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OPERATIONAL PLANNING OF INTERMODAL MARINE TERMINALS

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OPERATIONAL PLANNING OF INTERMODAL MARINE TERMINALS

Abstract

Effective management of intermodal marine terminals presents challenges and requires planning decisions at a strategic, tactical and operational level. At the operational level, problems are associated with decisions on equipment handling and management such as the crane scheduling problem, and short-term facilities allocation planning such as the berth allocation planning problem. These problems are dynamic in nature since the decisions require ongoing attention on a day-to-day basis. In many cases, real time models are more applicable to address the pertinent issues. This paper presents a real time information driven berth planning system with a graphical user interface that facilitates the on-site use by people with limited computer skills and an efficient database management component which allows for performance analysis and evaluation of terminal operations at a managerial level.

1. Introduction

Effective management of intermodal marine terminals presents challenges and requires planning decisions at a strategic, tactical and operational level (Imai et al., 1997).

A strategic decision involves the location of a terminal within a region. Strategic planning was firstly introduced in the 60's, once the decisions regarding port facilities started to be derived through a rationalized economic calculation. The problems that received the most attention were associated with the cost of time in port for the ocean vessels and with the justification of large investments in ports.

Tactical planning is primarily associated with the layout design or the cargo handling methods. On the tactical planning level, the expansion of containerization and intermodalism in the 70's brought a set of problems related to the size of new or under expansion terminals, the physical terminal layout and the intra-terminal traffic flows. At the beginning simple queuing models were adopted but soon the complexities of the physical systems made apparent the use of simulation tools that adequately represent the underlying system and give the planner the required flexibility to test different alternatives concurrently and in a fraction of time. Recently, the simulation models have become even more popular with the introduction of high-end visual-graphical interfaces backed up by increased computational capacity.

In contrast to the strategic and tactical problems, fewer studies have been conducted for the operational level problems. These problems are associated with decisions on handling equipment management and facility allocation planning in a short-term planning horizon. Typical problems include the berth allocation planning and the crane-scheduling problem. As expected, the operational level planning deals with problems which are dynamic in nature since the decisions require ongoing attention on a day-to-day basis. In many cases, real-time models are more applicable to address pertinent issues. It is anticipated that the terminals will increasingly seek to utilize online logistics information systems to improve their service standards. A shift towards information driven systems as opposed to computationally intensive solutions exists in the industry. There is a need for quick model development, fast run-time, and continuous input of real-time information of maximum accuracy into the model.

This paper focuses on the importance of a standardized method to collect, store, and disseminate information from the daily operations at a marine container terminal. An information system designed to integrate the cargo handling operations, referred to as Berth Planner, is developed and its functional and technical requirements are analyzed.

The current study effort examines the data requirements for the development of such an information system to manage the port operational planning including the allocation of berths and the handling of equipment and labor assignments. A brief introduction sets the objectives of the Berth Planner system and the potential benefits for both the port operator and the users. The discussion continues by addressing the importance of information collection and binding for the successful employment of such system. A framework is developed to describe the operational relationships between the entities of the port services system and the information flow requirements. The system components are then analyzed in detail along with additional requirements. Finally, an implementation scheme is proposed illustrating both functional and technological issues. Recommendations for future expansion of the model conclude the study.

2. Marine Terminal Operations – Problem Background

The importance of a Berth Planner arises from the actual operational environment in the port and the decision process with regards to cargo handling. A brief introduction in port operations illustrates the industry needs.

A marine container terminal is the place where containers received from ocean vessels are transferred to other ocean vessels or inland carriers, such as trucks, trains, or canal barges- and vice versa. Thus, it is a major node in any intermodal transportation network.

At first glance the operation of a container terminal is deceptively simple. In fact, it closely resembles a manufacturing "job shop". This successful analogy, of a container terminal with a job shop, was introduced in Chadwin et al. (1990) and is presented in this section. Containers arriving at the terminal are the "raw materials." Although most containers undergo no physical transformation, terminal workers and equipment perform various operations on the containers, which gives them added value. These operations may include unloading the containers from the vessel, moving them with terminal equipment to and from the yard, or mounting them on "chassis", specially designed truck trailers that have mounting pegs and locks on each container corner to hold the container fast. Eventually, the containers leave the terminal as "finished products".

The marine terminal must perform many of the same activities as any manufacturing facility- inventory control including raw materials (incoming containers), work in progress (stack and chassis management), and finished goods (clearing containers); controlling the work performed through work orders; establishing priorities for operations; maximizing productive time by minimizing set-up activities; and maintaining cost accounting procedures that provide the basis for pricing, billing, and allocating resources.

In a typical job shop, however, raw materials or parts of the same type are interchangeable. If a part is needed, a worker goes to a bin containing that type and takes any one s/he finds. In a marine terminal, when a trucker calls to pick up an inbound container (an "import box" in the jargon of the industry), s/he does not want just any import box. S/he is responsible for picking up and delivering one particular container, the one that holds the customer's cargo.

Another problem with the job shop analogy is that in the manufacturing sector the machine cycle times and the worker productivity are by far more controllable resulting in small time variation. In contrast, the container port operations depend upon a number of factors such as the characteristics of the ship and the crew unloading the ship, whether the ship is primarily being loaded or unloaded, berth characteristics, time of day, time during the shift, weather, and season. For example a modern large containership with no superstructures and on-vessel cranes to interfere with the operation of the ship-to-shore crane can be unloaded more quickly than a ship that requires more nonproductive moves by the wharfside crane.

Finally, it is important to realize that terminal operations often involve the participation of a number of organizations functioning in various different capacities. The terminal owner might be a public port authority that operates a "common user" terminal open to any vessel, or a private firm operating such a terminal under a long-term lease or management contract. Moreover, in many U.S. terminals the stevedore is an independent contractor hired by the ocean carrier, and there may be different companies within the terminal providing loading/unloading crews. So, the well-defined organizational structure of a manufacturing facility does not apply seamlessly to the various port organization entities.

These observations should always be taken into consideration when dealing with operations planning and productivity measures within a major marine container terminal. It is those special characteristics that make the port facility operations management a challenging task and raises the need for an adequate information system incorporating the numerous functions performed by the different system participants. In other words, it is regarded that efficient planning of the daily berth activities within the terminal location requires a total solution providing the decision-maker with an overall view and allowing him/her to leverage the demand by intelligently allocating the available resources.

3. Berth Planner Objectives Statement

A Berth Planner system is the equivalent of a reservation system utilized to keep a record of all pending customer requests, to store information on the available system resources, and to track the management decisions with respect to service requirements. More specifically:

- The system aims to automate the berth planning procedure. For each vessel arriving at the port on a scheduled basis, a reservation is initiated and the user will update accordingly the track by inputting information on pending job assignments associated with the particular voyage. The system assists the planner by providing a complete view of all current scheduled assignments. At the time of vessel departure a final report is triggered by the system for use in productivity analysis. The information is then stored permanently in the database for future reference. In addition to giving a snapshot of the current status the system knowledge basis is utilized to educate the planner's decision making. Thus, real-time information is used in conjunction with historical data.

- The system reporting capabilities provide the port manager with a tool to assess labor productivity and easily identify potential problems or possible improvements. Statistics provide an objective measurement of effectiveness for different decisions with respect to labor assignments and the corresponding equipment assignments. Customized reports can provide new insights on the terminal operational efficiency, less biased by vessel or voyage specific peculiarities.
- Further benefits at the operational level are apparent with respect to information sharing and communication among the different organizational entities within the port. The port management team has a common reference, and each part's decisions become electronically accessible to all members, eliminating the need for additional effort and ensuring a transparent operation across the organizational borders.

The Berth Planning system could eventually become the basis of an advanced billing system, since it integrates the information on the diverse services offered at a marine terminal.

4. Conceptual Framework

A conceptual framework of the Berth Planning system is shown in Figure 1. The framework consists of three layers: the input layer, the transaction layer, and the results layer. Each separate component in the framework is represented with a textbox. The arrows indicate the information flow requirements.

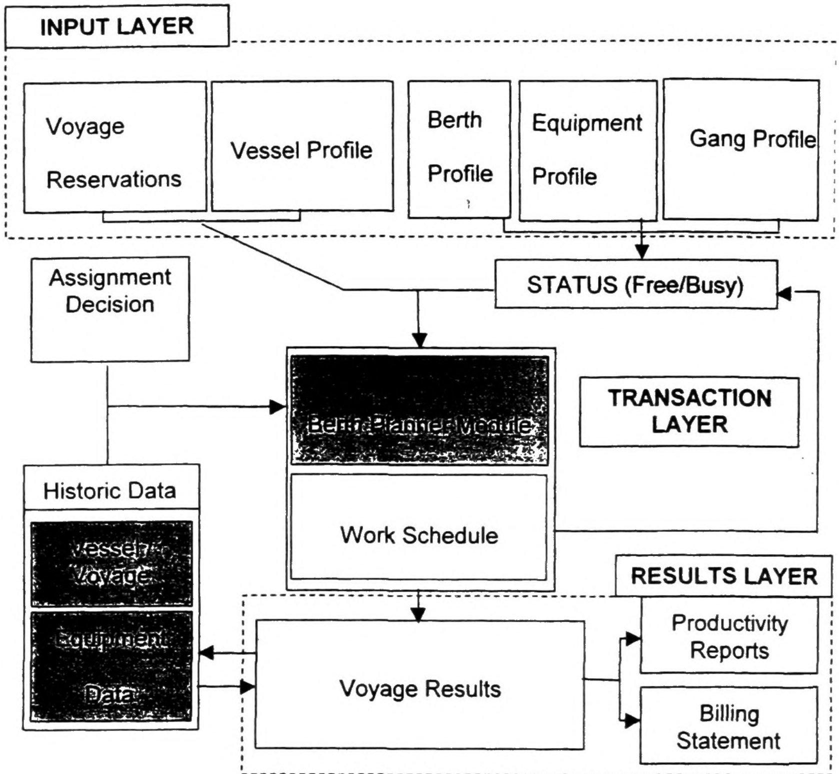


Figure 1. Conceptual Framework

4.1 Input Layer

The input layer relates to the characteristics of the physical entities in the port system and to the particular voyage reservation operational characteristics.

The Voyage Reservations list includes a record for each voyage scheduled to arrive at the port. An active record is kept for each voyage scheduled to arrive within fourteen days from the current date. A non-active record is kept for all completed voyages. Each record is identified through a combination of a vessel unique identifier (port internal code) and the voyage number assigned by the steamship line that owns the vessel. The voyage number is specified in a voyage manifest, which is send to the terminal by the ocean carrier. The voyages are also marked based on their status. A voyage is listed as "expected," when the steamship line sends over to the port the voyage manifest, usually about two weeks before the scheduled arrival. A voyage is marked as "in steam," when the vessel arrives at the port but the port manager has made no berth assignment. Accordingly, the voyage is marked as "at berth," when a vessel has been assigned to a specific port berthing facility. Note that such an assignment event can supersede the actual date of arrival. Non-active voyages are marked either as "cancelled" or as "completed" and data associated with them may be used for future reference.

In addition to the time-specific characteristics of the voyage reservation, the port manager is interested in storing information on the projected workloads. The steamship line is required to distribute a voyage manifest for all the imported containers on the vessel that need to be unloaded at the destination port. The port manager could also get an estimate on the number of export moves, empty or loaded. Finally, the vessel pre-planning provides an estimate on non-productive moves including vessel to vessel shifts and re-stows. The total number of expected moves, along with other special characteristics and conditions determine the needs in labor and handling equipment to serve the vessel and assist the berth planner in the decision process. It is highly possible that not all the information is available at the time of the initial reservation. However, it is anticipated that the reservation record will be updated based on current information before the actual assignment decision takes place. Whereas a berth assignment could be made in advance, usually the labor and equipment assignments are instructed after the vessel has arrived at the port.

Since most steamship lines operate under space charter pacts, the port usually receives a separate manifest from each involved company. Space charter pacts are agreements among ocean carriers to use vessels jointly to achieve operating economies. Space charter pacts reduce the number of port calls and concentrate carrier business at selected ports (Miller, 1995). Since the system is designed to potentially feed an electronic billing statement, it preserves detailed relevant information and aggregates only whenever required by port operational perspective.

Finally, as part of the voyage reservation, arrangements for navigational aid or for additional port services requested by the agents representing the steamship line at the particular port are inputted to inform the interested parties. A very common port service, for example, is the tug operations required to line at berth a modern large containership.

The Vessel Profile includes the unique identifier (port internal code), name and ownership details, and other descriptive characteristics like the length and the draft.

Similarly, the Berth Profile includes a unique identifier and the geometric or other descriptive characteristics of the berth facility.

The Equipment Table contains a record on each type of handling equipment, including the number of available machines at the terminal. An optional list allows the system user to track individual machines through a unique identifier, if requested by the port manager.

Finally, the Gang Profile contains the characteristics of each loading/unloading team to allow for tracking specific job assignments for each voyage.

4.2 Transaction Layer

The transaction layer includes tools needed to make the assignment decisions and update the pending work schedule, based on the information conveyed from the input layer. The decision on berth assignment and resource allocation is based on the experience of the port management team and historical information stored into the system. Since a permanent record is stored for each completed voyage, the user may retrieve vessel history data and adjust his/her decisions on expected service time and resource requirements accordingly. An estimate on the projected productivity rates can be ascertained by looking up the actual results of past voyages for a specific vessel or type of containership.

Once a new berth assignment is made, a visual display is automatically updated to include the most recent information. Thus, the berth planner requests are immediately disseminated at the enterprise level in a common format. The assignment process includes three steps. The first decision is with regard to the allocation of a berth. This assignment is constrained by the physical characteristics of the vessel and the berth facility. There may be additional operational constraints since an ocean carrier can have a long-term contract with the terminal port to use a particular berth in an exclusive manner. The planner, by looking at the visual display, verifies open slots within the two-week period of time following the reservation. Based on the vessel scheduled arrival date the planner specifies a starting and ending time for each assignment. If a preceding assignment falls in between a selected time-window, the system sends a warning message to the user, stating the status of the berth.

The next two steps include the labor assignments and equipment allocation. The order of the events is not explicitly defined but usually the stevedore gang assignment precedes the allocation of the yard handling equipment. The gantry crane scheduling is more restricted. Since a crane is primarily constrained by the berth and vessel geometric characteristics, the decision is linked to the preceding berth assignment.

The gangs are instructed to work in predetermined time shifts. The sea-side operations are usually active 24 hours per day and there may be multiple assignments of the same gang. Again, each assignment is recorded with a specific starting/ending time and warning messages prevent overlapping assignments. To determine the expected duration of an assignment, a productivity goal estimate based on historical data and real time information referring to weather conditions and available workers are used.

A similar procedure is followed for the equipment allocation. Two options are available: general assignment or individual machine tracking. In general, to record an assignment, the user needs to specify the type of equipment, the quantity, and the hours of operation. Optionally, the machine unique identifier could be used to record the assignment and the related productivity of a specific machine. Furthermore, the system allows the user to associate an equipment allocation to a gang assignment for further productivity analysis.

4.3 Results Layer

At the end of each assignment cycle, a final update is triggered to remove the reservation instance from the active menu lists. However, a permanent record is stored in the database for reporting purposes and for future use. The user inputs final information with respect to the actual reports on the assignment. This information is required to assess the actual productivity. For example, for a completed gang assignment the number of container moves is recorded. Dividing with the net hours of operation, a net productivity per hour is derived.

At the voyage level the final record update includes the actual departure time from the berth, the weather conditions during the loading/unloading operations, the average temperature, and the actual number of productive and non-productive container moves. After the update the item is removed from the list of pending or current voyages and the visual displays are updated accordingly.

5. Database Design

At the abstract level, the information system design involves a stepwise process that is represented schematically in Figure 2. The process modeling is a decomposition of the organization activities. Functional modeling expresses the decision process and the respective information flow requirements, as described previously.

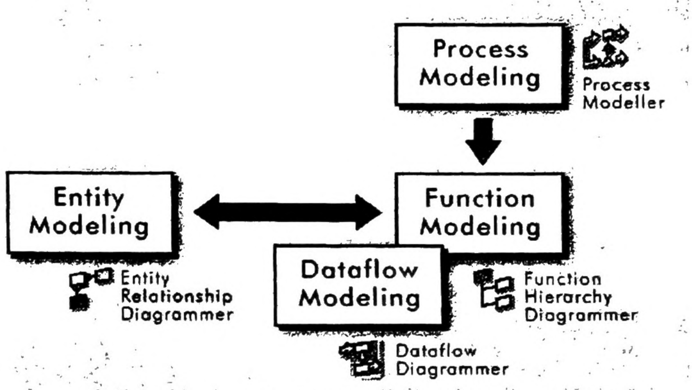


Figure 2. Database Design (*From Oracle Corporation, 1997*)

In order to conceive a database model abstraction of the physical process, a series of interviews were conducted with port managers at a major container terminal of the East coast. During formal discussions, the functional requirements of the information system were analyzed. The first step was to understand the current operating environment and the anticipated changes, and the type of data to be stored in the database along with the functional dependencies. A high-level description of the data to be stored in the database along with the constraints that hold over the system entities was developed.

A conceptual entity relationship model is shown in Figure 3. Several relationships between the system entities can be identified. As it may have been expected, the most important ones involve the voyage reservation record.

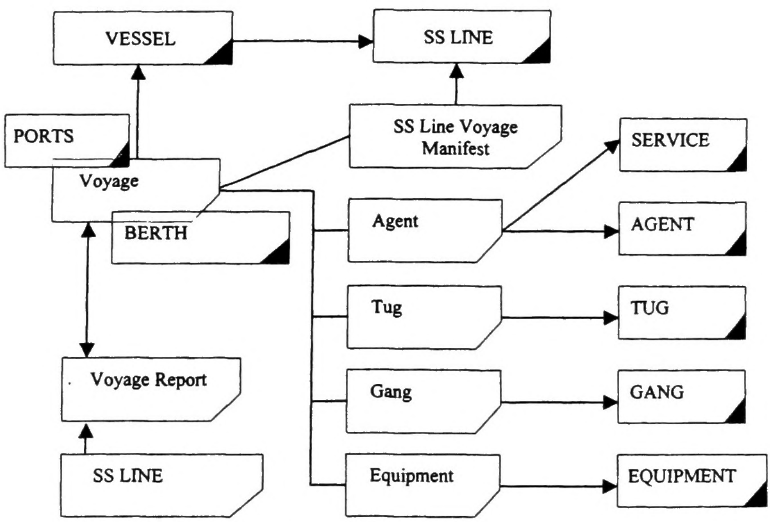


Figure 3. Entity Relationship Diagram

The next step in the design process was to convert the conceptual database design into a database schema in the relational model. The relational model is the dominant data model used to describe most business operations. Using a database management system (DBMS) prevents changes in the logical structure of the data, or changes in the choice of relations to be stored. This property is called logical data independence and is the core element of any DBMS model. In turn, the designed conceptual schema insulates users from changes in the physical storage of the data. This property is referred to as physical data independence. The conceptual schema hides details such a how the data is actually laid out on disk, the file structure, and the choice of indexes. As long as the conceptual schema remains the same, the storage details can be changed without altering applications (Ramakrishnan and Gehrke, 2000).

The decision to use the relational model DBMS was governed by two important practical considerations. First, it allows the use of the most widely used database language, namely the structured query language or SQL. SQL allows the user to obtain full access in reorganizing the data without ever altering the data structure. Second, an array of commercial packages is built on the relational data model, giving the opportunity for quick and consistent development. Many vendors offer relational DBMS packages based on SQL with the required tools for efficient data access, data integrity and security, and easy database administration.

The collection of relations in the defined relational schema was analyzed to identify potential problems and to eliminate unwanted functional dependencies.

6. Implementation – System Architecture

The application user interface was developed in Microsoft's Visual Basic (VB) 6.0. VB is an easy-to-use development language. It supports the newest data access technology, such as ADO (ActiveX Data Objects), and OLE DB (Williams, 1999).

ADO is the successor to DAO/RDO. It "flattens" the object model used by DAO (Data Access Objects) and RDO (Remote Data Objects), meaning that it contains fewer objects and more properties, methods (and arguments), and events. ADO is designed as an easy-to-use application level interface to Microsoft's newest and most powerful data access paradigm, OLE DB. OLE DB provides high-performance access to any data source, including relational and non-relational databases, email and file systems, and more. ADO is implemented for minimal number of layers between the front-end and data source — all to provide a lightweight, high-performance interface. ADO is called using a familiar metaphor — the OLE Automation interface. ADO uses conventions and features similar to DAO and RDO with simplified semantics that make it easy to learn (Gunderloy, 1999).

The Oracle 8.0 database server was used to create the database definitions and physically store the data. Microsoft ships with Visual Basic package a native OLE DB driver for Oracle databases that provides for high level data access.

A two-tier model is used, and the application talks directly to the data source. Figure 4 presents the system architecture.

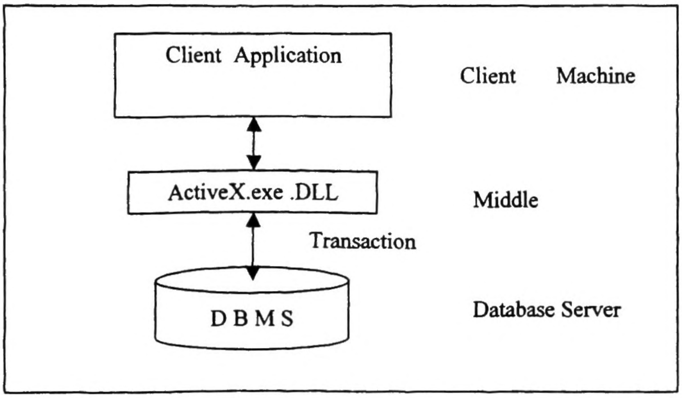


Figure 4. System Architecture

This requires an OLE DB driver that can communicate with the particular data source being accessed. User's commands are delivered to the database or other data source, and the results of those statements are sent back to the user. The data source may be located on another machine to which the user is connected via a network. This is referred to as a client/server configuration, with the user's machine as the client, and the machine housing the data source as the server. The network can be an intranet, which, for example, connects employees within a corporation, or it can be the Internet.

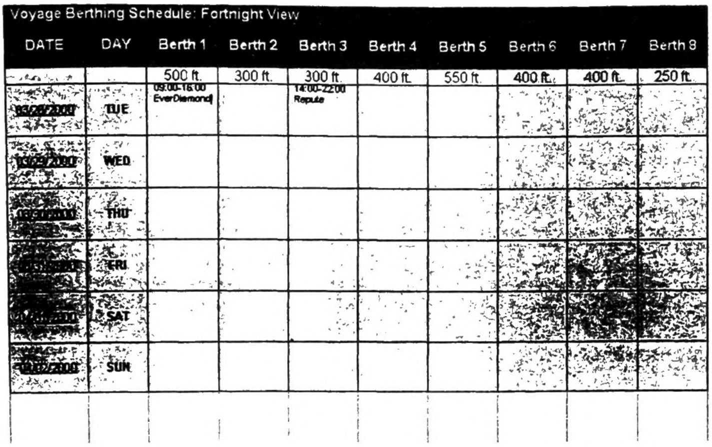
A security plan is implemented to prevent unauthorized users to gain access to the system's critical components. Three different groups of users are supported in this design, with clearly defined user privileges according to their level. These are: the berth planner, managers, and administrators.

7. Interface Design

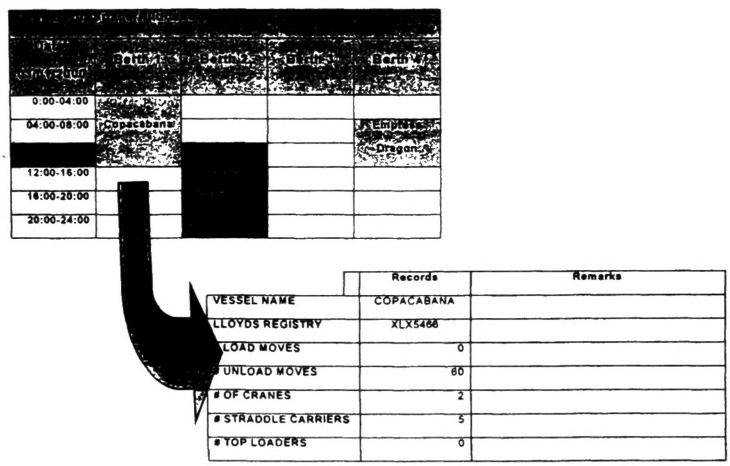
The graphical user interface consists of several linked forms. The environment has the familiar "windows" layout and includes self-documentation. The main menu of the software consists of three components. The first derives the program functionality and is designed for the needs of the berth planner. The second component is designed for the reporting needs at the managerial level. The third component includes database maintenance and administration utilities and is accessible only to the database administrator. The rest of this section describes the first component in more detail.

The initial screen displays in a tabular form all the scheduled vessel arrivals for a period extending two weeks (10 business days) from the current date. An example is shown in part (a) of Figure 5. A second screen displays a detailed view of a particular day, as shown in part (b) of Figure 5. The expected duration of port turnaround time is visualized with bar-shaped graphics. A color–coded schema is utilized to indicate the status of the reservation with respect to berth assignment.

These views are updated dynamically to reflect changes made through the voyage reservation menu. The main form of the voyage reservation menu includes a list of all existing/active reservations listed by date, as shown in the top left part of the form displayed in Figure 6. The user may add a new reservation to the list or select an existing reservation and proceed to review or update current information, and make assignment decisions/selections. Information related to a particular reservation selected from the reservations list is shown at the bottom of the left part of the form.



(a) Two-Week View



(b) Daily View

Figure 5. Voyage Schedule Visual Display

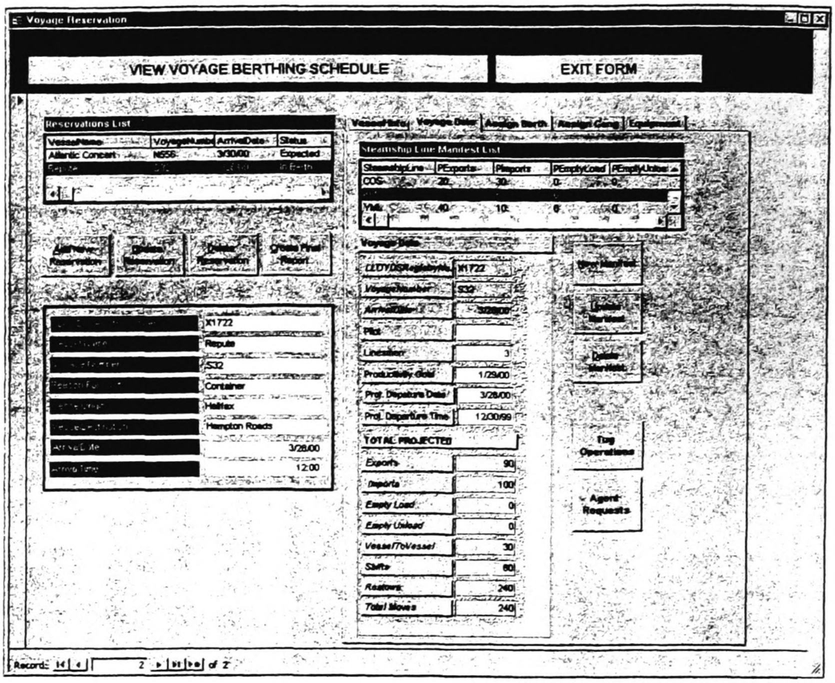


Figure 6. Voyage Data View.

Some of these data are linked to the vessel, voyage, berth, gang and equipment sub-forms. The user only needs to enter or update the data once, in the bottom left part of the form, and the display of the sub-forms is updated automatically.

Information related to each of the sub-forms may be viewed/updated by selecting the appropriate tab from the top right part of the voyage reservation form. Figure 6, for example, displays voyage related data, while Figure 7 shows the gang assignment sub-form.

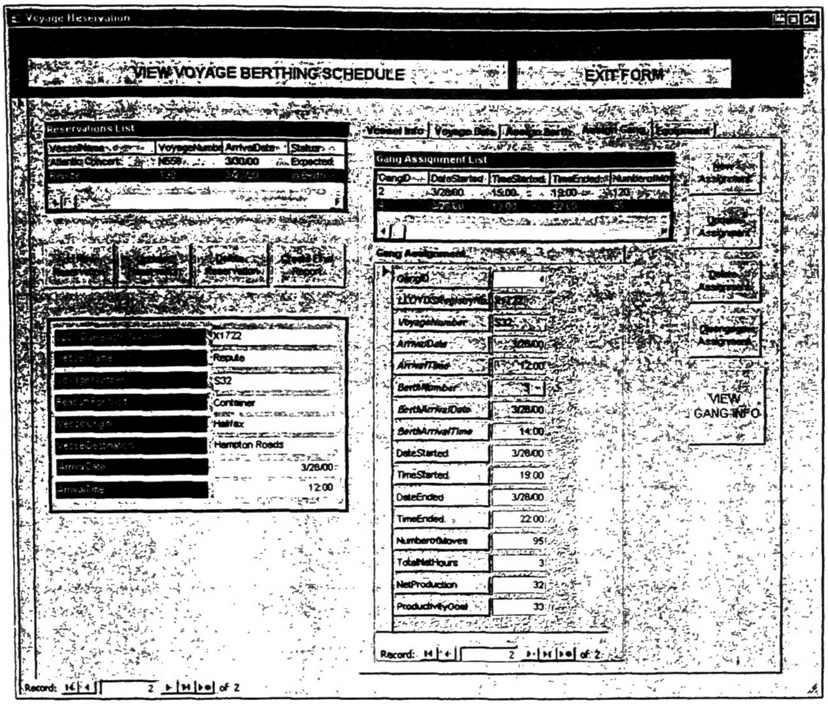


Figure 7. Gang Assignment View

8. Conclusions and Future Developments

An information management system was developed to support the berth allocation and equipment handling short term planning in major container terminals. The system stores information on scheduled voyages in a standard electronic format and provides an overview of all the interrelated tasks scheduled by the terminal operator.

Careful berth allocation and equipment handling is essential for efficient terminal utilization. In recent years, the steady growth in container traffic created a capacity shortage in many US major ports. From the operational perspective, the terminal operator is seeking to minimize the total service time for the vessels calling at the port. Reducing the average port turnaround time is critical for the steamship lines since the daily operating cost of modern containerships is very high. As a service provider, the operator of a public terminal benefits by lessening the customer dissatisfaction. Offering quicker loading and unloading creates a competitive advantage. Therefore, operations related decisions and strategies must support an optimal utilization of the available berths, equipment, and other resources.

A critical parameter in any attempt to model the operational planning problem refers to the actual time needed to serve a vessel based on the particular characteristics of the voyage and the ship. Whereas the long-term analysis can be facilitated by historical average service times, at the operational level a more comprehensive, real time information is required. As stated earlier, simple queuing models can hardly represent the complexities of the daily container handling operations. The model presented in this paper aids the decision making process in terminal operations on a real time basis.

Once information is gathered for a significant number of voyages, detailed statistics can be applied to unveil important patterns of the service characteristics at the berth and measure the productivity rate for the terminal in terms of various factors.

It is anticipated that by seeking to optimize the utilization of the available resources, the system can provide valuable help to the terminal operations planner.

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