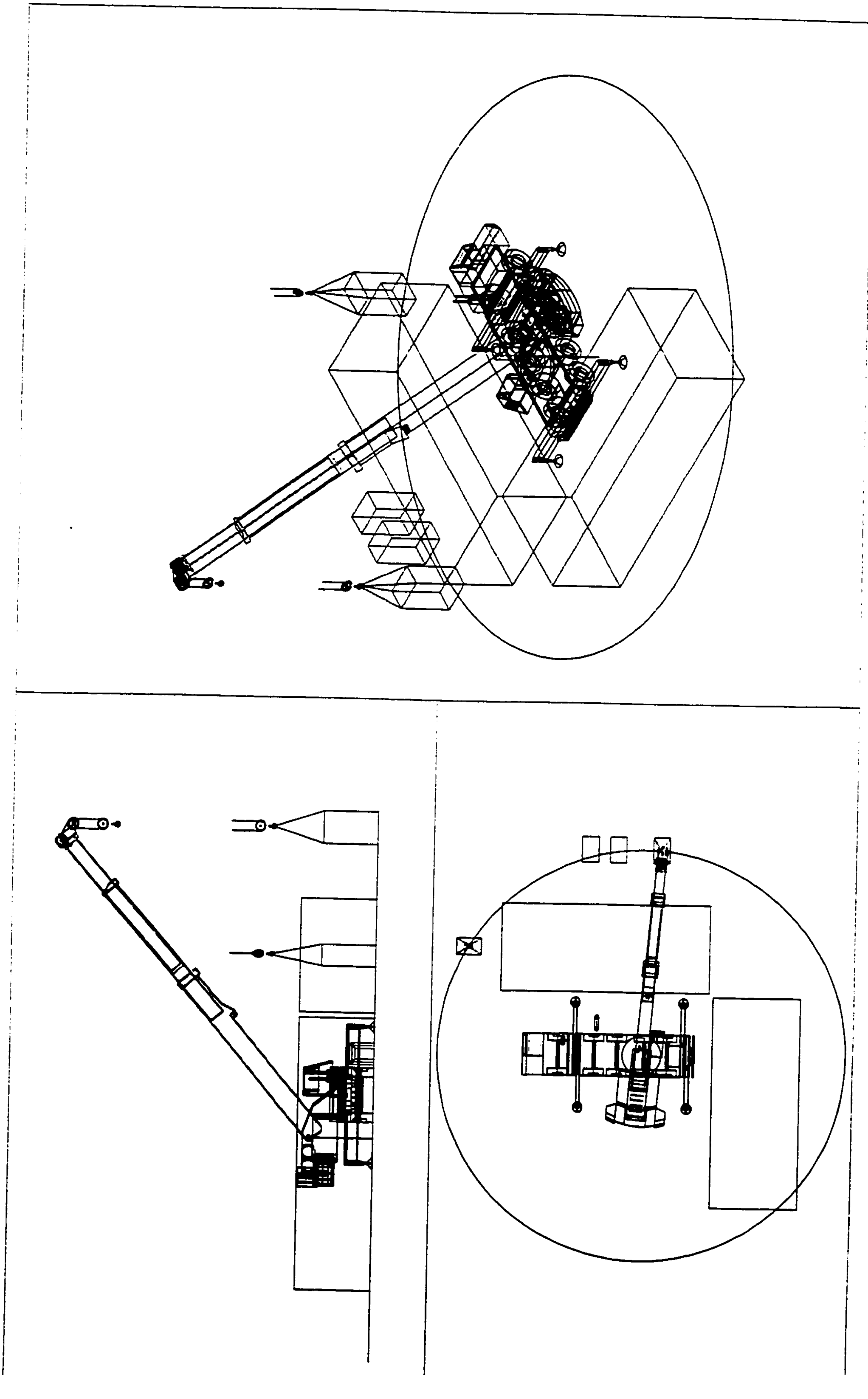
Replacement of Power Station Transferals





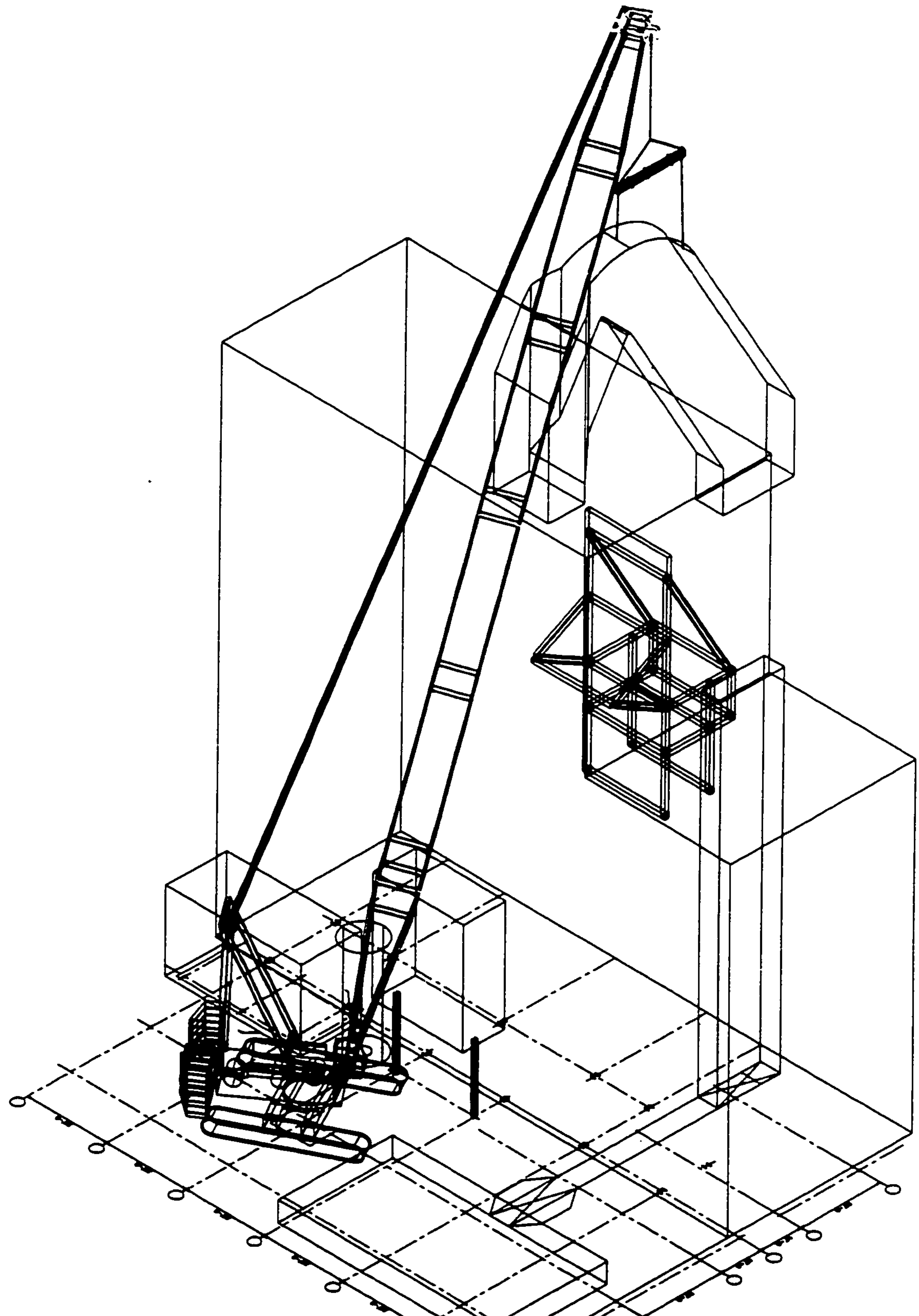


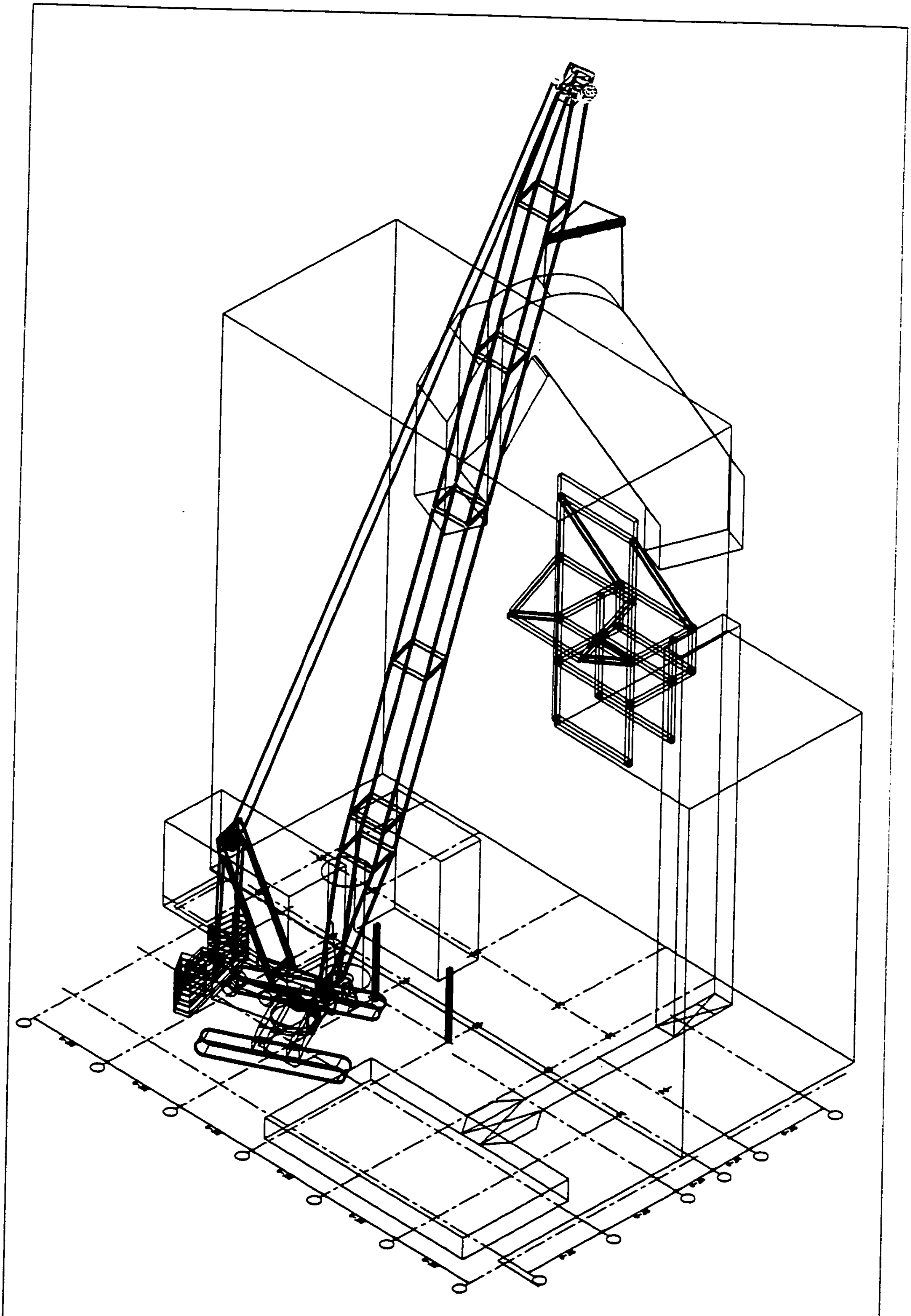


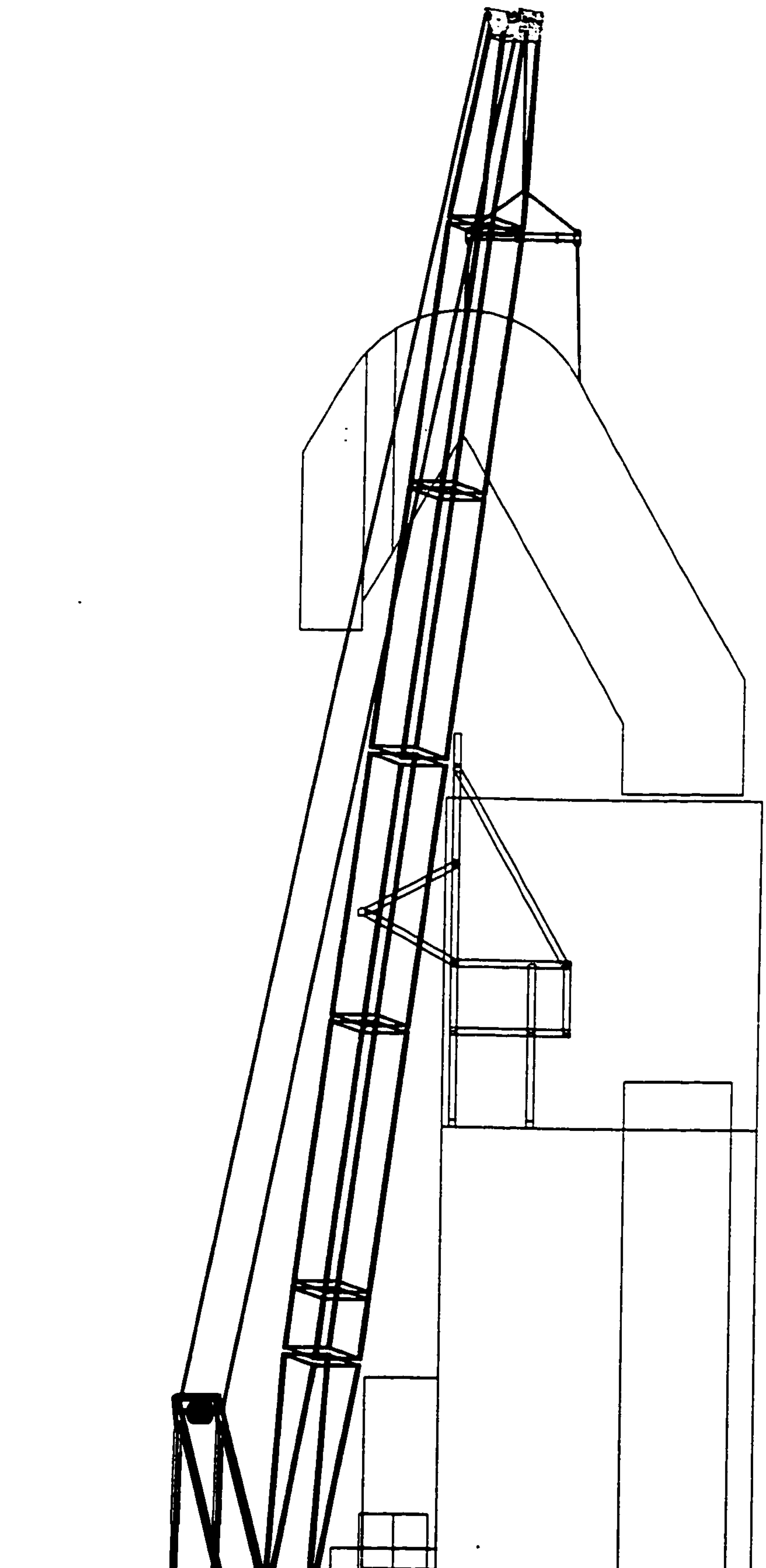


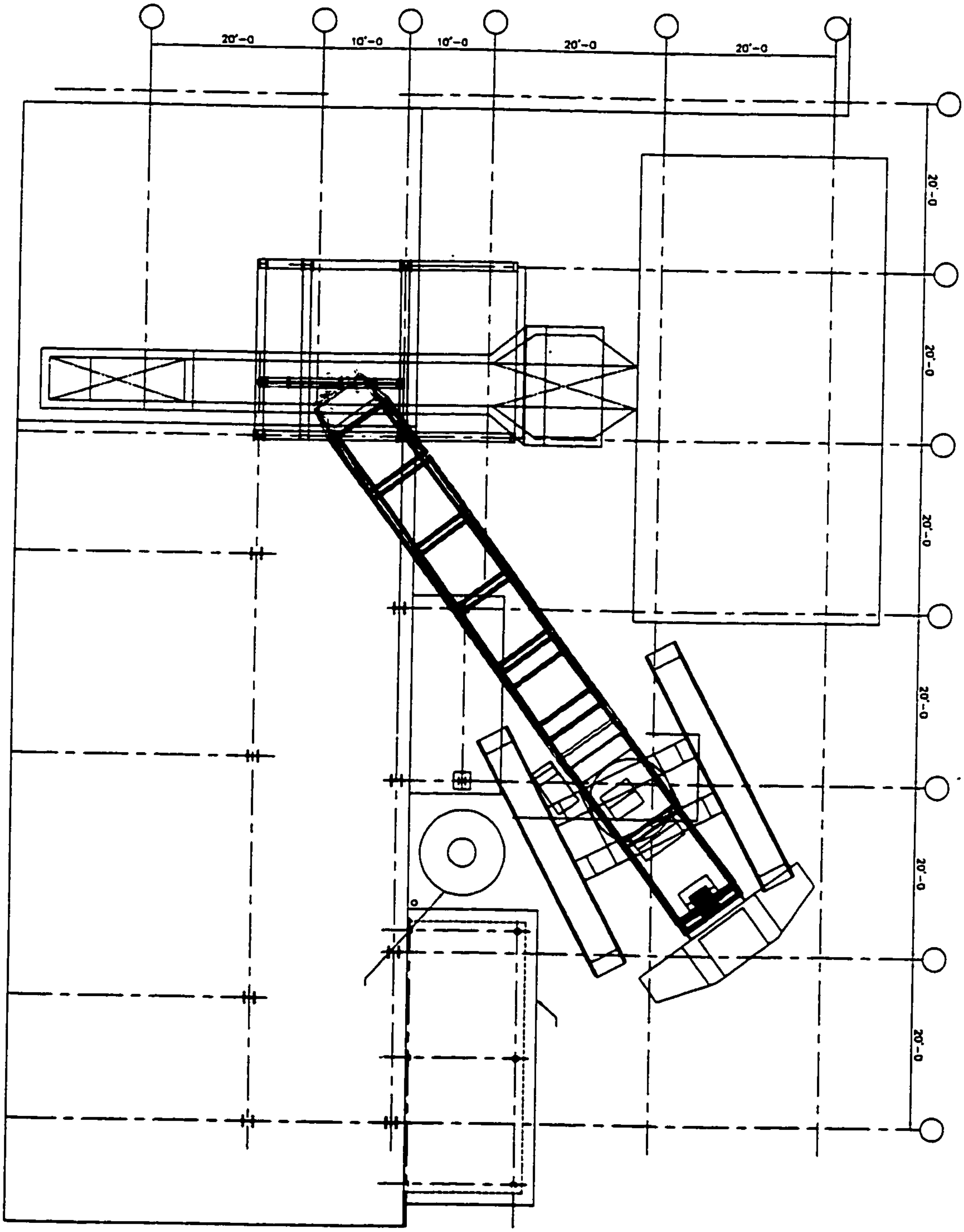
REPLACEMENT OF GOOSENECK CHIMNEY

(INDUSTRIAL PLANT)








20'-0
10'-0
10'-0
20'-0
20'-0
20'-0
20'-0
20'-0
20'-0
20'-0
20'-0

APPENDIX (F)

CRANES DATABASE SAMPLE RIPORT

Verification of capacities for E: 4 **IMPERIAL**

SettingID	Boom Length	Radius	Tip Height	Boom Angle	Jib Length	Jib Angle	Capacity	Support	Zone	Failure
214	59	39	127	88	59	19.65	260000	S - Outriggers SET	All - 360	•
215	59	46	123	88	59	27.18	246000	S - Outriggers SET	All - 360	•
217	59	53	118	88	59	35.41	206000	S - Outriggers SET	All - 360	•
218	59	59	112	88	59	43.44	169400	S - Outriggers SET	All - 360	•
219	59	66	102	88	59	54.78	148600	S - Outriggers SET	All - 360	•
220	59	39	148	88	79	14.02	244000	S - Outriggers SET	All - 360	•
221	59	46	146	88	79	19.35	228000	S - Outriggers SET	All - 360	•
222	59	53	142	88	79	24.91	208000	S - Outriggers SET	All - 360	•
223	59	59	138	88	79	29.97	181600	S - Outriggers SET	All - 360	•
224	59	66	133	88	79	36.24	158400	S - Outriggers SET	All - 360	•
225	59	72	127	88	79	42.13	138600	S - Outriggers SET	All - 360	•
226	59	79	119	88	79	49.95	122200	S - Outriggers SET	All - 360	•
227	59	85	109	88	79	58.16	108000	S - Outriggers SET	All - 360	•
228	59	46	166	88	98	15.07	204000	S - Outriggers SET	All - 360	•
229	59	53	163	88	98	19.39	193600	S - Outriggers SET	All - 360	•
230	59	59	160	88	98	23.23	181600	S - Outriggers SET	All - 360	•
231	59	66	156	88	98	27.85	165000	S - Outriggers SET	All - 360	•
232	59	72	152	88	98	32.01	145200	S - Outriggers SET	All - 360	•
233	59	79	147	88	98	37.16	128000	S - Outriggers SET	All - 360	•
234	59	85	141	88	98	41.95	113400	S - Outriggers SET	All - 360	•
235	59	92	133	88	98	48.07	100200	S - Outriggers SET	All - 360	•
236	59	98	124	88	98	54.11	89400	S - Outriggers SET	All - 360	•
237	59	46	187	88	118	12.12	168400	S - Outriggers SET	All - 360	•
238	59	53	185	88	118	15.64	165000	S - Outriggers SET	All - 360	•
239	59	59	182	88	118	18.73	160600	S - Outriggers SET	All - 360	•
240	59	66	179	88	118	22.40	155600	S - Outriggers SET	All - 360	•
241	59	72	176	88	118	25.65	147400	S - Outriggers SET	All - 360	•
242	59	79	172	88	118	29.57	132600	S - Outriggers SET	All - 360	•
243	59	85	168	88	118	33.10	118800	S - Outriggers SET	All - 360	•
244	59	92	162	88	118	37.40	105600	S - Outriggers SET	All - 360	•
245	59	98	156	88	118	41.34	93600	S - Outriggers SET	All - 360	•
246	59	112	140	88	118	51.84	75200	S - Outriggers SET	All - 360	•
247	59	53	206	88	138	13.02	138600	S - Outriggers SET	All - 360	•
248	59	59	204	88	138	15.63	135600	S - Outriggers SET	All - 360	•
249	59	66	201	88	138	18.69	132000	S - Outriggers SET	All - 360	•
250	59	72	198	88	138	21.38	127600	S - Outriggers SET	All - 360	•
251	59	79	195	88	138	24.58	123200	S - Outriggers SET	All - 360	•
252	59	85	192	88	138	27.42	116600	S - Outriggers SET	All - 360	•
253	59	92	187	88	138	30.83	104600	S - Outriggers SET	All - 360	•
254	59	98	183	88	138	33.86	96800	S - Outriggers SET	All - 360	•
255	59	112	171	88	138	41.50	79600	S - Outriggers SET	All - 360	•
256	59	125	156	88	138	49.65	67800	S - Outriggers SET	All - 360	•
257	59	138	135	88	138	59.74	58800	S - Outriggers SET	All - 360	•
258	59	59	224	88	157	13.44	110000	S - Outriggers SET	All - 360	•
259	59	66	221	88	157	16.10	107800	S - Outriggers SET	All - 360	•
260	59	72	219	88	157	18.41	105600	S - Outriggers SET	All - 360	•
261	59	79	216	88	157	21.16	103400	S - Outriggers SET	All - 360	•
262	59	85	213	88	157	23.58	101200	S - Outriggers SET	All - 360	•
263	59	92	210	88	157	26.44	96800	S - Outriggers SET	All - 360	•
264	59	98	206	88	157	28.97	92400	S - Outriggers SET	All - 360	•
265	59	112	196	88	157	35.18	84000	S - Outriggers SET	All - 360	•
266	59	125	184	88	157	41.47	70400	S - Outriggers SET	All - 360	•
267	59	138	170	88	157	48.52	59400	S - Outriggers SET	All - 360	•
268	59	151	151	88	157	56.93	50600	S - Outriggers SET	All - 360	•
269	59	66	242	88	177	14.00	81600	S - Outriggers SET	All - 360	•
270	59	72	240	88	177	16.03	79200	S - Outriggers SET	All - 360	•
271	59	79	238	88	177	18.42	77600	S - Outriggers SET	All - 360	•
272	59	85	235	88	177	20.51	76200	S - Outriggers SET	All - 360	•
273	59	92	232	88	177	22.99	74400	S - Outriggers SET	All - 360	•
274	59	98	229	88	177	25.15	72600	S - Outriggers SET	All - 360	•
275	59	112	221	88	177	30.39	68200	S - Outriggers SET	All - 360	•
276	59	125	211	88	177	35.56	63000	S - Outriggers SET	All - 360	•
277	59	138	200	88	177	41.12	55400	S - Outriggers SET	All - 360	•
278	59	151	186	88	177	47.29	48800	S - Outriggers SET	All - 360	•
279	59	164	168	88	177	54.37	43400	S - Outriggers SET	All - 360	•
280	59	177	144	88	177	63.22	39600	S - Outriggers SET	All - 360	•
281	59	72	262	88	197	14.14	64400	S - Outriggers SET	All - 360	•
282	59	79	259	88	197	16.27	63000	S - Outriggers SET	All - 360	•
283	59	85	257	88	197	18.12	61600	S - Outriggers SET	All - 360	•
284	59	92	254	88	197	20.30	59800	S - Outriggers SET	All - 360	•
285	59	98	251	88	197	22.20	58400	S - Outriggers SET	All - 360	•
286	59	112	244	88	197	26.75	55000	S - Outriggers SET	All - 360	•
287	59	125	236	88	197	31.18	51200	S - Outriggers SET	All - 360	•
288	59	138	226	88	197	35.85	47400	S - Outriggers SET	All - 360	•
289	59	151	215	88	197	40.85	43000	S - Outriggers SET	All - 360	•
290	59	164	201	88	197	46.30	38800	S - Outriggers SET	All - 360	•
291	59	177	185	88	197	52.44	35200	S - Outriggers SET	All - 360	•
292	59	190	163	88	197	59.75	32400	S - Outriggers SET	All - 360	•

SettingID	Boom Length	Radius	Tip Height	Boom Angle	Jib Length	Jib Angle	Capacity	Support	Zone	Failure
293	59	79	279	88	216	14.61	56200	S - Outriggers SET	All - 360	•
294	59	85	277	88	216	16.29	54200	S - Outriggers SET	All - 360	•
295	59	92	275	88	216	18.25	52000	S - Outriggers SET	All - 360	•
296	59	98	272	88	216	19.95	50200	S - Outriggers SET	All - 360	•
297	59	112	266	88	216	24.02	46600	S - Outriggers SET	All - 360	•
298	59	125	259	88	216	27.94	43200	S - Outriggers SET	All - 360	•
299	59	138	250	88	216	32.01	39800	S - Outriggers SET	All - 360	•
300	59	151	240	88	216	36.31	37200	S - Outriggers SET	All - 360	•
301	59	164	229	88	216	40.88	34400	S - Outriggers SET	All - 360	•
302	59	177	215	88	216	45.82	32000	S - Outriggers SET	All - 360	•
303	59	190	199	88	216	51.33	29800	S - Outriggers SET	All - 360	•
304	59	203	179	88	216	57.68	27800	S - Outriggers SET	All - 360	•
305	59	217	149	88	216	66.42	26400	S - Outriggers SET	All - 360	•
306	59	85	298	88	236	14.69	46200	S - Outriggers SET	All - 360	•
307	59	92	296	88	236	16.47	46200	S - Outriggers SET	All - 360	•
308	59	98	294	88	236	18.01	45800	S - Outriggers SET	All - 360	•
309	59	112	288	88	236	21.67	43200	S - Outriggers SET	All - 360	•
310	59	125	282	88	236	25.17	40200	S - Outriggers SET	All - 360	•
311	59	138	274	88	236	28.78	37200	S - Outriggers SET	All - 360	•
312	59	151	265	88	236	32.55	34200	S - Outriggers SET	All - 360	•
313	59	164	256	88	236	36.49	31000	S - Outriggers SET	All - 360	•
314	59	177	244	88	236	40.67	28600	S - Outriggers SET	All - 360	•
315	59	190	231	88	236	45.17	26400	S - Outriggers SET	All - 360	•
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317	59	217	194	88	236	56.14	22400	S - Outriggers SET	All - 360	•
318	59	230	170	88	236	62.88	21000	S - Outriggers SET	All - 360	•
319	79	39	147	88	59	18.92	260000	S - Outriggers SET	All - 360	•
320	79	46	143	88	59	26.40	250000	S - Outriggers SET	All - 360	•
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323	79	66	123	88	59	53.49	155800	S - Outriggers SET	All - 360	•
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325	79	46	166	88	79	18.81	230000	S - Outriggers SET	All - 360	•
326	79	53	162	88	79	24.34	212000	S - Outriggers SET	All - 360	•
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329	79	72	148	88	79	41.42	142000	S - Outriggers SET	All - 360	•
330	79	79	140	88	79	49.10	124400	S - Outriggers SET	All - 360	•
331	79	85	130	88	79	57.10	110000	S - Outriggers SET	All - 360	•
332	79	46	186	88	98	14.65	200000	S - Outriggers SET	All - 360	•
333	79	53	183	88	98	18.95	192600	S - Outriggers SET	All - 360	•
334	79	59	181	88	98	22.78	183800	S - Outriggers SET	All - 360	•
335	79	66	177	88	98	27.38	166600	S - Outriggers SET	All - 360	•
336	79	72	173	88	98	31.52	145600	S - Outriggers SET	All - 360	•
337	79	79	167	88	98	36.63	129800	S - Outriggers SET	All - 360	•
338	79	85	162	88	98	41.37	114800	S - Outriggers SET	All - 360	•
339	79	92	154	88	98	47.43	104800	S - Outriggers SET	All - 360	•
340	79	98	146	88	98	53.36	92600	S - Outriggers SET	All - 360	•
341	79	53	205	88	118	15.28	160600	S - Outriggers SET	All - 360	•
342	79	59	203	88	118	18.37	158800	S - Outriggers SET	All - 360	•
343	79	66	199	88	118	22.03	154600	S - Outriggers SET	All - 360	•
344	79	72	196	88	118	25.27	148600	S - Outriggers SET	All - 360	•
345	79	79	192	88	118	29.17	134200	S - Outriggers SET	All - 360	•
346	79	85	188	88	118	32.68	120400	S - Outriggers SET	All - 360	•
347	79	92	183	88	118	36.96	108200	S - Outriggers SET	All - 360	•
348	79	98	177	88	118	40.87	96800	S - Outriggers SET	All - 360	•
349	79	112	161	88	118	51.26	79200	S - Outriggers SET	All - 360	•
350	79	53	226	88	138	12.72	132000	S - Outriggers SET	All - 360	•
351	79	59	224	88	138	15.32	131000	S - Outriggers SET	All - 360	•
352	79	66	221	88	138	18.38	129200	S - Outriggers SET	All - 360	•
353	79	72	219	88	138	21.06	127200	S - Outriggers SET	All - 360	•
354	79	79	215	88	138	24.25	124400	S - Outriggers SET	All - 360	•
355	79	85	212	88	138	27.09	118800	S - Outriggers SET	All - 360	•
356	79	92	208	88	138	30.48	110000	S - Outriggers SET	All - 360	•
357	79	98	203	88	138	33.50	98000	S - Outriggers SET	All - 360	•
358	79	112	191	88	138	41.09	82800	S - Outriggers SET	All - 360	•
359	79	125	177	88	138	49.17	68800	S - Outriggers SET	All - 360	•
360	79	138	156	88	138	59.12	58400	S - Outriggers SET	All - 360	•
361	79	59	244	88	157	13.18	105600	S - Outriggers SET	All - 360	•
362	79	66	242	88	157	15.83	103800	S - Outriggers SET	All - 360	•
363	79	72	239	88	157	18.14	103000	S - Outriggers SET	All - 360	•
364	79	79	236	88	157	20.88	101600	S - Outriggers SET	All - 360	•
365	79	85	234	88	157	23.29	99400	S - Outriggers SET	All - 360	•
366	79	92	230	88	157	26.15	96800	S - Outriggers SET	All - 360	•
367	79	98	226	88	157	28.68	94600	S - Outriggers SET	All - 360	•
368	79	112	217	88	157	34.86	83600	S - Outriggers SET	All - 360	•
369	79	125	205	88	157	41.12	70800	S - Outriggers SET	All - 360	•
370	79	138	191	88	157	48.12	60600	S - Outriggers SET	All - 360	•
371	79	151	172	88	157	56.43	51800	S - Outriggers SET	All - 360	•
372	79	66	263	88	177	13.76	83800	S - Outriggers SET	All - 360	•
373	79	72	261	88	177	15.79	81400	S - Outriggers SET	All - 360	•
374	79	79	258	88	177	18.18	79800	S - Outriggers SET	All - 360	•

SettingID	Boom Length	Radius	Tip Height	Boom Angle	Jib Length	Jib Angle	Capacity	Support	Zone	Failure
375	79	85	256	88	177	20.27	78400	S - Outnggers SET	All - 360	•
376	79	92	252	88	177	22.74	76600	S - Outnggers SET	All - 360	•
377	79	98	249	88	177	24.90	74800	S - Outnggers SET	All - 360	•
378	79	112	241	88	177	30.12	70400	S - Outnggers SET	All - 360	•
379	79	125	232	88	177	35.27	65200	S - Outnggers SET	All - 360	•
380	79	138	220	88	177	40.81	57600	S - Outnggers SET	All - 360	•
381	79	151	206	88	177	46.94	51800	S - Outnggers SET	All - 360	•
382	79	164	189	88	177	53.95	43400	S - Outnggers SET	All - 360	•
383	79	177	165	88	177	62.67	39600	S - Outnggers SET	All - 360	•
384	79	72	282	88	197	13.93	67200	S - Outnggers SET	All - 360	•
385	79	79	279	88	197	16.05	65600	S - Outnggers SET	All - 360	•
386	79	85	277	88	197	17.91	64200	S - Outnggers SET	All - 360	•
387	79	92	274	88	197	20.08	62400	S - Outnggers SET	All - 360	•
388	79	98	272	88	197	21.98	61000	S - Outnggers SET	All - 360	•
389	79	112	265	88	197	26.52	57600	S - Outnggers SET	All - 360	•
390	79	125	256	88	197	30.94	54000	S - Outnggers SET	All - 360	•
391	79	138	247	88	197	35.59	50000	S - Outnggers SET	All - 360	•
392	79	151	236	88	197	40.57	45600	S - Outnggers SET	All - 360	•
393	79	164	222	88	197	45.99	41400	S - Outnggers SET	All - 360	•
394	79	177	205	88	197	52.09	37800	S - Outnggers SET	All - 360	•
395	79	190	184	88	197	59.32	35000	S - Outnggers SET	All - 360	•
396	79	79	299	88	216	14.42	56200	S - Outnggers SET	All - 360	•
397	79	85	297	88	216	16.09	54200	S - Outnggers SET	All - 360	•
398	79	92	295	88	216	18.05	52000	S - Outnggers SET	All - 360	•
399	79	98	292	88	216	19.75	50200	S - Outnggers SET	All - 360	•
400	79	112	286	88	216	23.82	46600	S - Outnggers SET	All - 360	•
401	79	125	279	88	216	27.72	43200	S - Outnggers SET	All - 360	•
402	79	138	271	88	216	31.79	39800	S - Outnggers SET	All - 360	•
403	79	151	261	88	216	36.07	37200	S - Outnggers SET	All - 360	•
404	79	164	250	88	216	40.62	34400	S - Outnggers SET	All - 360	•
405	79	177	236	88	216	45.55	32000	S - Outnggers SET	All - 360	•
406	79	190	220	88	216	51.02	29800	S - Outnggers SET	All - 360	•
407	79	203	200	88	216	57.31	27800	S - Outnggers SET	All - 360	•
408	79	217	170	88	216	65.91	26400	S - Outnggers SET	All - 360	•
409	79	85	318	88	236	14.52	44000	S - Outnggers SET	All - 360	•
410	79	92	316	88	236	16.29	44000	S - Outnggers SET	All - 360	•
411	79	98	314	88	236	17.83	43800	S - Outnggers SET	All - 360	•
412	79	112	308	88	236	21.49	43000	S - Outnggers SET	All - 360	•
413	79	125	302	88	236	24.98	40200	S - Outnggers SET	All - 360	•
414	79	138	294	88	236	28.59	37200	S - Outnggers SET	All - 360	•
415	79	151	286	88	236	32.34	34200	S - Outnggers SET	All - 360	•
416	79	164	276	88	236	36.27	31000	S - Outnggers SET	All - 360	•
417	79	177	265	88	236	40.44	28600	S - Outnggers SET	All - 360	•
418	79	190	252	88	236	44.92	26400	S - Outnggers SET	All - 360	•
419	79	203	236	88	236	49.81	24400	S - Outnggers SET	All - 360	•
420	79	217	215	88	236	55.81	22400	S - Outnggers SET	All - 360	•
421	79	230	191	88	236	62.48	21000	S - Outnggers SET	All - 360	•
422	98	39	166	88	59	18.24	260000	S - Outnggers SET	All - 360	•
423	98	46	163	88	59	25.67	252000	S - Outnggers SET	All - 360	•
424	98	53	158	88	59	33.73	220000	S - Outnggers SET	All - 360	•
425	98	59	152	88	59	41.52	189200	S - Outnggers SET	All - 360	•
426	98	66	143	88	59	52.30	162800	S - Outnggers SET	All - 360	•
427	98	39	188	88	79	13.00	242000	S - Outnggers SET	All - 360	•
428	98	46	185	88	79	18.30	230000	S - Outnggers SET	All - 360	•
429	98	53	182	88	79	23.80	212000	S - Outnggers SET	All - 360	•
430	98	59	178	88	79	28.80	189200	S - Outnggers SET	All - 360	•
431	98	66	173	88	79	34.97	165000	S - Outnggers SET	All - 360	•
432	98	72	168	88	79	40.74	144200	S - Outnggers SET	All - 360	•
433	98	79	160	88	79	48.32	126600	S - Outnggers SET	All - 360	•
434	98	85	150	88	79	56.13	112200	S - Outnggers SET	All - 360	•
435	98	46	205	88	98	14.25	189600	S - Outnggers SET	All - 360	•
436	98	53	203	88	98	18.54	185200	S - Outnggers SET	All - 360	•
437	98	59	200	88	98	22.35	179800	S - Outnggers SET	All - 360	•
438	98	66	196	88	98	26.93	170600	S - Outnggers SET	All - 360	•
439	98	72	192	88	98	31.05	153000	S - Outnggers SET	All - 360	•
440	98	79	187	88	98	36.13	134200	S - Outnggers SET	All - 360	•
441	98	85	181	88	98	40.83	118800	S - Outnggers SET	All - 360	•
442	98	92	174	88	98	46.82	105600	S - Outnggers SET	All - 360	•
443	98	98	166	88	98	52.66	99000	S - Outnggers SET	All - 360	•
444	98	53	224	88	118	14.95	154000	S - Outnggers SET	All - 360	•
445	98	59	222	88	118	18.03	151800	S - Outnggers SET	All - 360	•
446	98	66	219	88	118	21.68	149600	S - Outnggers SET	All - 360	•
447	98	72	216	88	118	24.91	145200	S - Outnggers SET	All - 360	•
448	98	79	212	88	118	28.79	133600	S - Outnggers SET	All - 360	•
449	98	85	208	88	118	32.29	120400	S - Outnggers SET	All - 360	•
450	98	92	202	88	118	36.54	110000	S - Outnggers SET	All - 360	•
451	98	98	197	88	118	40.42	99000	S - Outnggers SET	All - 360	•
452	98	112	180	88	118	50.71	84800	S - Outnggers SET	All - 360	•
453	98	53	245	88	138	12.44	127600	S - Outnggers SET	All - 360	•
454	98	59	243	88	138	15.03	126600	S - Outnggers SET	All - 360	•
455	98	66	241	88	138	18.09	125000	S - Outnggers SET	All - 360	•
456	98	72	238	88	138	20.76	123200	S - Outnggers SET	All - 360	•

SettingID	Boom Length	Radius	Tip Height	Boom Angle	Jib Length	Jib Angle	Capacity	Support	Zone	Failure
457	98	79	235	88	138	23.95	121400	S - Outnggers SET	All - 360	•
458	98	85	231	88	138	26.77	118000	S - Outnggers SET	All - 360	•
459	98	92	227	88	138	30.15	110000	S - Outnggers SET	All - 360	•
460	98	98	223	88	138	33.16	99000	S - Outnggers SET	All - 360	•
461	98	112	211	88	138	40.71	84800	S - Outnggers SET	All - 360	•
462	98	125	196	88	138	48.73	71800	S - Outnggers SET	All - 360	•
463	98	138	176	88	138	58.53	61600	S - Outnggers SET	All - 360	•
464	98	59	263	88	157	12.93	103400	S - Outnggers SET	All - 360	•
465	98	66	261	88	157	15.58	102000	S - Outnggers SET	All - 360	•
466	98	72	259	88	157	17 89	101200	S - Outnggers SET	All - 360	•
467	98	79	256	88	157	20.62	100200	S - Outnggers SET	All - 360	•
468	98	85	253	88	157	23.03	99000	S - Outnggers SET	All - 360	•
469	98	92	249	88	157	25.88	96800	S - Outnggers SET	All - 360	•
470	98	98	246	88	157	28.39	92400	S - Outnggers SET	All - 360	•
471	98	112	236	88	157	34.55	83600	S - Outnggers SET	All - 360	•
472	98	125	225	88	157	40.78	71600	S - Outnggers SET	All - 360	•
473	98	138	211	88	157	47.73	60600	S - Outnggers SET	All - 360	•
474	98	151	192	88	157	55.96	51800	S - Outnggers SET	All - 360	•
475	98	66	282	88	177	13.54	82600	S - Outnggers SET	All - 360	•
476	98	72	280	88	177	15.56	80600	S - Outnggers SET	All - 360	•
477	98	79	277	88	177	17.95	79200	S - Outnggers SET	All - 360	•
478	98	85	275	88	177	20.04	77600	S - Outnggers SET	All - 360	•
479	98	92	272	88	177	22.50	76400	S - Outnggers SET	All - 360	•
480	98	98	269	88	177	24.66	74800	S - Outnggers SET	All - 360	•
481	98	112	261	88	177	29.87	70400	S - Outnggers SET	All - 360	•
482	98	125	251	88	177	35 00	65000	S - Outnggers SET	All - 360	•
483	98	138	240	88	177	40.52	57600	S - Outnggers SET	All - 360	•
484	98	151	226	88	177	46.61	51800	S - Outnggers SET	All - 360	•
485	98	164	209	88	177	53.56	45600	S - Outnggers SET	All - 360	•
486	98	177	186	88	1/7	62.15	40000	S - Outnggers SET	All - 360	•
487	98	72	301	88	197	13.73	67200	S - Outnggers SET	All - 360	•
488	98	79	299	88	197	15.85	66000	S - Outnggers SET	All - 360	•
489	98	85	296	88	197	17.70	63800	S - Outnggers SET	All - 360	•
490	98	92	294	88	197	19.87	61600	S - Outnggers SET	All - 360	•
491	98	98	291	88	197	21.76	59400	S - Outnggers SET	All - 360	•
492	98	112	284	88	197	26.30	55400	S - Outnggers SET	All - 360	•
493	98	125	276	88	197	30.71	52200	S - Outnggers SET	All - 360	•
494	98	138	267	88	197	35.34	49000	S - Outnggers SET	All - 360	•
495	98	151	255	88	197	40 31	45200	S - Outnggers SET	All - 360	•
496	98	164	242	88	197	45.70	42000	S - Outnggers SET	All - 360	•
497	98	177	225	88	197	51 75	37400	S - Outnggers SET	All - 360	•
498	98	190	204	88	197	58.91	34600	S - Outnggers SET	All - 360	•
499	98	79	319	88	216	14.24	52800	S - Outnggers SET	All - 360	•
500	98	85	317	88	216	15.91	52800	S - Outnggers SET	All - 360	•