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CONTAINER SHIP LOADING AND UNLOADING SIMULATION

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INTRODUCTION

The use of containers has revitalized the shipping industry. Fast and efficient container ships are continually being built. For these ships to earn a profit, their port turnaround time must be kept to a minimum. Delays in port time can easily destroy economic gains earned by fast efficient voyages. This study presents a computer program which simulates the loading and unloading operations of a container ship. The interaction between the ship and the terminal along with the variations in ship displacement, stability, trim, and heel are monitored during the simulation. The simulated system consists of a container ship, containers, container handling vehicles, a container terminal yard, and a dockside crane. The physical constraints of the system are established by the user. The computer language used in this program was IBM's General Purpose Simulation System (GPSS).

The mathematical modeling of a general container handling system was emphasized in the program. However, the practical application of such a model was always considered. This program is an initial step toward optimizing the various components which constitute a profitable marine transportation system. The programming method and various comparative results are of immediate technical interest. Naval architects must consider such a system if they are to improve marine transportation.

STATEMENT OF THE PROBLEM

Simulation is a technique that provides an effective means of testing, evaluating, and manipulating a system without performing any direct action on that system. The first step in simulation is to isolate the system's elements and formulate the logical rules governing their interaction. The result is known as a model of the system. In this study the model represents the various operations and interactions which take place at a container terminal. The flow of containers as modified by the physical constraints of the system is simulated in this program. The use of a simulation language such as GPSS facilitates the performance of this task.

The loading and unloading of a container ship requires many participants. Simulating a meaningful and efficient interaction of these participants is a complex task. This study formulates a sequence table of individual instructions covering the container loading/unloading process. Four basic operations are listed in this table: loading, unloading, crane movement, and hatch removal or replacement. The deployment and movement of containers throughout the terminal yard is also examined. In addition to the cargo handling simulation, a continuous record of the ship's displacement, stability, trim, and heel is maintained.

Five components must be considered when modeling a container handling system. These components are: 1) the container ship, 2) containers, 3) cranes, 4) container handling vehicles, and 5) the container terminal yard. Several different sizes and types of containers must be permitted. These various containers are stored aboard ship in a two dimensional array either above or below deck. Vertical columns are referred to as cells. Transverse rows are called tiers. Both the operating characteristics of the crane and the performance characteristics of the container handling vehicles must be considered. To accurately simulate the movement and storage of containers, the physical layout of the container yard must be studied.

The required input for this program is classified into three categories: 1) ship characteristics, 2) terminal characteristics, and 3) current operating conditions. These three categories are further defined as follows. The required ship characteristics are determined from hydrostatic curves of form, loading constraints, and hatch design data. The terminal characteristics are determined by analyzing the relationship between the terminal yard layout and the container handling equipment. The current operating conditions are those operating variables which change in day to day operation. The user establishes these operating conditions from actual or probablistic data.

The desired program output is a series of results which reflect the system's overall performance as well as the performance of the individual components. The purpose of this program is to produce information which can be used in optimization studies. The optimization parameter is determined by the user.

METHOD AND THEORY

For a system to be simulated, two basic requirements must be met. First, the system must be broken down into a finite set of operations. Second, the operations must be united by a series of logical rules. Having met these requirements, a general procedure for studying the interaction of the various operations may be formulated. GPSS provides the means for such a general procedure. This language is built around a set of simple elements which can be classified as either dynamic, operational, statistical, or logical. The dynamic elements are called transactions. Transactions move through the system causing various actions to occur. Associated with each transaction are several parameters which represent characteristics of that particular transaction. In this study, the transactions represent containers. Parameters represent such characteristics as size, weight, destination, and type. Operational elements refer to the equipment of the system. The equipment operates on the containers. There are two types of equipment, facilities and storages. Facilities handle only one transaction at a time whereas storages handle several transactions simultaneously. For example, the dockside crane is a facility and the container handling vehicle pool is a storage. Statistical elements measure the behavior of a system. Queues are used to evaluate delays which might occur during the flow of transactions. Tables collect and store frequency distribution patterns. For example, the average time required to move a container from an arrival queue to a storage location would be recorded in a table. The final group of elements, logical elements, provides the operating logic of the system. These elements regulate the sequential flow of transactions. Based on actual or probabilistic studies, a particular combination of container arrival characteristics can be predicted. For example, one may assume that of all containers arriving for shipment, approximately 65% will be destined for port A, 25% for port B, and

10% for port C. One may also predict container weight, size, and type.* Whereas the overall composition of arriving containers may be estimated, the individual arrival sequence is random. Consequently, the program must be able to randomly assign various characteristics to arriving containers. The user determines the distribution of these characteristics.

During the loading/unloading process, containers are continuously arriving from inland locations. As the containers arrive at the terminal gate, they are placed in a queue. The containers are distributed to a storage location as soon as possible. In distributing the containers around the terminal yard, certain bottlenecks may occur. Bottlenecks form whenever the current demand for a service exceeds the availability of that service. At these points of congestion the containers form a queue and wait their turn. For example, if the unloading process was performed quickly but only one container handling vehicle was operational, a queue of containers would form on the pier. Queues are used in simulation studies to gather statistics on items which are delayed by a common set of causes. The need for such statistics cannot be minimized since it is very important to achieve an economic balance between the cost of service and the cost of waiting for that service. Figure (1) illustrates the basic process used in modeling a queueing situation. Items requiring service are generated by an input source. These items, experiencing a delay, join a queue. Every so often, a member of the queue is selected for service by a rule known as the service discipline. An example of a service discipline is FIFO, that is, the first container to arrive is the first container to be serviced. A service mechanism, such as a container handling vehicle, performs the required service. The serviced item then leaves the queueing system.

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*Type indicates whether the container is to be stored above or below the deck.

When a container ship arrives, the loading/unloading process begins according to a planned strategy. This loading/unloading sequence table is the heart of the program. In this table the user specifies the order of operations. The program allows considerable latitute for employing various strategies. Modifications in the loading/unloading process are easily made. The table is composed of N rows and nine columns. Each row represents an operation, loading, unloading, hatch removal, etc. The column headings are given in Figure (2).

The unloading process consists of seizing a container, lowering it to a queue on the pier, and moving it either to an inland storage location or to a reloading position. The dock-side queue compensates for variations in container handling vehicle supply and demand during the unloading phase. Unloading and transit times are based upon equipment performance characteristics and availability, the onboard location of the container, and the container's final yard storage location.

The loading process consists of selecting the proper container from among the available containers, moving it to the ship, and loading it aboard. To minimize crane travel, whenever possible loading and unloading instructions should be sequential. Two functions are used to evaluate loading time variations. The first function evaluates the time it takes for a carrier to seize a container from storage and transport it to the loading pier. The second function evaluates the loading time as a function of the container's onboard location and of the crane performance. Selecting the proper container to load is an important part of the program. The operator indicates in the loading/unloading sequence table the desired container size, type, destination, and the target weight for any particular hold location. The target weight generally equals the weight of the container that was at the same location when the ship arrived. If the space was void, an arbitrary weight is assigned. The program then scans the containers in the storage yard selecting the first one having the desired size, type, and port parameters. If none are found, a warning code is printed. If an acceptable container is found, its weight is compared to the target weight using a tolerance of $\pm$ 4 tons. If this weight is acceptable, the container is seized and the loading process begins. Otherwise, the scan continues. If no acceptable weight can be found, the tolerance on the target weight is arbitrarily changed to $\pm$ 12 tons and the scanning process is repeated. If there are still no acceptable container weights, a warning code is printed. A warning code indicates that operator intervention is required.

As the loading/unloading process continues, certain hydrostatic properties of the container ship must be measured. These are stability, trim, heel, and displacement. These four values are computed after each loading or unloading operation. To calculate these values, the following relationships must be known.

1. KM_T vs Displacement
2. MT1 inch vs Displacement
3. Feasible GM_T vs Displacement
4. LCB vs Displacement
5. Hold, tier, and cell lever arms about amidships, baseline, and centerline respectively.
6. Displacement, KG, trim, and heel at the time of arrival.
7. Maximum allowable heeling angle.
8. Maximum allowable trim.

Displacement is the first of the four values to be calculated. The actual GM_T of the ship is then calculated as the difference between the KM_T and the KG. Trim is derived by dividing the trimming moment by the moment to trim one inch at the given displacement. The calculations used in finding the angle of heel are similar to those used in the classic inclining experiment. The actual GM_T of the ship is then compared to the feasible range of GM_T for that displacement. Likewise, both trim and heel are compared with their maximum permissible values. For example, the maximum permissible angle of heel occurs when the containers begin to jam against the cell guides. If an unacceptable condition is discovered, a warning code is displayed. If a warning code is displayed the user interupts the program and rectifies the situation.

RESULTS AND CONCLUSION

The purpose of this project was to formulate a program which would enable optimization studies to be conducted on a container handling terminal. Consequently, results indicating the utilization of the various components of the system are required. Facility utilization and queue delays are reported statistically. The time involved in distributing a container during the various phases of the operation is also given statistically. The composition of the container yard and the computed results for ship displacement, stability, trim, and heel are presented as discrete values. The results are printed out in a tabular form. These results highlight those facilities having insufficient or excessive capabilities allowing management to re-evaluate specific areas of operation and, thereby, improve investments in capital and manpower.

Due to the versatility of GPSS the user can easily modify the amount of output. The majority of operations occuring in a container handling system are stochastic. Furthermore, these operations are not independent of each other. Consequently, it is difficult to accumulate identical output from a given model. This problem is further magnified since the arrival characteristics of the containers are based on random variables. For example, Figure (3) shows two ship displacement patterns based on the same loading/unloading sequence table. These patterns vary because the inventory of container weights in the terminal yard was randomly generated. Thus, it is difficult to confirm the number of simulations necessary to assure a given level of confidence in the stochastic output. However, the validity of the results can be established by examining the trends produced when systematically varying certain attributes of the model. The case study performed as part of this project employs this procedure.

An analysis of the results indicates that satisfactory trends were achieved by this program. The program, however, represents only an initial step in marine transportation simulation. Naval architects must realize that ships are only part of the total portal to portal transportation system. Their job is to make marine transportation profitable. Herein lies the importance of the program at hand. While it is of immediate value, it also lends itself to future research in improving the profitability of marine transportation.

The principle component of this program is the loading/ unloading sequence table. This table of instructions may be varied to fit different strategies. The individual ship and port facilities can be modified by the program operator. The program, therefore, has a high degree of versatility. For example, the program can be used for economic sensitivity studies. By altering the performance characteristics of the dockside crane, various turnaround times can be calculated. This data can help determine an optimum crane/turnaround cost ratio. The program can also be used in an operations environment. For example, the optimum number of container handling vehicles required during a specific time can be determined. This result would be useful in labor utilization studies. The versatility of this program is a result of the language used. The program is important not only for its content but also for its demonstration of GPSS capabilities in marine studies.

ACKNOWLEDGMENTS

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REFERENCES

[1] General Purpose Simulation System/360 Introductory User's Manual, IBM Publication, H20-0304-3, August 1969.

[2] General Purpose Simulation System/360 User's Manual, IBM Publication, H20-0326-2, August 1969.

[3] Schriber, Thomas J., General Purpose Simulation System/360: Introductory Concepts and Case Studies, The University of Michigan Press, Ann Arbor, Michigan, September 1968.

APPENDIX - A CASE STUDY

INTRODUCTION

This case study has three purposes. The first purpose is to develop a hypothetical container handling system. The second is to study the system by systematically varying the crane performance characteristics and the number of container handling vehicles. The third is to examine the computed results for validity and usefulness. This case study illustrates that simulation can be used effectively in cargo handling studies.

THE MODEL

The preparation of a model is the first requirement in a simulation study. Figure (4) represents a model of the system simulated in this case study. It has three basic components: blocks, lines, and time estimates. The blocks symbolize activities. The lines indicate the flow of containers through the terminal. The time estimate is the expected mean time to complete a segment of the operation. Associated with each time estimate is a uniformly distributed tolerance. The actual time required to perform the operation is determined randomly.

The containers are assumed to arrive at the terminal gate every 8 ± 4 minutes. The actual arrival time is computed from a uniformly distributed probability function. The characteristics of the arriving containers are also randomly determined. The four discontinuous functions in Figure (5) show the constraints applied to the port, size, type, and weight parameters associated with each container. This study assumed that the influx of containers is unaffected by the arrival or departure of the container ship. The arriving containers are immediately placed in a queue until a container handling vehicle is available to move them to a storage yard. This queue absorbs the variation between the container arrival pattern and the current supply of container handling vehicles.

The storage yard may be considered a two dimensional array. In this model, the arriving containers are stored column by column. Associated with each container in this array is an estimate of the expected time required to transfer the container from its storage location to the pier.

The container ship loading and unloading process is controlled by the loading/unloading sequence table. This table indicates those containers which should be unloaded. It also designates the characteristics of the containers to be loaded aboard. The positioning of cranes and the removal or replacement of the hatch covers is also controlled by this table. In this model the following strategy is employed.

A. Position the dockside crane at the first hold requiring service.

B. If necessary, remove the above deck containers cell by cell starting with the inboard cel.

C. If necessary, remove the hatch cover.

D. Starting with the inboard cell, unload as many containers as necessary from this first cell.

E. Begin loading the first cell while unloading the next cell. Continue these alternate loading/unloading operations until the hold is completely serviced.

F. If necessary, replace the hatch cover.

G. Load the above deck containers (if any) cell by cell beginning with the outermost cell.

H. Reposition the crane at the next cell that requires service.

I. Repeat the loading/unloading process.

The time required to either load or unload a container is a function of the container's onboard cell and tier location as well as crane performance characteristics.

Those containers which will be reloaded are moved from the dockside queue to the terminal storage yard. The rest of the unloaded containers on the pier are moved to an 'inland' storage yard. From this location, they are distributed toward their final destination.

In order to monitor the stability, trim, and heel of the container ship during the loading/unloading process, four hydrostatic functions are required. These are: KM_T versus displacement, MT1 inch versus displacement, feasible GM_T versus displacement, and LCB versus displacement. The feasible range of the transverse metacentric heights is plotted in Figure (6).

THE EXPERIMENT

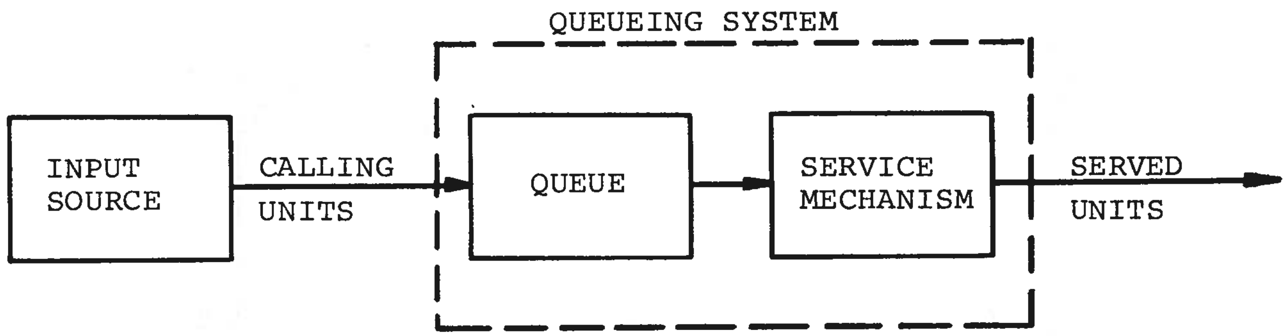
The system was studied by systematically varying the number of container handling vehicles and the loading phase performance characteristics of the crane. Nine computer simulations were run. Three, four, or five container handling vehicles were available during the various simulations. The experimental time required to load a container was varied to account for using different cranes in actual practice. These time variations were either one, two, or three times the standard expected time.

RESULTS AND CONCLUSION

The following table indicates the variations made in the nine different computer simulations.

Run number	1	2	3	4	5	6	7	8	9
Number of container handling vehicles	3	4	5	3	4	5	3	4	5
Loading time constant	1	1	1	2	2	2	3	3	3

Comparative results from these runs are plotted in Figures (7) and (8). Figure (9) is a graph of the variations in ship displacement, stability, trim, and heel during a typical loading/unloading operation. The trends indicated by these graphs agree with intuitive reasoning concerning ship turn-around time. Assigning an economic value to each operation and facility would lead to a series of economic trade-off studies. The eventual goal is the optimization of a container handling system as part of a total transportation complex.



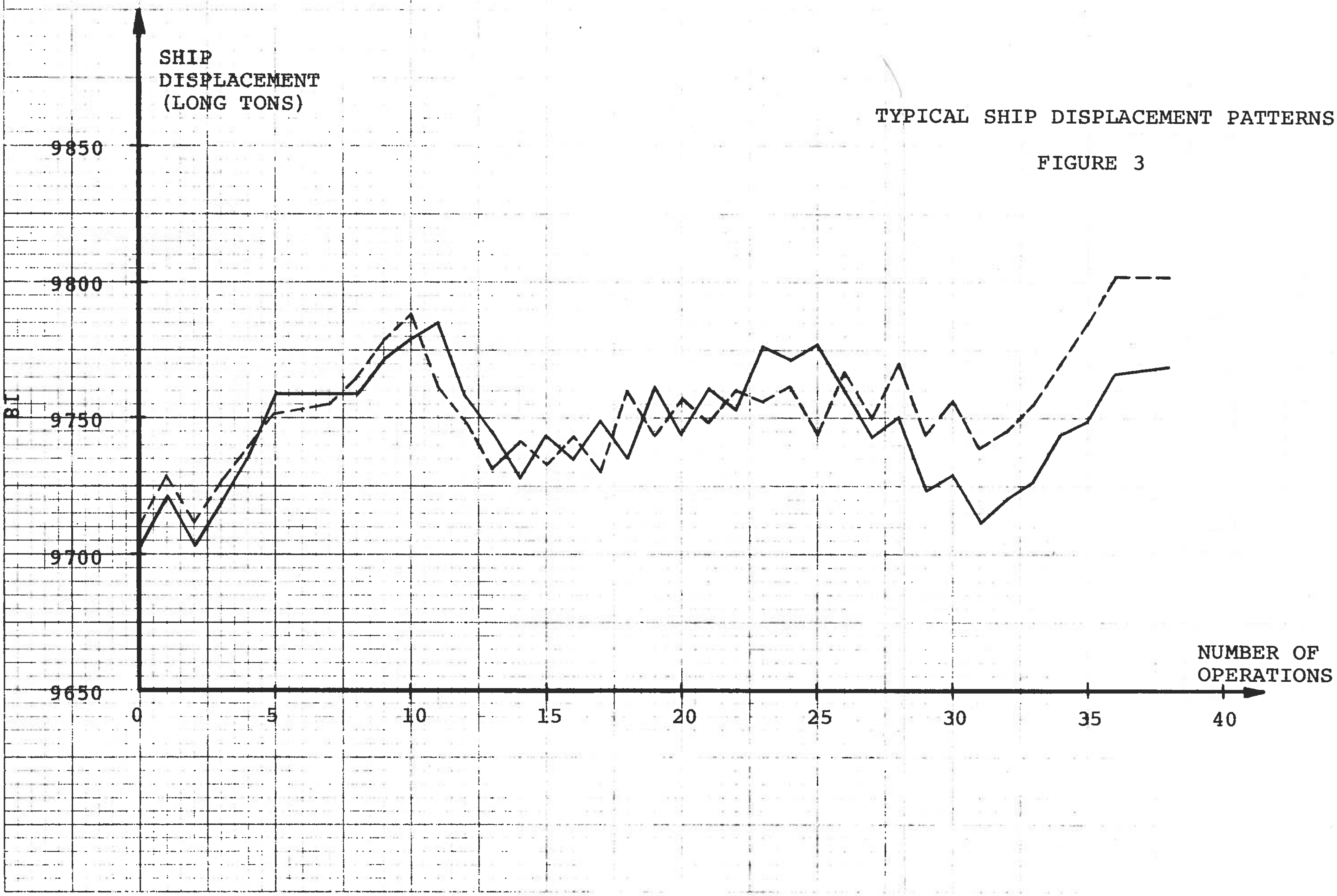
BASIC QUEUEING SITUATION

FIGURE 1

COLUMN	CONTENT
1	PURPOSE OF THE OPERATION
2	HOLD TO BE SERVICED
3	ABOVE OR BELOW DECK INDICATOR
4	TIER NUMBER
5	CELL NUMBER
6	PORT OF DESTINATION
7	KEY NUMBER
8	ACTUAL OR TARGET WEIGHT
9	THE ACTUAL WEIGHT LOADED ABOARD OR A WARNING CODE

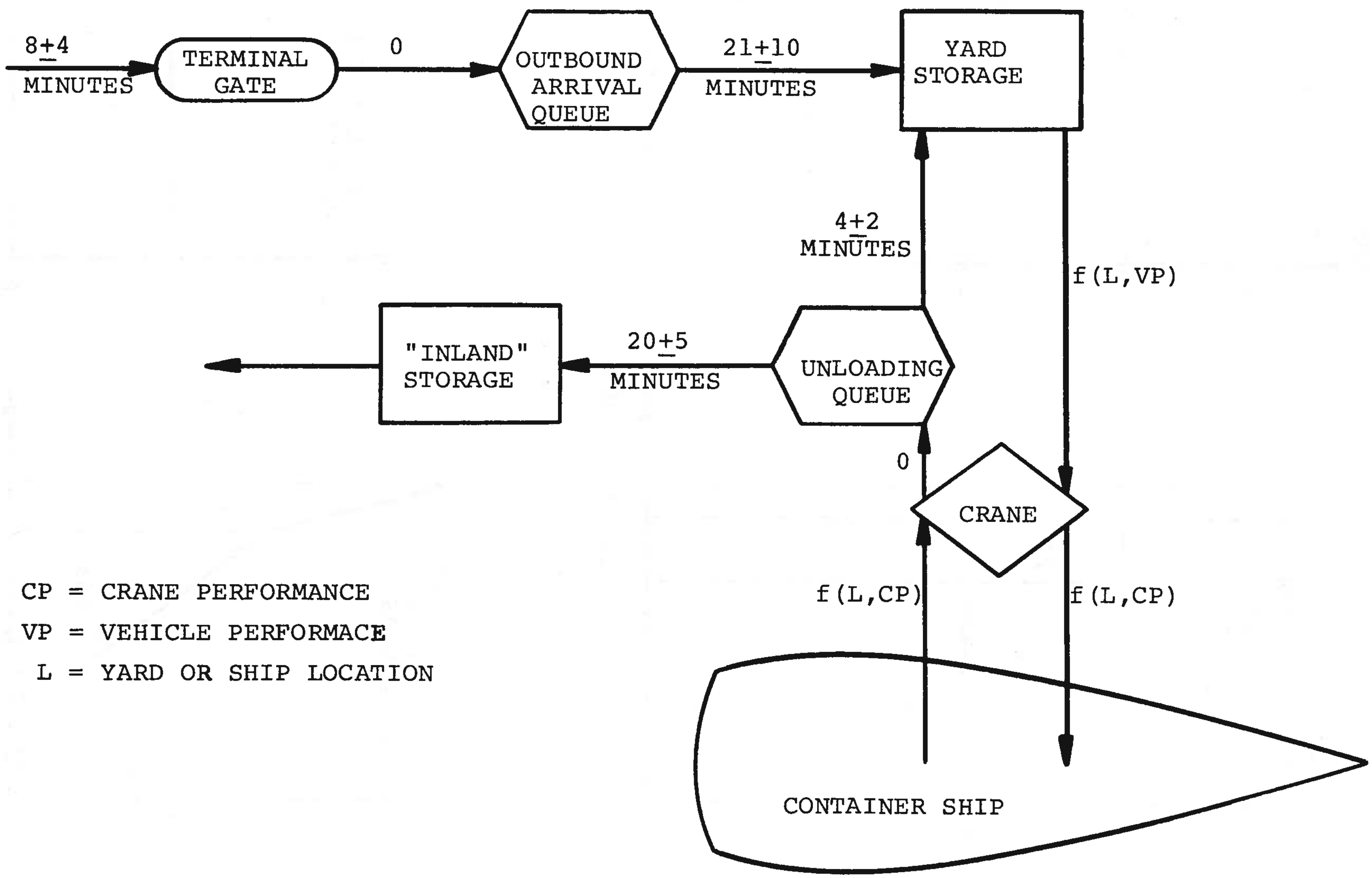
COLUMN HEADINGS FOR THE
LOADING/UNLOADING SEQUENCE TABLE

FIGURE 2



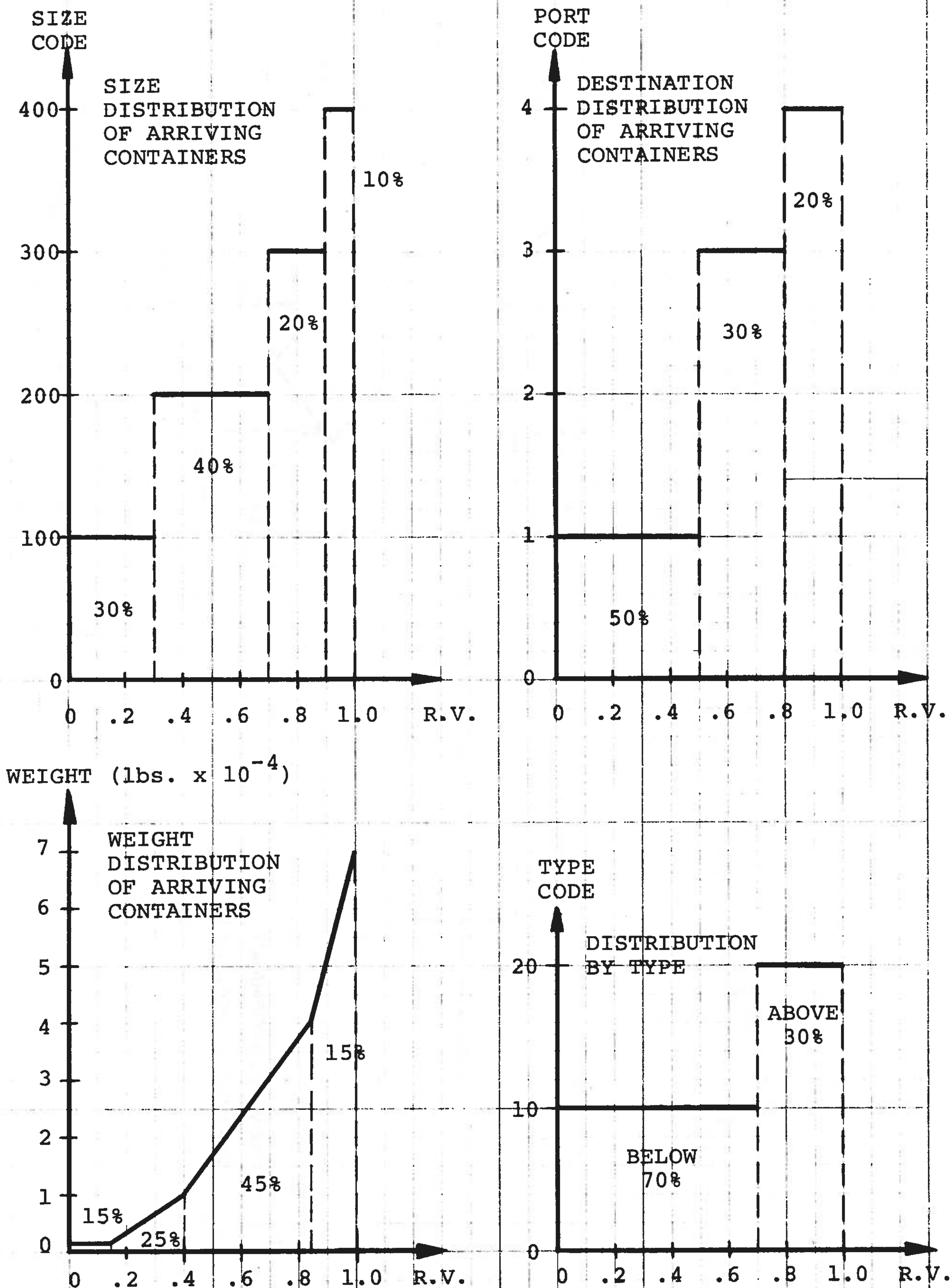
TYPICAL SHIP DISPLACEMENT PATTERNS

FIGURE 3

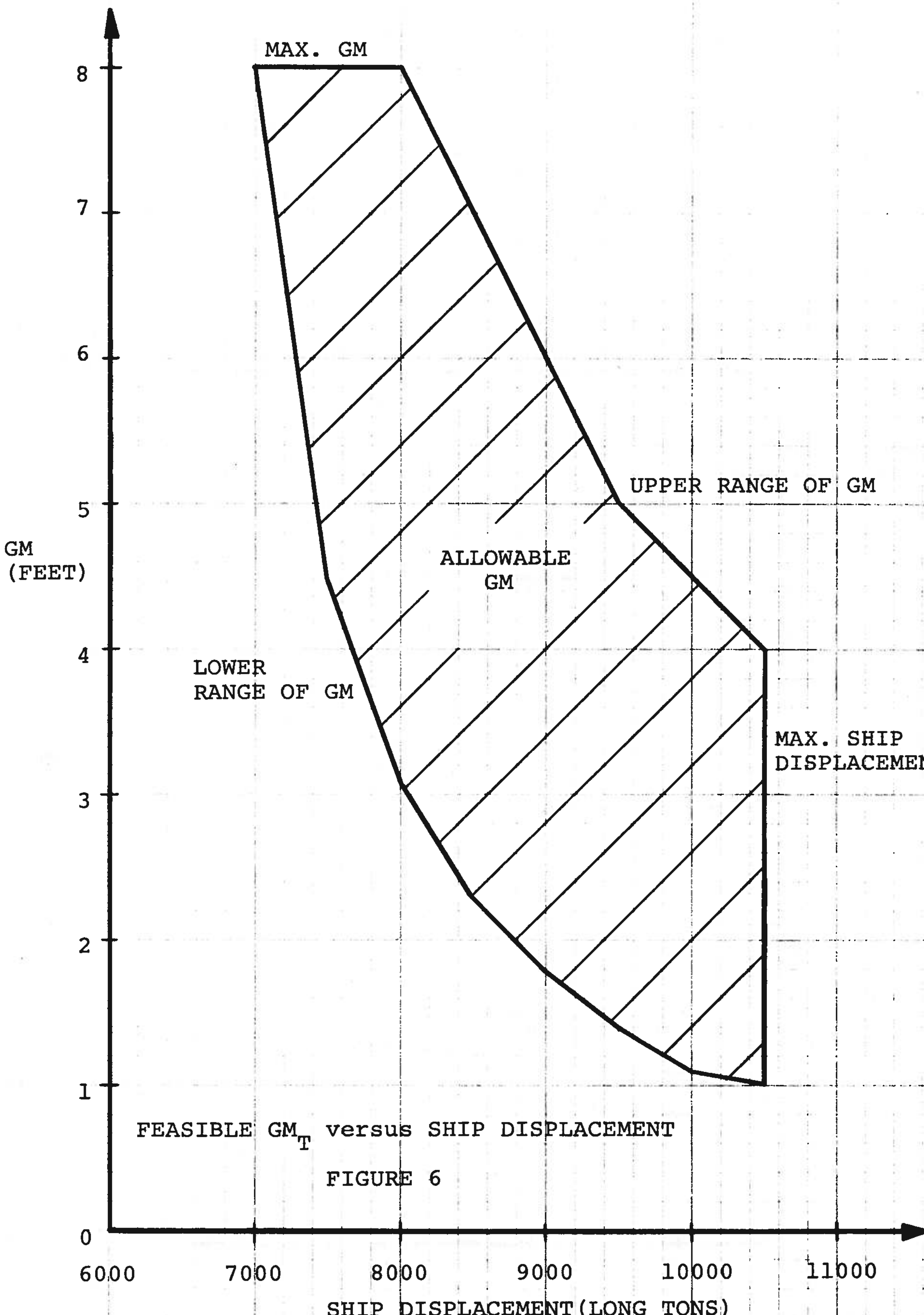


CONTAINER TERMINAL MODEL

FIGURE 4

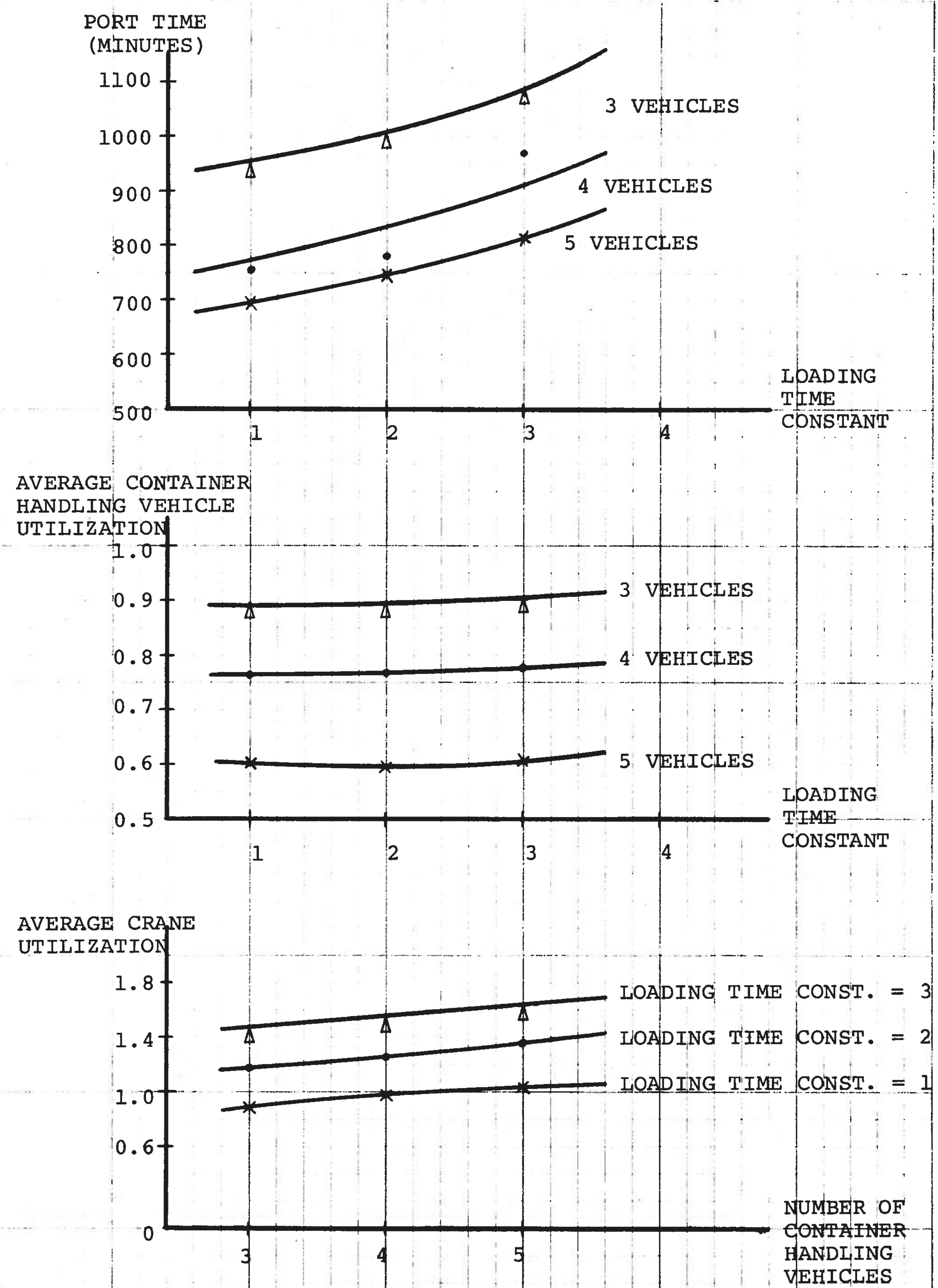


DISTRIBUTION OF RANDOMLY ARRIVING CONTAINERS
FIGURE 5



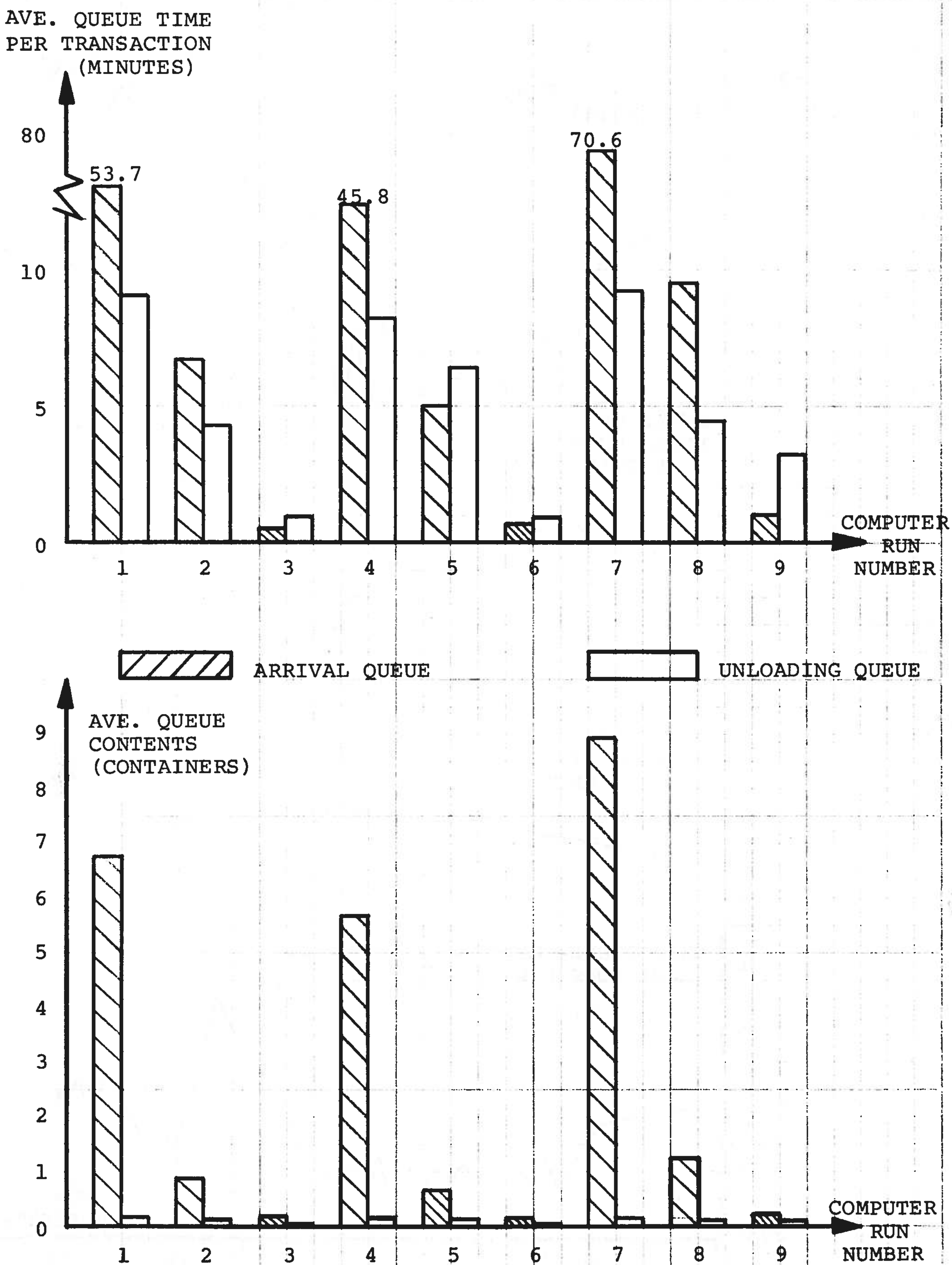
FEASIBLE GM_T versus SHIP DISPLACEMENT

FIGURE 6

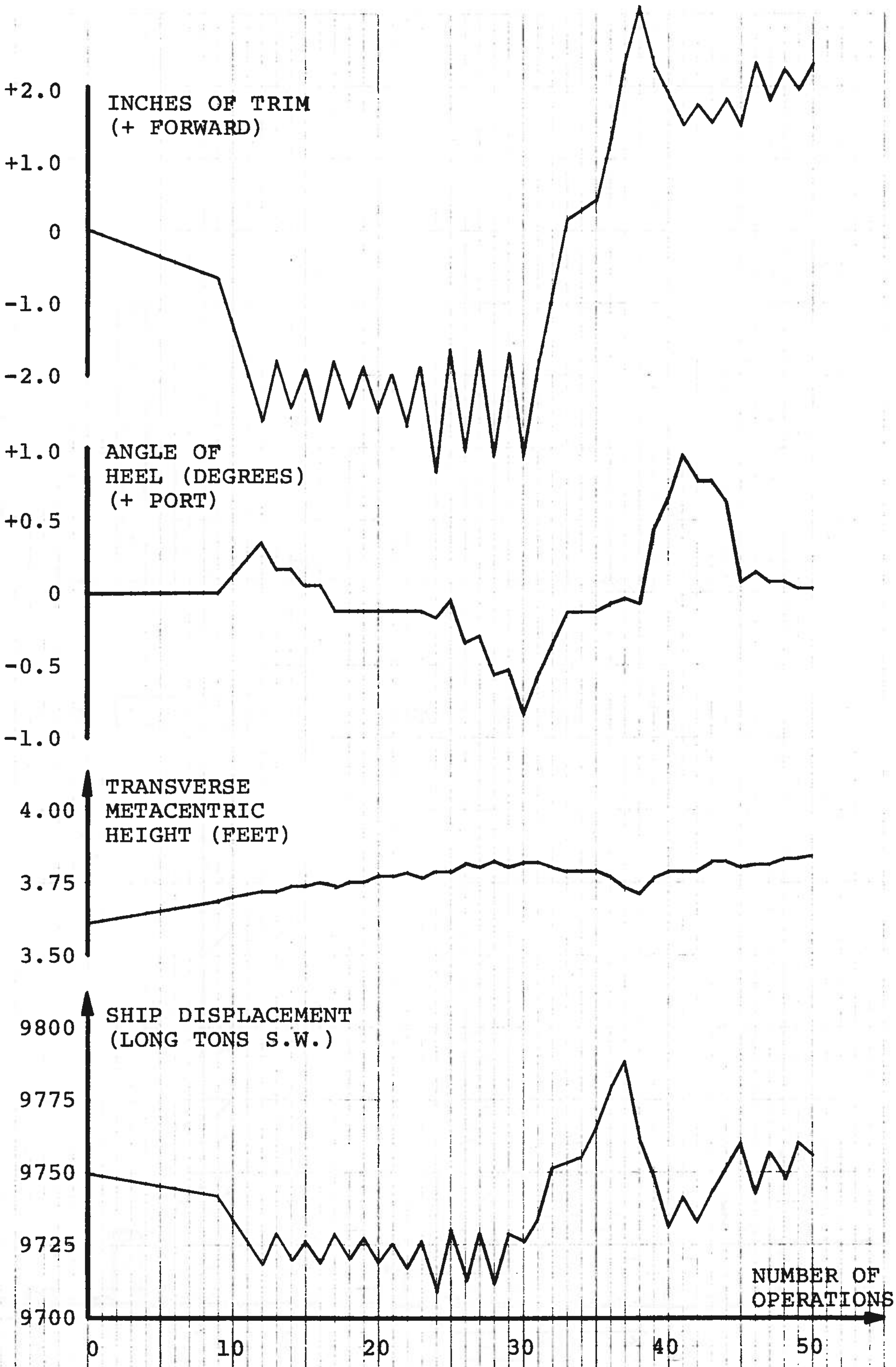


COMPARITIVE RESULTS

FIGURE 7



COMPARITIVE RESULTS
FIGURE 8



SHIP DISPLACEMENT, TRANSVERSE METACENTRIC HEIGHT, HEEL, AND TRIM versus NUMBER OF LOADING/UNLOADING OPERATIONS

FIGURE 9

Appendix B - Modifications

Since the publication of this paper, several major improvements have been made in the simulation program. These improvements increase the versatility, realism, and usefulness of the program's output. Improvements were made in seven areas.

1 The arriving containers were pre-marshalled into separate storage yards according to their port of destination.

2 These containers were assigned to the first available spot in the appropriate storage section.

3 Traffic patterns were improved by assigning certain groups of container handling vehicles to certain tasks.

4 A pierside loading queue was established.

5 The simultaneous use of different cranes at different holds was permitted.

6 Intership reshuffling of containers was incorporated into the loading/unloading strategy.

7 Improvements were made in the calculations and printed output for ship displacement, stability, trim, and heel.

The arrival sequence of the containers is random. However, to minimize the future onboard handling of containers, it is advantageous to load each hold as full as possible with containers destined for one particular port. Consequently, pre-marshalling of the containers into separate storage yards according to their port of destination simplifies retrieving a set of similar containers. Pre-marshalling is achieved by examining the port parameter of each arriving container (transaction). The container is then assigned to the correct storage section for that particular port. Within each section of the storage yard, the containers are stored row by row. However, the containers selected for loading are randomly distributed throughout the storage section. Therefore, as loading progresses, voids occur in the storage section. Minimizing the total acerage allotted to storage is accomplished by filling these voids with arriving containers. This operation is accomplished by scanning the correct storage section row by row until the first void spot is found. The arriving container is then moved to this location. To eliminate needless container handling vehicle traffic patterns, the movement of any particular vehicle is restricted. This restriction amounts to keeping certain vehicles in certain areas of the yard. The new traffic pattern is shown in figure 1. This pattern is achieved by establishing two separate container handling vehicle pools (storages).

A pierside loading queue is incorporated into the computer program to reduce turnaround time (figure 1). This queue absorbs the variation between the rate at which containers are removed from storage and the rate at which they can be loaded aboard. Thus, this queue permits the removal of containers from storage prior to the time they are actually needed for loading. Consequently, the percent utilization of the costly dockside crane can be increased in addition to reducing turnaround time. When large container ships are involved, two or three dockside cranes can be employed to further reduce the turnaround time. These cranes are restricted to working on only one hold at a time. Two cranes cannot service the same hold simultaneously. The correct crane to use is determined from the loading/unloading sequence table. Incorporated into the number of the hold is the number of the crane to be used at that hold. For example, hold number 5 and crane number 2 would be represented in the loading/unloading sequence table by the number 52 in column 2. The program determines the correct crane by moduloly dividing this number by 10. Thus 52 @ 10 equals 2 since only the remainder is saved. This remainder, therefore, indicates that crane number 2 should be used at hold number 5.

During the unloading process, it may be necessary to unload several containers which will need to be reloaded before the ship sails. This situation arises when access to a required container is blocked by a container which is not destined for the current port. In an effort to reduce the confusion and time involved in this reloading process, an intership transfer option is available as part of the loading/unloading strategy. This option permits a container to be moved from one cell to another if such a move does not further hamper the unloading process. Also, this movement must not adversely effect the stability, trim, or heel of the ship. The operation number 7 in the loading/unloading sequence table indicates an intership transfer from the given cell and tier to the cell and tier given in the next command. Intership transfers between holds are not permitted.

Since GPSS truncates all fractional values, it was difficult to produce meaningful results for values of GM_T, trim, and heel. To circumvent this problem, values for the following ship properties are initially set at 100 times their actual value.

These are: arrival KG,

maximum allowable trim,

maximum allowable angle of heel,

maximum allowable GM_T,

allowable GM_T versus ship displacement, and

KM_T versus ship displacement.

The user mentally divides the computed values for GM_T, heel, and trim by 100 to determine the correct values to two decimal places.

Limiting particular container handling vehicles to certain locations within the yard reduced the ship turnaround time while still retaining the same level of vehicle utilization. In an actual situation, cost studies could be conducted to determine whether a reduction in turnaround time or a reduction in the total number of container handling vehicles would be more economical. The use of two cranes and the intership reshuffling of containers further reduced the loading/unloading time. Still more time was saved by creating the loading queue. These results further confirm the algorithm of this program. Also, the practical application of the program as well as the realism of the simulation is improved by these additions.

Finally, the program's flexibility should be mentioned. One of the primary goals of this study is to show the adaptability of GPSS to marine studies. A secondary goal is the development of a useful computer program which would help analyze the economics of a container handling terminal. Both these goals have been reached. The current program is more than an initial step in container handling simulation. If used judiciously, it can provide meaningful input data for the rational development of an efficient container terminal.

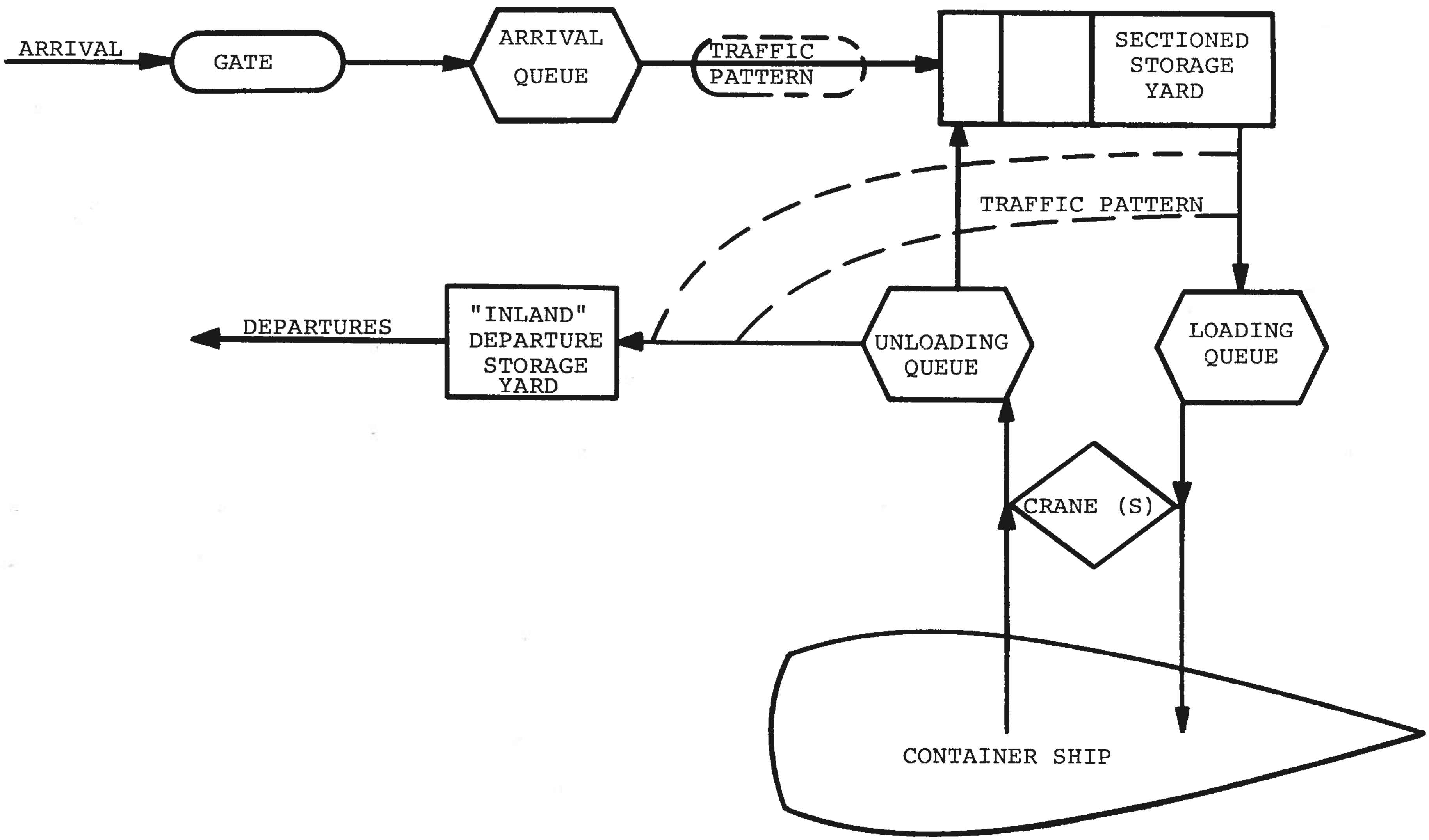


FIGURE 1 CONTAINER TERMINAL MODEL