Marine Technology, Vol. 21, No. 4, Oct. 1984, pp. 370–383

Containership Stowage: A Computer-Aided Preplanning System

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It is well known that the advent of cargo containerization has revolutionized the art of ship stowage by greatly increasing cargo handling efficiency. However, in order to take full advantage of this capability, and to optimize the use of the containership itself, the physical distribution of containers on board the vessel must be carefully planned. In this paper, a computer software system designed to aid in this planning process is described. First, the particular difficulties of containership stowage are discussed and a set of stowage objectives is developed. The solution algorithm, employing a combination of simulation and a Monte Carlo technique, is described. Finally, the implementation of the system by a major U.S. shipping line is discussed.

Introduction

SINCE the advent of cargo containerization some 20 years ago, the shipping industry has steadily continued to evolve. Today there is an increasing share of containers moving under the control of the ship operator through several different land and sea transport modes. As the economic benefits of this intermodal network have been wrung out of the system, they have largely been passed on to the purchaser of transportation. Competition in the marketplace has increased, forcing rates down and levels of service and dependability to all-time highs.

In order to achieve efficiency through economy of scale the size of containerships has increased dramatically. The first fully cellular vessels, Sea-Land's C-2 class ships, carried 226 thirty-five-foot containers or about 350 TEU's (twenty-foot equivalent units). Matson's 1970 state-of-the-art vessel, the 071 class, was designed with a capacity of 1500 TEU's. In the past year American President Lines has completed construction of three new C-9 class vessels with a design capacity of 2500 TEU's. There is every indication that this trend is continuing, with United States Lines currently building new vessels larger than 4000 TEU's.

In addition to big ships, the economy-of-scale concept requires large numbers of containers. Thus, in order to feed enough cargo into the ports, operators are placing even greater reliance on intermodal systems. In this way, ocean shipping has become just one element of a worldwide transportation network, with the marine container terminal providing the interface.

Since the transfer of containers to and from the vessel is a critical link in the transport chain, it becomes very important that it be carried out rapidly and efficiently. With the large vessels of today, requiring literally thousands of container movements to load and discharge, this can be very difficult to achieve. Further, for any shipping operation to be cost-effective it is essential to optimize the utilization of the vessel itself. These two concepts, port efficiency and vessel utilization, though quite distinct, are largely determined by a common factor. This is the arrangement of cargo on board the vessel, or vessel stowage. The task of determining the best of such arrangements is both an art and a science, called stowage planning or preplanning.

About 15 years ago, an early attempt at introducing the computer into this process was reported by Van Dyke and Webster [1].[2] Although the development was a bold step forward, the procedure failed to be attractive enough to merit regular use. The Maritime Administration, recognizing the importance of this concept, promoted a further development of this system, but it too did not achieve acceptance in the industry.

Since that time two important events have taken place. First, the revolution in computer technology has led to large, fast, inexpensive and interactive computers. Second, American President Lines (APL), the sponsor of the research presented here, recognized that a workable, computer-based stowage system must be quite complex if it is to adequately address all of the important issues. As a result, they have completed a four-year development of a system in which APL's stowage planning and operations personnel had a continuing and significant input. This system, called CAPS for Computer Aided Pre-Planning System, is now in daily use at APL.

The CAPS system is described herein, beginning with an introduction to the stowage planning task and outlining the objectives of good stowage. The special problems of a vessel serving many different ports are examined, and it is shown why this may lead to less efficient stows. The computer system is then introduced, including both data base elements and a tactical stowage planning program. Next the important algorithms used in the program are discussed in detail, and, finally, implementation of the system in its operational environment is described.

The preplanning task

Preplanning usually takes place on shore at a centralized location, or alternatively at the container terminal. The job is performed by skilled "preplanners" who must have a working knowledge of ship stability, container stowage constraints, and a certain amount of imagination in order to come up with the best loading from the myriad of possibilities. In addition, these preplanners must be familiar with the cargo space geometry and any special operational problems of each of their company's vessels.

Preplanning is done prior to a vessel's arrival at the load port so that precious time will not be wasted when the vessel is at the dock. Unfortunately, in many cases, much of the cargo booked for the vessel may not have arrived at the terminal when preplanning commences. At the least, this means that the weights of some of the individual containers are not known. At the worst, some of the booked containers may not materialize at all. This contrasts with the old break-bulk days when cargo was required to be at the pier, documentation complete, at least 48 hours before the ship arrived. Now, at some ports, as much as 40 percent of the expected outbound containers may still be moving through the intermodal system enroute to the port when stowage operations

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[2] Numbers in brackets designate References at end of paper.

Presented at the April 14, 1983 meeting of the Northern California Section of THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS.

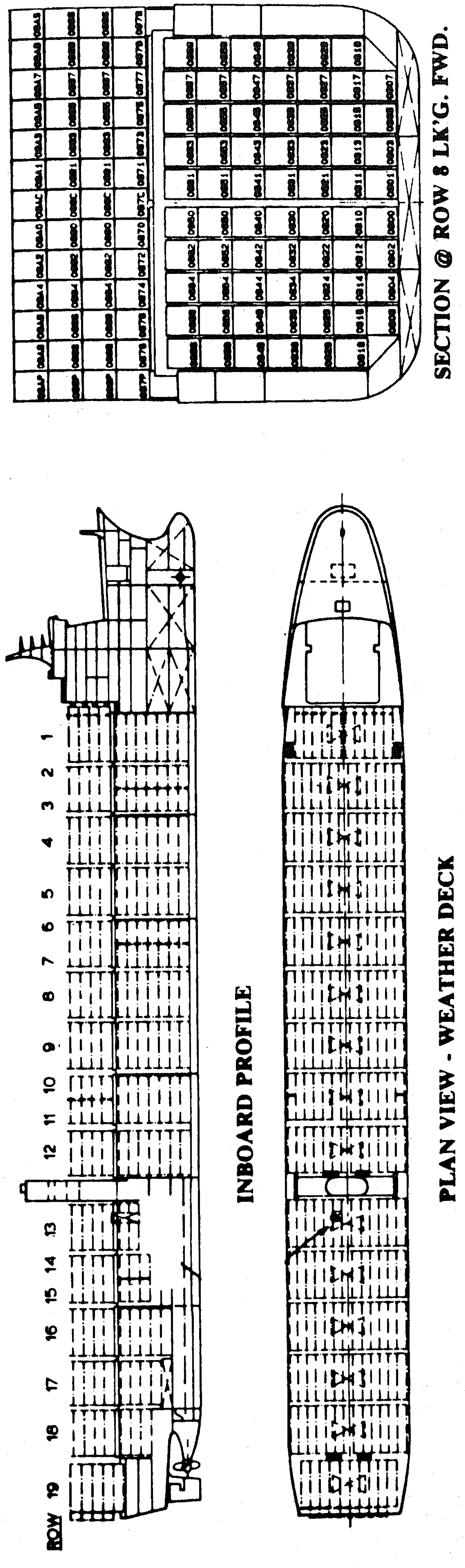


Fig. 1 Stowage arrangement for the C-9. Both plan view an profile are shown with the maximum number of 20-ft containers. Forty-foot containers may be stowed in place of paired 20's at Rows 10–11 and 14–15 only.

commence, and there are always a few flat tires or hot boxes along the way. This change is demanded by today's high level of competition, and today's rapid computer data processing permits it.

Once the preplanner has obtained his best estimate of what the actual cargo will be, and has received a sailing wire or cargo plan from the prior port giving the inbound stowage arrangement, he may begin. The first step is to determine which containers on the inbound ship are to be discharged and which are to remain. The discharged containers include all those destined for the current port plus all other containers which must come off in order to access these. A container in this latter category is called a "rehandle," since it must be discharged and then restowed. Containers on board the vessel which will become rehandles (because they block access to containers for nearer destinations) are called "overstows." Obviously one of the primary objectives of good stowage is to avoid overstows, since rehandling is totally nonproductive. Unfortunately, this is not always possible because of cargo space arrangement problems. Figure 1 shows the stowage arrangement of a typical modern containership, in this case APL's new C-9 class. The containers are stowed in vertical stacks below deck and again above deck. As can be seen, large hatch covers separate the two sets of stacks and, thus, discharge of below deck containers can be made only if all those containers on the hatch cover above are removed. In the case of the C-9, this means the discharge of a single below deck container could require as many as 56 extra crane movements in discharging and reloading the 28 containers stowed above.

Once the unloaded ship configuration has been determined, the preplanner will then generate a target outbound stow plan called the preplan. The stowage represented by this preplan must satisfy a variety of constraints. These contraints arise as a result of physical limitations of the vessel and containers. First, not all containers are alike. Several lengths are used; 20 ft, 40 ft, and 45 ft in the APL system. Widths are usually 8 ft-0 in., but heights usually vary from 8 ft-0 in. to 9 ft-6 in. Further, some containers are built for transport of specialized cargo. Refrigerated containers for perishable goods, called reefers, are insulated and equipped with electrically powered compressors. Tank containers are built for liquid cargoes, and open flatrack containers are provided for oversize bulk items. Even if two containers are physically identical, they may have important differences arising from their contents. The cargo may be refrigerated or may require special ventilation. Dangerous and hazardous cargoes must also be considered. Finally, the weight of the container depends on the contents and may vary from 2 to 30 tons.

Second, a similar situation occurs with the shipboard stowage locations or "slots." That is, not all slots are the same. Many of the slots are restricted to a particular length of container while others are optional. For example, certain slots may accommodate one 40-ft container or two 20-ft containers. Slots below deck have different ventilation and humidity distinctions than those on deck. Only slots with good ventilation and protection from the elements can be used for the stowage of reefers. In addition, each reefer requires an electrical outlet nearby from which to draw power for the compressor. Certain ports along the route may have restricted access to certain slots due to crane limitations. These slots may not be usable for cargo bound for these destinations. Cargo carried above deck must be securely lashed. This imposes restrictions on the weight of each container in a vertical stack. In addition, hatch covers and other structural components may have limited strengths, limiting total stack weights. Stack heights may also have limitations imposed by the tank top to hatch cover clearance below deck and crane height limitations or navigational visibility requirements above deck. These limitations will govern the number of containers in each stack, which will vary depending on the heights of the individual containers.

As a result of this diversity in container characteristics and slot characteristics, it is not an inconsequential problem to determine

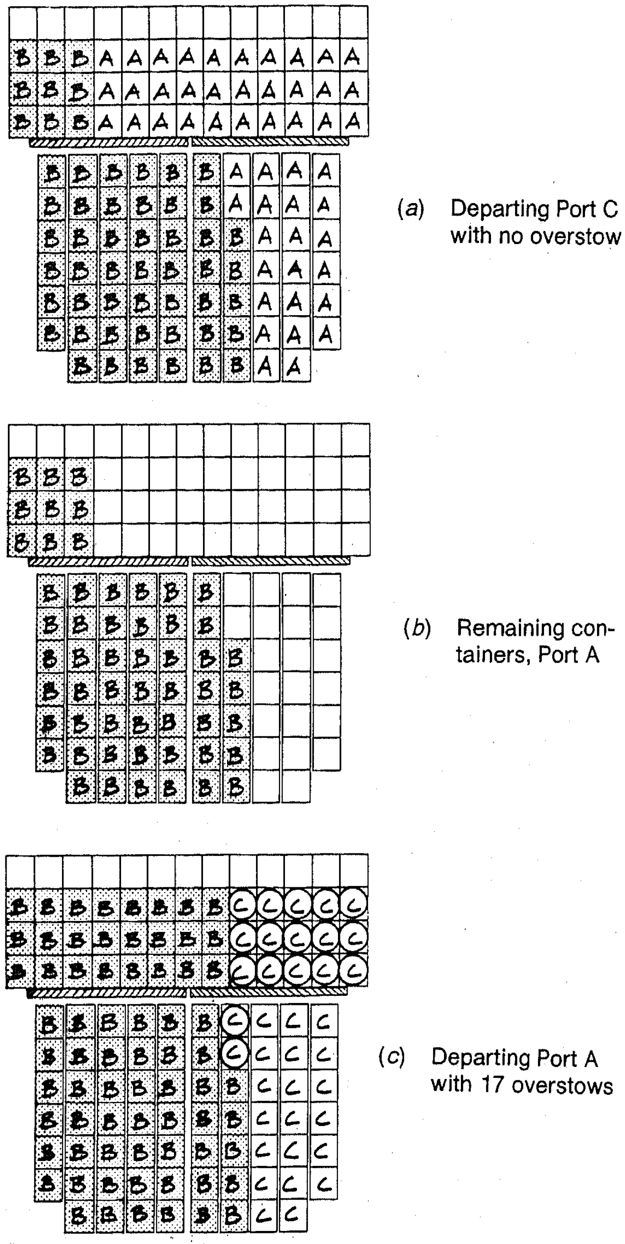


Fig. 2 Container loading arrangement with total of 17 rehandles required

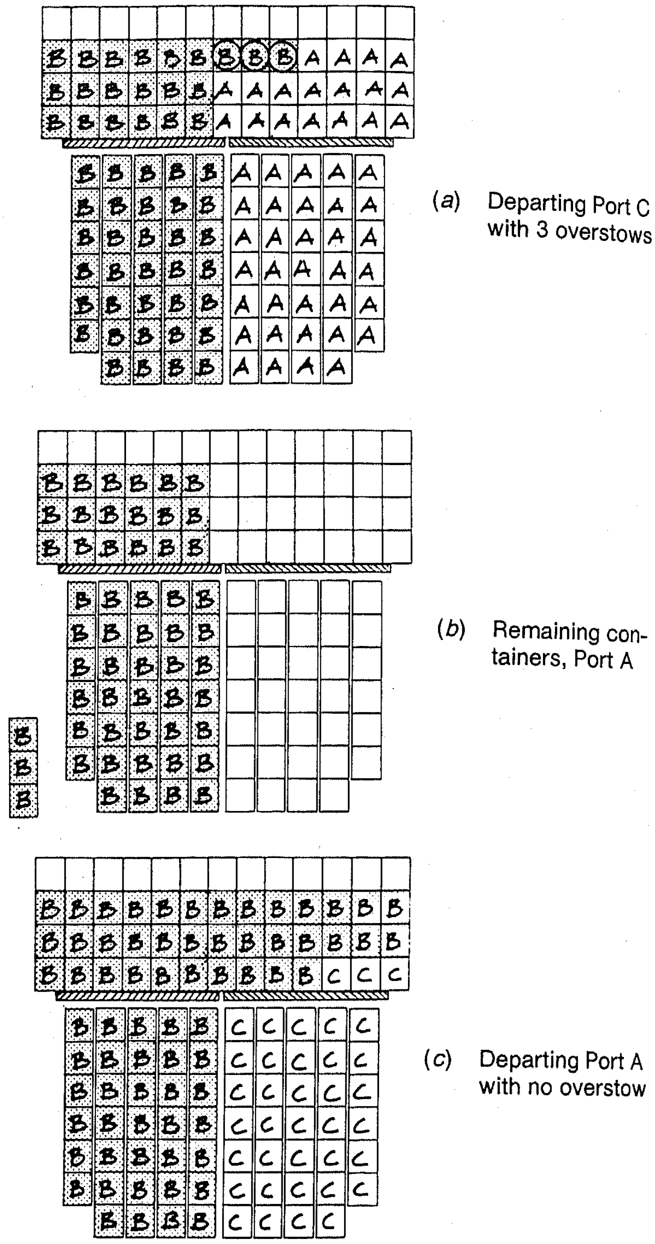


Fig. 3 Container loading arrangement with total of 3 rehandles required

a loading which meets the basic stowage constraints. Further, the satisfaction of these constraints, although necessary, is not a sufficient condition for a loading to be feasible. It is a further requirement that the cargo weight distribution be within acceptable bounds set by metacentric height (GM) requirements, deadweight limits, draft restrictions, and hull strength limitations.

Once all of the aforementioned stowage constraints have been addressed, the preplanner must focus on a more interesting and difficult problem. As we have stated, the high level of competition in the container shipping industry makes it extremely important to optimize utilization of all resources. In terms of stowage, this means arranging the containers for optimal port efficiency and vessel utilization. Port efficiency means spending a minimum amount of time in port discharging and loading. This can be achieved through the reduction of rehandling, hatch cover lifting, and longitudinal crane movements. The objectives of optimal vessel utilization are twofold. First, it is desirable to minimize required ballast and optimize trim, in order to achieve lower resistance and increased seaworthiness; hence, a net reduction in fuel oil burn. Second, as pointed out by Harlander [3], operators tend to push containership capacity beyond design limits by stacking containers higher and higher on deck. It therefore becomes an important preplanning objective to maximize capacity subject to stability constraints when the vessel is operating in an overbooked market.

A fundamental preplanning difficulty arises from the differences between port and vessel considerations. Port considerations are affected primarily by the distribution of container destinations, whereas vessel considerations are affected by distribution of container weight. Since these two container characteristics are not independent, the preplanner must be prepared to make tradeoffs. For example, he may have to choose between one foot of trim or ten overstows. Such decisions require an analysis of the associated economic implications, which can be difficult when many tradeoffs are involved.

Multiple-port routes

When a vessel serves many different ports on each voyage, the difficulty in achieving good stowage increases very rapidly. In a multiple-port trade each port loads containers for several different destinations. The space available on board the vessel for these containers is precisely just those locations where inbound containers were discharged. As the number of ports increases, the percentage of the total load which is discharged at any one port decreases. This means the available space for loading becomes a smaller percentage of the total cargo space. The net result is an increasing number of different container destinations being stowed in a smaller and more restricted volume. This decrease in stowage flexibility often leads to progressively less efficient stows as the vessel transits its route.

The progressive degradation of stowage efficiency reflects the fact that a vessel carries with it the compounded history of each port's activity. This history, expressed by the on-board cargo arrangement, persists until the vessel is completely discharged, if ever. In order to avoid the stowage degradation associated with this history, there are two alternatives. The first is to completely discharge and reload the vessel at every port. This is obviously an undesirable solution. The more practical but much more difficult alternative is to stow the containers at each port in a fashion that will minimize problems at future ports. In order to do so, all containers to be loaded at future ports must be considered in the development of the stowage for each individual port. In this way, a correct formulation of the pre-planning problem involves all ports and trade simultaneously.

In order to illustrate this multiple-port problem, let us consider a simplified example. For this purpose we restrict our attention to a single bay of a containership and the cargo stowage in this bay. Let the vessel be engaged in trade between three ports, designated A, B, and C. Let these ports be called upon in rotating alphabetical order, that is, A:B:C:A:B: etc.

Imagine the vessel completely empty and at the dock at Port C. Containers will be loaded here bound for Ports A and B. Assume that these are loaded as shown in Fig. 2(*a*). Here the individual containers are indicated by a letter corresponding to their destination. Notice that the containers have been arranged so that there is no overstow. Therefore, from the perspective of Port C, this loading appears quite satisfactory.

Now, let the vessel sail for Port A. Upon arrival, all containers bound for Port A are discharged with no rehandles. The containers that will remain on board are shown in Fig. 2(*b*). Now the containers originating at Port A for Ports B and C may be loaded as shown in Fig. 2(*c*). As indicated by the circles, 17 containers bound for Port C are now overstowed. These overstows were unavoidable due to the arrangement of existing containers. This will result in a total of 34 additional container moves in order to discharge and restow the vessel in Port B.

Let us now return to the first port (Port C) again and try a different arrangement of the same containers [Fig. 3(*a*)]. Unlike the first arrangement, this stow plan includes three overstows to be rehandled in Port A. Therefore, from the perspective of the first port, this loading does not appear as efficient as our original one. However, let us see what happens down line.

Let the vessel sail for Port A, as before, and be discharged [Fig. 3(*b*)]. The discharged containers include the three overstows, indicated on the lower left, which will be reloaded. This configuration of remaining containers is considerably better than the original, as now it is possible to load the vessel in Port A with no overstow [Fig. 3(*c*)]. Therefore, by starting with a loading which initially appeared inferior, we are able to reduce the total number of overstows from 17 to 3.

The purpose of this exercise has been to illustrate that the quality of a loading cannot be judged from the perspective of one port alone. Instead, it is necessary to "look ahead" to future operations and consider cargo yet to be loaded, in order to avoid difficulties down line. The full impact of this concept can be realized when one extrapolates the example to a realistic deployment such as that shown in Fig. 4, where vessels call as many as 10 ports on a voyage. Further, as one might imagine, it is quite possible to have an arrangement problem with container weights similar to the one just described for container destinations.

The CAPS approach

From the foregoing discussion, it should be evident that the sheer complexity of containership stowage precludes an exact mathematical formulation of the problem. For this reason, the usual analytical tools for solution of optimization problems, such as linear programming, are not applicable. Instead, it becomes necessary to solve the problem with a random search technique, employing a random simulation procedure known as the Monte Carlo method [4]. In this formulation, the vessel, containers and ports are modeled with software elements. Using this model, many different possible ship loadings are generated with an algorithm designed to closely resemble the thinking process of human preplanners. However, the computer's inherent superiority in speed and accuracy is used to generate literally hundreds of different solutions. The computer evaluates each solution against a set of metrics and gives it a score. Those loadings which appear the most efficient (that is, those with the best scores) are retained, and after many trials the best of these are returned as the result.

The stowage plans developed by the computer are not perfect. They cannot be, since the cargo calculated to be loaded in future downline ports are only probabilities at the time the plan is developed, not actualities. However, they provide information to the preplanner which cannot be obtained through manual methods. In this way, CAPS represents an interesting use of the computer in an operational environment. In most practical applications, the computer is used to perform bookkeeping or numerical computation tasks in a prescribed fashion. While these tasks may be too tedious to perform by hand, they are, nevertheless, straightforward in their execution. In contrast, CAPS comes much closer to the concept of artificial intelligence, in its ability to create and compare different alternatives.

No matter how good such a program may be, in dealing with such a complex problem there will always be exceptional cases it will not be able to handle. For this reason, the design philosophy used from the onset has been to develop a tool to serve as an aid to intelligent human users, rather than a black box to replace them. This approach is based on the belief that, for problems of this nature, the combination of man and machine is superior to either alone. The resulting system allows manual control and overrides at every step of the process and integrates smoothly into the usual preplanning procedure.

In addition to the sophisticated tactical program outlined in the preceding, CAPS includes a database portion which interfaces with real-time terminal operations. In itself, this portion of the system provides for tracking and communication of stowage data and for calculation of stability for actual ship loadings. The data captured in the database are then used as input to the stowage planning program. In order to describe the total system, the next section begins with a brief description of the database portion. In the section following this, the stowage planning program is then described in detail.

Database subsystem

The database portion of the system is composed of a set of five different modules, each containing several FORTRAN language programs. Each module addresses a different aspect of the stowage planning task as described in the following. For reference purposes, example outputs from these are given in Appendix 1.

a. Stability module. This is the fundamental element of the system and contains programs to enter and display containership stowage data and to calculate vessel stability. The container stow and on-board tankage status may be input by the user with a program that is both interactive and graphic. Stowage bay plans are displayed on the computer terminal, giving the destination,

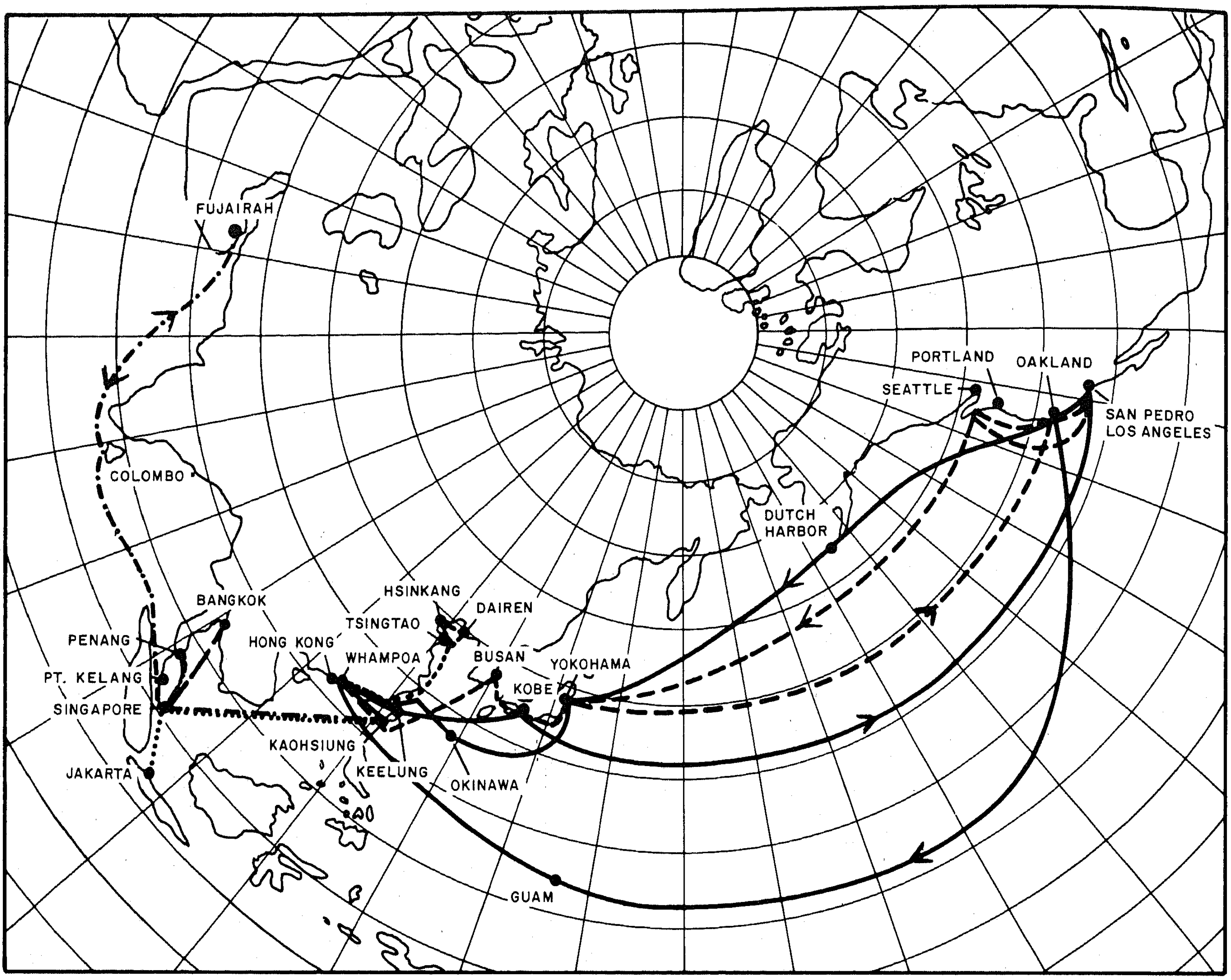


Fig. 4 Deployment of APL vessels

type and weight of each container on board. To enter or update these data, the user moves the cursor to the appropriate slot and types in the required information. All input is checked for reasonableness and a warning message is issued to the user if it is not so. In addition to container and tankage data, a summary of vessel stability is also displayed on the terminal. The *GM*, *GM* margin, draft, hull stress, trim, heel and deadweight are updated automatically as the user alters the stow. Output programs of the stability module produce stowage bay plans, a condensed stow plan, vessel stability data, a required lashing plan and several numerical stowage summaries (see Appendix 1 for examples).

b. Stowage module. This portion of the system is used by the preplanner as an aid in some of the more fundamental preplanning tasks. Included is a program which simulates the unloading of a vessel, separating an inbound stow plan into discharged and remaining containers. The second portion of the stowage module is a program which assigns weights to preplanned containers for the estimation of vessel stability. The weights assigned are based on historical averages and are stratified vertically in a statistical manner, in order to assess accurately the vessel's transverse stability. For example, historical data may indicate that dry 40-ft containers stowed in Oakland and bound for Hong Kong have an average weight of 18.3 tons. Initially, all preplanned containers of this category are assigned this weight. Next, the weight of each container is multiplied by a factor that depends on its location on board the ship. These factors are also generated from historical data and may reflect an attempt to stow heavy containers on the bottom for maximum stability. Finally, all container weights are adjusted either up or down proportionally so that the net average remains at 18.3 tons. Using this algorithm, very accurate stability predictions are obtained at the preplanning stage.

c. Statistics module. This module is designed to track actual ship stowage data so that historical statistics of stowage performance may be generated. Included is a program that saves all of the important stowage data in a database each time a vessel departs a port. The data include number, type and average weight of all containers on board for each destination. Also included are cargo centers of gravity, statistical distribution of container weights, vessel tankage status, $\overline{GM}$, draft, trim, stress and attitude. A program is provided to access this database and generate reports in a variety of formats.

d. Port module. This portion of the system consists of a data file which contains information on each port facility. A program is provided to enter/update and print characteristics of the ports such as draft restrictions, berth availability, arrival time limitations, crane specifics, working hours and a variety of other pertinent information.

e. Fuel module. This module is used for the calculation of fuel consumption during a voyage. A program is provided to predict the fuel burn on each leg of a voyage given either transit times or vessel speed. A table of port-to-port mileages is maintained in the computer for this purpose. The program utilizes vessel fuel rate curves developed at APL for each vessel class.

Loading strategy program

The loading strategy program, called STRAT, consists of two distinct parts. The first and largest of these is devoted to the generation of ship loadings. The second part is concerned with the evaluation and ranking of these loadings. In the following these two parts are described in turn.

A variety of different algorithms could be used to generate ship loadings. The simplest procedure might be one in which the containers are loaded in a completely random fashion. The number of possible stowage configurations, while large even for small vessels, increases like the factorial of the number of container slots. Thus, in order to arrive at an optimal loading using this scheme, a very large number of trials would be necessary, particularly for the large vessels of today. At the very least, such a procedure would be costly. More realistically, it would not converge within time constraints. Therefore, it is desirable to bias the loading generation process in a manner that will tend to produce good results. By doing so, computer time will not be wasted in generating and evaluating unreasonable loadings.

In order to achieve this, an algorithm is used which closely models the thinking process of the human preplanner. Experience has shown that such a scheme is the most straightforward and flexible to different vessel, cargo and voyage parameters. In this scheme, the containers are allocated to stow positions in groups. Each group consists of containers with the same characteristics. For example, one group may be the 40-ft refrigerated containers bound for Hong Kong. The groups will be stowed one at a time, beginning with those destined for the farthest port and concluding with those destined for the nearest port.

Let us now consider the stowage of a single container group. The first step is to search the ship for all legal stow positions. We define a legal stow position as a slot which is unoccupied and will accept the container type without violation of stowage constraints. Once all of these have been found, we will attempt to select the optimum positions from this set. The selection will be based on a user-defined stowage strategy. This strategy consists of a set of "guidelines" which the pre-planner normally keeps in mind when performing the task manually. These may be, for example, to avoid overstows, to load heavy containers low in the ship, or to block stow containers with similar characteristics. We consider each of the guidelines in turn, and eliminate the stow positions which fail to meet the particular criterion. Each time we perform this editing, we check the remaining stow positions to see if they all lie in the same row of the ship. If so, containers from the group are allocated to the positions. Otherwise, we attempt to further reduce the set by considering the next guideline. If all of the guidelines are exhausted without finding a unique row, a random selection is made from the remaining stow positions in the set.

While the stowage guidelines may define a generally good stowage strategy, it is possible that certain guidelines will contradict others. For example, stowing the heaviest containers low in the ship may necessitate overstowage. Thus, the result achieved depends on the particular hierarchy in which the guidelines are considered. Since the merit of any particular loading can be evaluated only after all of the containers are stowed, it follows that it is very difficult to know what this hierarchy should be. Therefore, it becomes desirable to allow the program to explore different arrangements of the hierarchy. We do this with a special algorithm as described in the following.

Imagine a circular dartboard with several different pie-shaped target areas as shown in Fig. 5. Let each of the target areas correspond to a different stowage guideline (avoid overstow, load heavy containers low, etc.). Further, let the size of each target be proportional to the relative importance of the associated guideline. Now, imagine a dart thrower who is capable of hitting the dart board on every throw, but who otherwise has no control over his shots. The probability of a dart hitting any particular target (hence, selecting a stowage guideline) will be proportional to the size of the target. In the program, we replace the dart thrower by a random number generator and allow the user to define the target sizes. In this way, we generate a hierarchy of stowage guidelines that is random, but may be biased toward any arrangement. Using this scheme, we assure that many different loading configurations will be explored.

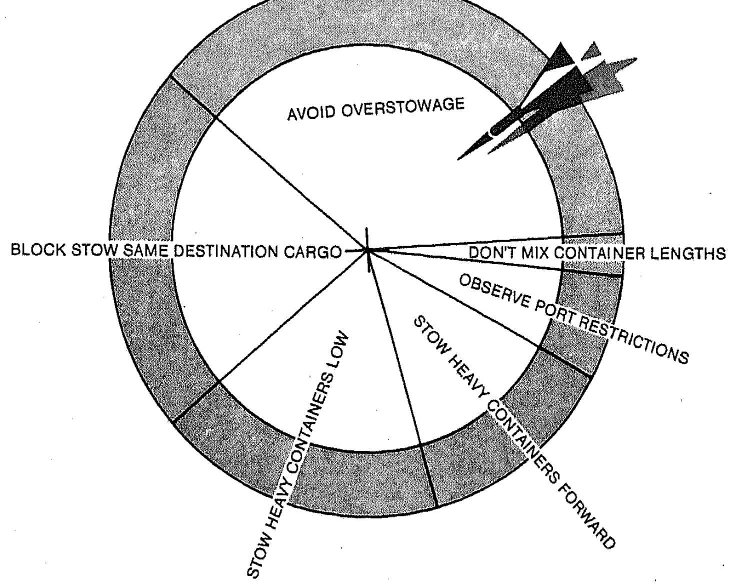


Fig. 5 Random dart technique

Finally, once all of the containers have been stowed, we may evaluate the loading and rank it. The ranking will consist of a penalty score which is assigned to the loading. These penalties are designed to reflect various operational costs that will be incurred as a result of the stowage. The penalties are broken down into eleven categories:

- *Overstows*—For each container that is overstowed a penalty is assigned. This penalty reflects the cost of rehandling the container in port and may vary depending on the labor costs and productivity of the particular port.
- *Hatch access*—For each hatch cover that must be removed for either loading or discharge, a penalty may be assigned. Excessive hatch access is a symptom of poor block stowage of same destination cargo.
- *Port restriction violations*—It may be necessary to violate restrictions concerning placement of containers for certain destinations in certain slots, in order to load all of the cargo. In these cases, penalties are assigned to reflect the difficulty in accessing these containers at their destination port, or the need to restow them at a prior port.
- *Cargo left behind*—A penalty is assigned for each container the program failed to load. This may occur as a result of poor use of cargo space.
- *Stowage over void spaces*—A penalty is assigned for each unused belowdeck slot to reflect the lost potential revenue of carrying a container there.
- *Lashing penalties*—A calculation of the required lashing for on-deck containers is made based on the target weight of each container. Penalties are assigned to reflect the labor cost of implementing this lashing.
- *Incomplete rows*—When several ports are loading toward a completely full ship, any rows which are not filled completely at ports prior to the port at which the ship will be full are penalized. This reflects the fact that one of the subsequent ports will

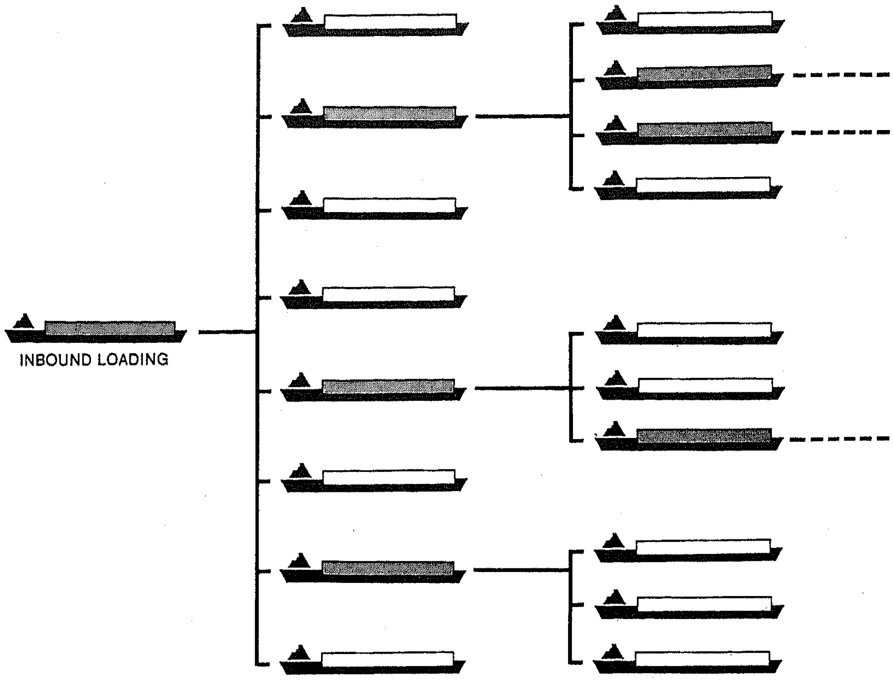


Fig. 6 Loading solution chain

have to load containers on these rows, requiring a longitudinal crane movement.

• *Mixing of lengths*—When a single row contains both 20-ft and 40-ft containers in slots that can accommodate either length, a penalty is assigned to reflect the loss in crane productivity associated with having to handle both lengths.

• *New destination cargo added to rows*—A penalty is assigned each time a container is loaded into a row that previously did not have other containers of the same destination. These penalties reflect the cost of having to move a crane to that row at the port of the destination. High penalties in this category are an indication of poor block stowage.

• *Ballast required*—The amount of ballast required is computed with the following scheme. First, the weight and moments of cargo, operating light ship, and fuel are summed assuming no ballast is required. The vessel stability is then computed and the *GM*, trim, draft and stress are compared against requirements. If the requirements are not met, the program attempts to correct the problem by filling ballast tanks. The order in which the tanks are filled depends on which stability criteria were not satisfied. Each time a tank is filled, the stability is recomputed and checked against the criteria. This algorithm continues until the criteria are met or no more tanks are available to fill. Finally, a penalty is assigned for each ton of required ballast.

• *Stability penalties*—After ballasting as just described, penalties are assigned if the requirements concerning *GM*, trim, draft, heel or stress are not satisfied. The penalties have high values, as failure to meet these requirements results in an infeasible loading solution.

So far we have described a process for generating an optimum containership loading for a single port. However, as previously discussed, this is not adequate when a vessel services many ports. In this case, we must consider the containers to be loaded and discharged at future ports, in order to avoid difficulties down line. In order to do so, the voyage of the vessel is simulated by "sailing" each of the best loadings from the first port through subsequent ports in the route. In this way, the impact of each loading upon future operations can be determined. This is accomplished in the following way.

We begin with the actual inbound loading, represented by the darkened vessel on the left of the diagram in Fig. 6. Based on this inbound configuration, many trial loadings are generated for the first (current) port, as shown to the right. Each of these is ranked and the best ones are saved. We now proceed to the second port and consider each of these best loadings from the first port as an inbound loading. Beginning with each of these, several second port loadings are generated and ranked. However, the score of the inbound loading is added to the total score. In this way, the score reflects the cost of the entire voyage through the two ports. The loadings with the best cumulative scores are saved, and the process repeats for the third and subsequent ports. Finally, those loading solutions with the lowest cumulative scores through the last port considered are printed. The user will then make the final selection of the preplan from these.

Implementation

Following a four-year development and testing period, CAPS was implemented in early 1981 at American President Lines. Since that time the system has been in daily use on a worldwide basis. Originally the hardware supporting the system consisted of two IBM System 34 minicomputers, one based on the U.S. West Coast and one in Hong Kong. In the fall of 1983 CAPS was converted to APL's new IBM 370 system mainframe, primarily in order to take advantage of the company's satellite supported global communications network. At this time there are CAPS users in every major Pacific Basin port.

As a direct result of the communications network, the system now provides the additional function of transmitting the on-board container inventory from port to port as the vessels transit the routes. Further, the network allows key APL personnel to monitor stowage performance and perform the preplanning function from centralized locations.

The CAPS users are divided into two groups, those who are located at the various port facilities and those at preplanning centers in Oakland, California and Hong Kong. The port personnel, who actually control the loading of the vessel, utilize their CAPS workstation to receive the preplan from the preplanning center. They attempt to follow the plan as closely as possible, and update the preplan file with the inevitable changes as the ship is loaded. Once loading is complete the updated preplan file becomes an actual or "outbound" file. CAPS provides various programs to access this file and generate reports needed by the port and vessel personnel, such as the trim and stability report.

When the vessel has sailed, the outbound file will automatically be saved in the CAPS historical database. Further, since the outbound information is the "inbound" information for the next port, it serves as a starting point in planning the next port's stowage. Utilizing this information, along with trade projections from the Traffic Department and historical data, the preplanner will execute the STRAT program and generate a new preplan file. In this way a complete new cycle begins for the subsequent port.

During the past three years, APL has derived substantial benefits from the use of CAPS in the following areas:

- Increased vessel capacity. Increases both in terms of TEU's and cargo deadweight have been realized throughout the APL fleet. This increase has been as high as 250 TEU's for the C-9 class, or 10 percent above designed capacity.
- More precise vessel/container allocation. Early vessel stability projections have proven to be very accurate, allowing effective decision-making with regard to allocation of containers to vessels and thus resulting in improved fleet utilization.
- Increases in cargo handling efficiency. Some reduction in overstowage has been realized, but this has proven difficult to measure objectively.
- Fuel oil savings. Some savings have been realized due to improved trim, but substantial savings have been realized by reduction of Asian fuel oil purchases for stability purposes.
- Facilitated preplanning. The system has greatly facilitated the task of preplanning, enabling planners to utilize their time more effectively. In addition, the historical database generated by the system has proved useful in various areas of decision-making throughout the company.

References

1 Webster, W. C. and Van Dyke, P., "Automated Procedures for the Allocation of Containers on Shipboard," Hydronautics, Inc., Laurel, Md., Oct. 1969.

2 Van Dyke, P. and Cojeen, H. P., "Automated Sequencing of Containers for Containership Loading and Unloading," Hydronautics, Inc., Laurel, Md., Feb. 1977.

3 Harlander, L. A., "Container System Design Developments Over Two Decades," MARINE TECHNOLOGY, Vol. 19, No. 4, Oct. 1982.

4 Webster, W. C., "Monte Carlo Methods in Ship Design," Presented at University of Michigan Computer-Aided Ship Design Conference, Ann Arbor, June 1970.

5 Leeming, J., *Modern Ship Stowage*, Edward W. Sweetman Company, New York, 1968.

6 Webster, W. C. and Van Dyke, P., "Containership Loading: A Container Allocation Model," Presented at University of Michigan Computer-Aided Ship Design Conference, Ann Arbor, June 1970.

7 Rath, E., *Container Systems*, Wiley, New York, 1973.

8 Stockdale, S. C., "Design and Selection of Shipboard Microcomputer Systems," MARINE TECHNOLOGY, Vol. 20, No. 1, Jan. 1983.

Metric Conversion Table

1 ft = 0.3048 m
1 in. = 25.4 mm
1 long ton = 1.016047 metric tons

Appendix 1

Some examples of system output

Departure stow plan giving container destinations, origins, types, and weights

CAPS - MAPPER 13:52:51 A M E R I C A N P R E S I D E N T L I N E S 04/09/83 PAGE 3

SHIP - PRES. LINCOLN CAL PORT - OAK VOYAGE - 04W CONTAINERS ON DEPARTURE

ROW 08

08AP	08A8	08A6	08A4	08A2	08A0	08AC	08A1	08A3	08A5	08A7	08A9	08AS
KAO/OAK 4T M45 089P	KAO/OAK 4T M45 0898	KAO/OAK 4T M45 0896	KAO/OAK 4T M45 0894	KAO/OAK 4T M45 0892	KAO/OAK 4T M45 0890	KAO/OAK 4T M45 089C	KAO/OAK 4T M45 0891	KAO/OAK 4T M45 0893	KAO/OAK 4T M45 0895	KAO/OAK 4T M45 0897	KOB/OAK 4T M40 0899	KOB/OAK 4T M40 089S
KAO/SPE 3T M40 088P	KAO/SPE 3T M40 0888	KAO/SPE 3T M40 0886	KAO/SPE 3T M40 0884	KAO/SPE 3T M40 0882	KAO/SPE 3T M40 0880	KAO/SPE 3T M40 088C	KAO/SPE 3T M40 0881	KAO/SPE 3T M40 0883	KAO/SPE 3T M40 0885	KAO/SPE 3T M40 0887	KAO/SPE 3T M40 0889	KAO/SPE 3T M40 088S
SIN/SPE 12T D40 087P	SIN/SPE 8T D40 0878	KHI/SPE 20T D40 0876	SUB/SPE 23T D40 0874	BKK/SPE 18T R40 0872	SUB/SPE 20T R40 0870	KAO/SPE 3T M40 087C	KAO/SPE 3T M40 0871	KAO/SPE 3T M40 0873	KAO/SPE 3T M40 0875	KAO/SPE 3T M40 0877	KAO/SPE 3T M40 0879	KAO/SPE 3T M40 087S

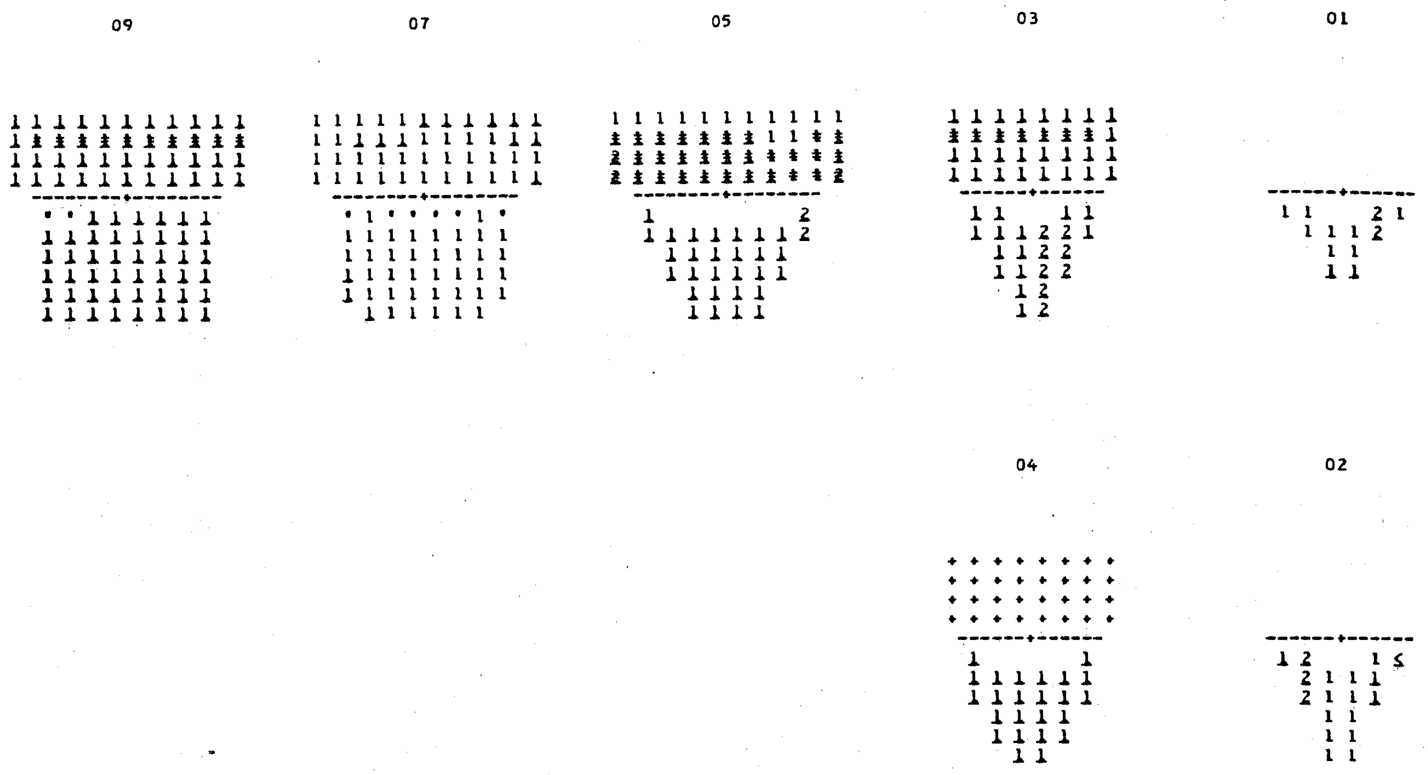
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

KHI/SPE 21T D40 0868	KAO/SPE 9T D40 0866	KEE/SPE 14T D40 0864	CMB/SPE 9T D40 0862	SIN/SPE 10T D40 0860	SIN/SPE 19T D40 0861	KHI/SPE 8T D40 0863	SUB/SPE 14T D40 0865	SIN/SPE 21T D40 0867	SIN/SPE 8T D40 0869
BOM/SPE 23T D40 0858	BOM/SPE 18T D40 0856	MNL/SPE 17T D40 0854	SIN/SPE 12T D40 0852	CHT/SPE 22T D40 0850	KHI/SPE 20T D40 0851	BOM/SPE 20T D40 0853	SIN/SPE 22T D40 0855	SIN/SPE 22T D40 0857	KHI/SPE 21T D40 0859
BOM/SPE 24T D40 0848	SIN/SPE 21T D40 0846	SIN/SPE 22T D40 0844	SUB/SPE 23T D40 0842	BOM/SPE 23T D40 0840	BOM/SPE 23T D40 0841	BOM/SPE 23T D40 0843	BKK/SPE 24T D40 0845	BOM/SPE 23T D40 0847	CHT/SPE 21T D40 0849
HKG/SPE 3T D40 0838	BOM/SPE 24T D40 0836	BOM/SPE 24T D40 0834	BOM/SPE 24T D40 0832	PEN/SPE 24T D40 0830	PEN/SPE 24T D40 0831	BOM/SPE 24T D40 0833	BOM/SPE 24T D40 0835	BKK/SPE 24T D40 0837	BOM/SPE 23T D40 0839
HKG/SPE 26T D40 0828	CHT/SPE 22T D40 0826	BKK/SPE 24T D40 0824	BKK/SPE 24T D40 0822	PEN/SPE 24T D40 0820	PEN/SPE 24T D40 0821	PEN/SPÉ 24T D40 0823	BKK/SPE 24T D40 0825	BOM/SPE 24T D40 0827	SUB/SPE 23T D40 0829
HKG/SPE 26T D40 0818	BOM/SPE 24T D40 0816	BOM/SPE 24T D40 0814	BOM/SPE 24T D40 0812	BOM/SPE 24T D40 0810	PEN/SPE 25T D40 0811	BOM/SPE 24T D40 0813	BOM/SPE 24T D40 0815	BOM/SPE 24T D40 0817	MNL/SPE 23T D40 0819
	BKK/SPE 25T D40 0806	BKK/SPE 25T D40 0804	MNL/SPE 26T D40 0802	MNL/SPE 26T D40 0800	MNL/SPE 25T D40 0801	BKK/SPE 25T D40 0803	BKK/SPE 25T D40 0805	BKK/SPE 25T D40 0807	

TIME 09:57 DATE 04/30/84 A M E R I C A N P R E S I D E N T L I N E S CAPS RLSE 4 PAGE 1

PRE-PLAN FOR KOB1

VESSEL - PRESIDENT JOHNSON VOYAGE - 094 PORT - KOB1 STOWAGE CONDITION - OUTBOUND



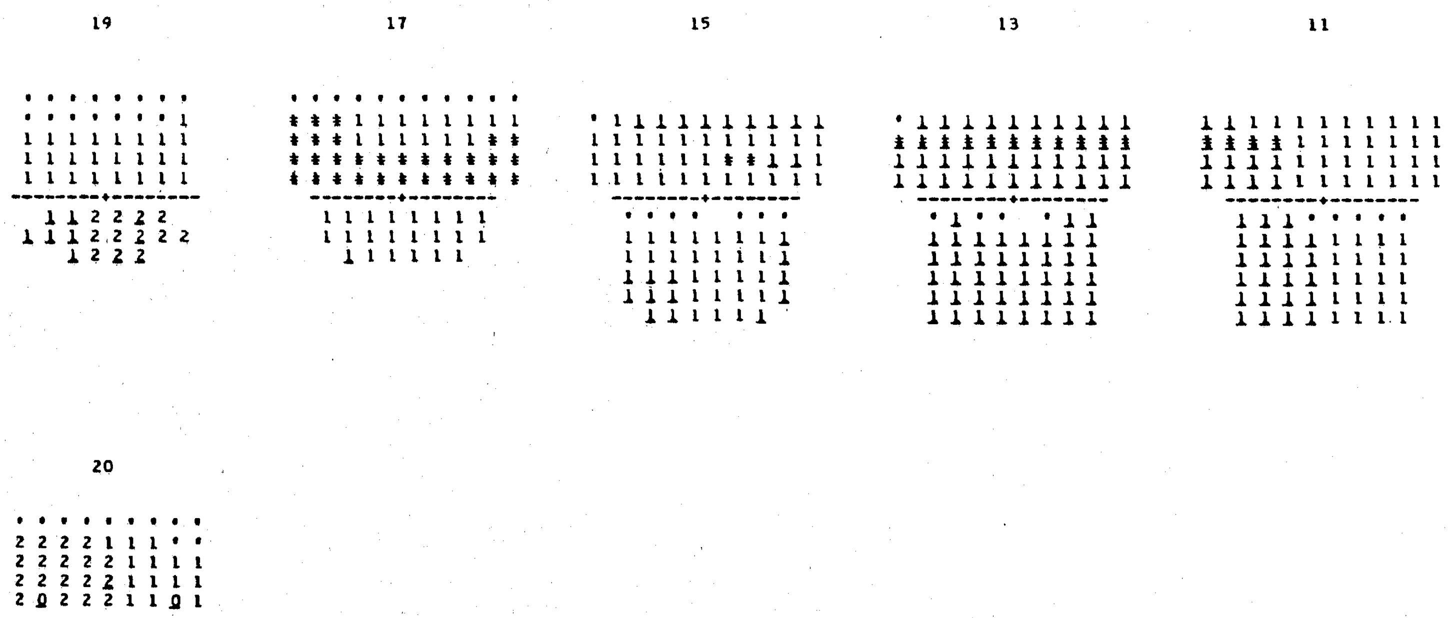
LEGEND

0 = UNKNOWN 1 = SPE 2 = OAK
= = 045 < = M20

TIME 09:57 DATE 04/30/84 A M E R I C A N P R E S I D E N T L I N E S CAPS RLSE 4 PAGE 2

PRE-PLAN FOR KOB1

VESSEL - PRESIDENT JOHNSON VOYAGE - 094 PORT - KOB1 STOWAGE CONDITION - OUTBOUND



LEGEND

0 = UNKNOWN 1 = SPE 2 = OAK
= = 045 < = M20

EVALUATION OF PRE-PLAN FOR KOB1

VESSEL - PRESIDENT JOHNSON VOYAGE - 094 PORT - KOB1 STOWAGE CONDITION - OUTBOUND

VOLUME OF CONTAINERS	
FULL TEUS	1386
EMPTY TEUS	1
TOTAL TEUS	1387

VANS:	20'	40'	45'
RFR	0	0	0
DRY	118	539	95
MTY	1	0	0

CONTAINER MOVE COUNT	
DISCHARGE	249
LOAD	343
TOTAL MOVES	592

--------- PENALTY POINT BREAKDOWN FOR THIS PLAN ----------

CATEGORY	OCCURENCES	SCORE
OVERSTOWS (FUTURE RELOADS)	0	0
CUMMULATIVE ACTUAL RELOADS	30	60
FUTURE LID MOVES TO DISCHARGE CARGO	25	50
CUMMULATIVE ACTUAL LID MOVES	11	22
PORT PLACEMENT VIOLATIONS	0	0
REALIZED PORT PLACEMENT VIOLATIONS	0	0
CONTAINERS LEFT BEHIND	0	0
STOWAGE OVER VOID SPACES	0	0
NEW SINGLE LASHINGS REQUIRED	34	3
NEW DOUBLE LASHINGS REQUIRED	5	1
LASHING LIMIT VIOLATIONS	6	6
INCOMPLETE ROWS	0	0
ROWS WITH MIXED LENGTHS ON DECK	0	0
NEW DESTINATION CARGO ADDED TO ROWS	1	4
CRANE SPLIT PENALTIES	0	0
TRANVERSE MOMENT OF CONTAINERS	-2360	5

	DEPART	ARRIVE	
BALLAST REQUIRED (TONS)	2144.	3121.	15
GM MARGIN (FEET)	0.21	0.03	0
MAXIMUM DRAFT (FEET)	32.5	33.6	0
TRIM (FEET, + BY THE BOW)	-5.5	-9.5	3
LIST (DEG., + TO STARBOARD)	-0.0	-0.0	0
LOADING NUMERAL (+ HOG)	70.4	79.0	0

----------- CONTAINERS REHANDLED AT THIS PORT ------------

26 SPE2 D40 3 SPE2 D45 1 OAK2 D40

TOTAL SCORE 169

Breakdown of all containers on board, including average weights

CAPS - LISTER 13:58:42 A M E R I C A N P R E S I D E N T L I N E S 04/09/83 PAGE 1

SHIP - PRES. LINCOLN CAL PORT - OAK VOYAGE - 04W CONTAINERS ON DEPARTURE

CONTAINER STOWAGE SUMMARY

ROW	WGT	MTY 20	MTY 40	MTY 45	YOK 20	YOK 40	KOB 20	KOB 40	BUS 20	BUS 40	BUS 45	KAO 20	KAO 40	HKG 20	HKG 40	SUM 20	SUM 40	SUM 45
01	1042	-	-	-	-	-	-	-	-	11	1	-	40	-	4	-	55	1
02	898	-	-	-	30	22	3	-	1	-	-	5	-	7	-	46	22	-
03	718	-	-	-	26	-	3	-	2	-	-	20	-	1	-	52	-	-
04	1540	-	16	-	-	-	-	-	-	70	3	-	-	-	-	-	86	3
05	1551	-	-	-	-	-	-	-	-	-	-	-	84	-	-	-	84	-
06	1890	-	9	-	-	7	13	49	13	14	-	-	-	-	-	26	79	-
07	443	-	-	-	-	-	13	-	-	-	-	13	-	-	-	26	-	-
08	1671	-	22	11	-	-	-	-	-	-	-	-	71	-	3	-	96	11
09	1191	-	1	-	14	17	-	-	-	-	-	19	35	-	-	33	53	-
X9	377	1	-	-	14	-	-	-	-	-	-	18	-	-	-	33	-	-
10	1953	-	-	-	-	1	4	1	4	64	-	-	34	-	-	8	100	-
11	69	-	-	-	-	-	-	-	4	-	-	4	-	-	-	8	-	-
12	1800	-	-	-	-	83	-	-	-	-	-	-	-	-	11	-	94	-
13	632	-	22	-	-	27	-	-	-	6	-	-	-	-	-	-	55	-
14	811	-	-	-	-	4	2	18	18	-	-	-	1	-	-	20	23	-
15	255	-	-	-	1	-	6	-	6	-	-	4	-	3	-	20	-	-
16	624	-	71	-	-	-	-	-	-	-	-	-	20	-	-	-	91	-
17	265	-	86	-	-	-	-	-	-	-	-	-	-	-	-	-	86	-
18	215	-	70	-	-	-	-	-	-	-	-	-	-	-	-	-	70	-
19	375	-	-	6	-	-	-	-	-	22	-	-	2	-	-	-	24	6
TOT	18320	1	297	17	85	161	44	68	48	187	4	83	287	11	18	272	1018	21

	YOK 20	YOK 40	KOB 20	KOB 40	BUS 20	BUS 40	BUS 45	KAO 20	KAO 40	KAO 45	HKG 20	HKG 40	SUM 20	SUM 40	SUM 45
DRY	85	125	44	47	48	182	4	83	281	-	11	7	271	642	4
RFR	-	36	-	21	-	5	-	-	6	-	-	11	-	79	-
MTY	-	36	-	2	-	33	6	1	226	11	-	-	1	297	17
DRY	13.6	15.8	15.7	19.4	14.1	18.9	20.8	13.1	18.5	-	10.7	20.4	13.8	18.2	20.8
RFR	-	22.3	-	25.2	-	22.6	-	-	21.7	-	-	24.3	-	23.3	-
MTY	-	3.0	-	4.0	-	3.0	4.0	7.0	3.1	4.0	-	-	7.0	3.1	4.0

On-board tankage status

CAPS - TRIM 14:00:23 A M E R I C A N P R E S I D E N T L I N E S 04/09/83 PAGE 1

SHIP - PRES. LINCOLN CAL PORT - OAK VOYAGE - 04W CONTAINERS ON DEPARTURE

TANKAGE STATUS - ON DEPARTURE OAK

BALLAST	WEIGHT	LCG	VCG	TCG	L. MOM	V. MOM	T. MOM	FS.MOM
DB 2 C	75.0	-122.89	3.01	0.00	-9217.	226.	0.	10050.
DB 3A P	159.7	-55.98	3.26	-29.31	-8940.	521.	-4681.	0.
DB 3A S	159.7	-55.98	3.26	29.31	-8940.	521.	4681.	0.
DB 4 C	200.0	96.99	3.00	0.00	19398.	600.	0.	10050.
WT 4 P	450.0	94.50	22.99	-46.44	42525.	10346.	-20898.	644.
WT 4 S	450.0	94.50	22.99	46.44	42525.	10346.	20898.	644.
TOTAL BALLAST	1494.4	51.76	15.10	0.00	77351.	22558.	0.	21388.

FUEL OIL	WEIGHT	LCG	VCG	TCG	L. MOM	V. MOM	T. MOM	FS.MOM
WT 1 P	160.0	-210.74	22.93	-29.07	-33718.	3669.	-4651.	291.
WT 1 S	160.0	-210.74	22.93	29.07	-33718.	3669.	4651.	291.
WT 2 P	440.9	-120.90	24.62	-43.02	-53305.	10855.	-18968.	43.
WT 2 S	440.9	-120.90	24.62	43.02	-53305.	10855.	18968.	43.
WT 3A P	357.6	-56.51	23.06	-46.28	-20208.	8246.	-16550.	45.
WT 3A S	357.6	-56.51	23.06	46.28	-20208.	8246.	16550.	45.
WT 3B P	413.6	-13.08	21.74	-46.78	-5410.	8992.	-19348.	52.
WT 3B S	413.6	-13.08	21.74	46.78	-5410.	8992.	19348.	52.
WT 3C P	419.9	30.43	21.58	-46.96	12778.	9061.	-19719.	53.
WT 3C S	419.9	30.43	21.58	46.96	12778.	9061.	19719.	53.
SERVICE	105.0	157.30	32.95	-48.18	16517.	3460.	-5059.	45.
SETTLING	220.0	172.52	14.59	-36.52	37954.	3210.	-8034.	322.
DT 2 UPPER P	585.9	-279.61	32.84	-11.56	-163824.	19241.	-6773.	2237.
DT 2 UPPER S	585.9	-279.61	32.84	11.56	-163824.	19241.	6773.	2237.
TOTAL FUEL OIL	5080.8	-93.08	24.96	-2.58	-472903.	126798.	-13093.	5809.

FRESH WATER	WEIGHT	LCG	VCG	TCG	L. MOM	V. MOM	T. MOM	FS.MOM
POTABLE P	85.0	-321.49	51.12	-18.75	-27327.	4345.	-1594.	287.
POTABLE S	85.0	-321.49	51.12	18.75	-27327.	4345.	1594.	287.
RESERVE FEED	60.0	217.95	49.23	48.59	13077.	2954.	2915.	30.
DISTILLED	60.0	239.90	49.38	48.45	14394.	2963.	2907.	30.
TOTAL FRESH WATER	290.0	-93.73	50.37	20.08	-27182.	14607.	5822.	634.

OTHER TANKS	WEIGHT	LCG	VCG	TCG	L. MOM	V. MOM	T. MOM	FS.MOM
D.O. SERVICE	110.0	146.50	32.43	-29.83	16115.	3567.	-3281.	274.
D.G. BLENDED	75.0	151.87	32.96	48.33	11390.	2472.	3625.	27.
D.O. SETTLNG	105.1	192.26	32.48	-46.01	20207.	3414.	-4836.	40.
D.O. STORAGE	185.5	175.70	15.08	36.50	32592.	2797.	6771.	244.
D.G. L.O.	28.4	169.88	32.91	47.79	4825.	935.	1357.	10.
L.O. SETTLNG	50.0	219.33	49.10	-48.58	10967.	2455.	-2429.	24.
L.O. STORAGE	50.0	239.90	49.25	-48.44	11995.	2463.	-2422.	27.
CYL.O. SERV	1.0	237.54	44.66	16.71	238.	45.	17.	0.
CYL.O. INBD	30.0	245.16	51.00	8.06	7355.	1530.	242.	0.
CYL.O. OUTBD	30.0	245.16	51.00	14.79	7355.	1530.	444.	0.
USED L.O.	20.0	212.32	27.99	-41.99	4246.	560.	-840.	16.
SLUDGE	20.0	161.92	4.35	-21.84	3238.	87.	-437.	24.
OILY BILGE	20.0	243.26	4.44	0.00	4865.	89.	0.	1338.
TOTAL OTHER TANKS	725.0	186.74	30.27	-2.47	135387.	21943.	-1790.	2024.

Vessel stability summary for West Coast departure

CAPS - TRIM 14:05:34 A M E R I C A N P R E S I D E N T L I N E S 04/09/83 PAGE 1

SHIP - PRES. LINCOLN CAL PORT - OAK VOYAGE - 04W CONTAINERS ON DEPARTURE

WEIGHT AND STABILITY SUMMARY - ON DEPARTURE OAK

ITEM	WEIGHT	LCG	VCG	TCG	L. MOM	V. MOM	T. MOM	FS.MOM
OPERATING LIGHTSHIP	19858.0	26.75	39.26	0.06	531263.	779567.	1286.	
CONTAINERS	18320.0	8.32	51.65	0.48	152419.	946165.	8792.	
BALLAST	1494.4	51.76	15.10	0.00	77351.	22558.	0.	21388.
FUEL OIL	5080.8	-93.08	24.96	-2.58	-472903.	126798.	-13093.	5809.
FRESH WATER	290.0	-93.73	50.37	20.08	-27182.	14607.	5822.	634.
OTHER TANKS	725.0	186.74	30.27	-2.47	135387.	21943.	-1790.	2024.
TOTALS FOR SHIP	45768.2	8.66	41.77	0.02	396335.	1911636.	1017.	29855.

	computed	requirement	margin
GM (CORRECTED)	3.48 ft.	2.64 ft. (3 high)	0.83 ft.
		2.64 ft. (4 high)	0.83 ft.

	computed	restriction	margin
DRAFT AT FWD MARKS	32.4 ft.	34.5 ft.	2.1 ft.
DRAFT AT AFT MARKS	33.6 ft.	34.5 ft.	0.9 ft.
DRAFT AT LOAD LINE	33.0 ft.	35.1 ft. (summer)	2.2 ft.
		34.4 ft. (winter)	1.4 ft.

	computed	allowable	margin
TRIM	1.2 ft. by stern	4.0 ft.	2.8 ft.
HEEL	0.4 deg to stbd	5.0 deg	4.6 deg
LOADING NUMERAL	47. per cent hog	85. per cent	38. per cent

Overhead view of vessel giving container lashing requirements

CAPS - LISTER 13:38:02 A M E R I C A N P R E S I D E N T L I N E S 04/09/83 PAGE 3
SHIP - PRESIDENT TYLER PORT - OAK VOYAGE - 31W CONTAINERS ON DEPARTURE

L A S H I N G P L A N

	17	16	15	14 13	12	11	10	09	08	07 06	05	04	03	02	01	
8				X	X	X		X	S		S	X	X			8
6	X	X	X	S	S	X	X	D	D	D	S	D	S	S	D	6
4	X	X	X	S	S	X	X	S	D	S	S	D	S	S	S	4
2	X	X	X	S	X	S	X	S	D	S	S	S	S	S	S	2
0	X	X	X	S	X	S	X	S	D	D	S	S	D	S	S	0
C	X	X	X	S	S	S	X	S	D	D	D	S	X	S	S	C
1	X	X	X	S	S	S	X	S	S	D	S	S	S	S	S	1
3	X	X	X	S	S	S	X	S	D	D	X	S	S	S	S	3
5	X	X	X	X	S	X	X	S	D	D	X	S	X	S	S	5
7	X	X	X	X	S	X	X	S	D	D	S	S	S	S	D	7
9				X	X	X		X	X		X	X	X			9
	17	16	15	14 13	12	11	10	09	08	07 06	05	04	03	02	01	

X = NO LASH S = SINGLE LASH D = DOUBLE LASH * = LASH LIMIT EXCEEDED # = WEIGHT LIMIT EXCEEDED

Container weight distribution statistics, showing vertical stratification by tier

CAPS - LISTER 13:58:42 A M E R I C A N P R E S I D E N T L I N E S 04/09/83 PAGE 2
SHIP - PRES. LINCOLN CAL PORT - OAK VOYAGE - 04W CONTAINERS ON DEPARTURE

CONTAINER WEIGHT STATISTICS

	DRY 20			DRY 40			DRY 45			RFR 40		
tier	number	avg weight	factor	number	avg weight	factor	number	avg weight	factor	number	avg weight	factor
0	28	16.4	1.19	36	24.5	1.35	-	-	-	8	27.3	1.17
1	34	14.5	1.06	48	23.5	1.29	-	-	-	6	24.2	1.04
2	36	14.7	1.07	55	22.5	1.24	-	-	-	6	21.8	0.94
3	37	14.1	1.02	60	21.2	1.16	-	-	-	2	24.0	1.03
4	34	15.1	1.10	70	19.9	1.09	-	-	-	2	23.5	1.01
5	38	14.6	1.06	78	17.7	0.97	-	-	-	1	23.0	0.99
6	48	10.1	0.74	84	14.1	0.77	-	-	-	-	-	-
7	4	15.5	1.13	94	19.3	1.06	-	-	-	41	23.3	1.00
8	4	11.5	0.84	94	12.9	0.71	4	20.8	1.00	13	21.2	0.91
9	4	8.5	0.62	23	8.1	0.44	-	-	-	-	-	-
A	4	6.8	0.49	-	-	-	-	-	-	-	-	-
B	-	-	-	-	-	-	-	-	-	-	-	-
SHIP	271	13.8	-	642	18.2	-	4	20.8	-	79	23.3	-

* "factor" is the average weight of containers on each tier divided by the average weight of the same type of container for the ship.

Vessel-by-vessel comparison of preplan stowage versus stowage actually achieved (from statistics module)

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COMPARISON OF ACTUAL AND PRE-PLAN SAILING CONDITIONS

VES	VOY	PORT	DATE	SERVICE	CARGO TONS	CARGO LCG	CARGO VCG	BALLAST TONS	FUEL TONS	DISPL. TONS	GM FT	GM REQ FT	DRAFT FWD	DRAFT AFT	DRAFT LDL	LOAD NUMERAL	PLAN BY
TYL	28W	OAK	9/ 9/82	CAO	10849.	20.7	56.6	5118.	4688.	36336.	8.31	3.81	28.9	30.8	30.0	16.	MKC
PRE-PLAN:					11224.	20.6	58.3	5118.	4688.	36711.	7.57	3.71	29.3	31.0	30.2	11.	
HOO	29W	OAK	9/24/82	CAO	10659.	12.5	59.4	3854.	4811.	34871.	5.98	4.23	30.0	28.9	29.4	43.	JRM
PRE-PLAN:					11136.	16.3	60.1	3854.	4811.	35348.	5.44	4.10	30.1	29.3	29.7	41.	
GRA	29W	OAK	10/ 7/82	CAO	11788.	17.2	57.8	5871.	5020.	38559.	6.83	3.20	34.1	30.2	31.9	29.	MKC
PRE-PLAN:					12294.	16.2	58.1	5871.	5020.	39065.	6.43	3.07	34.6	30.4	32.3	22.	
TYL	29W	OAK	10/22/82	CAO	11637.	3.4	58.3	3287.	4696.	35198.	5.68	4.14	29.1	29.7	29.4	21.	JRM
PRE-PLAN:					11847.	2.3	58.7	3287.	4696.	35408.	5.40	4.08	29.5	29.7	29.6	19.	
HOO	30W	OAK	11/ 3/82	CAO	11601.	29.7	56.1	5214.	4859.	37306.	6.15	3.54	31.9	30.2	30.9	45.	MKC
PRE-PLAN:					11973.	33.9	57.0	5214.	4859.	37678.	5.66	3.44	31.8	30.6	31.1	42.	
GRA	30W	OAK	11/17/82	CAO	11497.	63.1	56.3	5988.	3630.	36876.	7.82	3.66	30.1	30.7	30.4	91.	MKC
PRE-PLAN:					12343.	52.7	58.3	5988.	3630.	37722.	6.66	3.43	31.6	30.7	31.1	97.	
TYL	30W	OAK	12/ 4/82	CAO	12647.	25.4	55.0	3618.	4858.	36938.	6.11	3.64	29.5	31.1	30.4	34.	MKC
PRE-PLAN:					12907.	26.6	56.0	3618.	4858.	37198.	5.60	3.57	29.6	31.3	30.5	36.	
HOO	31W	OAK	12/16/82	CAO	11321.	24.2	58.1	2684.	4924.	34570.	6.09	4.32	28.3	29.5	29.0	58.	MKC
PRE-PLAN:					11549.	19.7	59.4	2684.	4924.	34798.	5.51	4.26	28.9	29.4	29.2	59.	
AVERAGE OF ACTUAL CONDITIONS					11500.	24.5	57.2	4454.	4686.	36332.	6.62	3.82	30.2	30.1	30.2	42.	
AVERAGE OF PRE-PLAN CONDITIONS					11909.	23.5	58.2	4454.	4686.	36741.	6.03	3.70	30.7	30.3	30.5	41.	
DIFFERENCE (ACTUAL - PREPLAN)					-409.	1.0	-1.0	0.	0.	-409.	0.59	0.11	-0.4	-0.1	-0.3	1.	
PERCENT DIFFERENCE					-3.44					-1.11							

Comparison of containers on board for Kobe, Japan and Busan, Korea for eight different West Coast departures (from statistics module)

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COMPARISON OF TOTAL CONTAINERS ON BOARD BY DISCHARGE PORT

VES	VOY	PORT	DATE	SERVICE	KOB D20		KOB D40		KOB D45		KOB R40		KOB M20		KOB M40		KOB M45	
TYL	28W	OAK	9/ 9/82	CAO	11	12.1	49	16.6	0	0.0	16	21.9	1	6.0	0	0.0	0	0.0
HOO	29W	OAK	9/24/82	CAO	26	10.9	55	18.1	0	0.0	12	22.2	1	4.0	3	3.0	0	0.0
GRA	29W	OAK	10/ 7/82	CAO	22	13.9	89	18.1	0	0.0	12	21.9	0	0.0	4	3.0	0	0.0
TYL	29W	OAK	10/22/82	CAO	20	12.7	68	14.5	0	0.0	44	21.7	15	2.1	0	0.0	0	0.0
HOO	30W	OAK	11/ 3/82	CAO	17	13.1	44	19.1	0	0.0	14	23.4	1	4.0	0	0.0	0	0.0
GRA	30W	OAK	11/17/82	CAO	37	16.7	63	18.1	0	0.0	8	23.5	1	8.0	5	3.0	1	3.0
TYL	30W	OAK	12/ 4/82	CAO	40	14.5	26	20.3	0	0.0	18	23.3	1	4.0	3	3.0	0	0.0
HOO	31W	OAK	12/16/82	CAO	30	15.4	65	19.2	0	0.0	10	24.6	1	4.0	0	0.0	0	0.0
TOTAL FOR KOB					203		459		0		134		21		15		1	
AVERAGE FOR KOB					25	14.1	57	17.8	0	0.0	16	22.5	2	3.0	1	3.0	0	3.0

VES	VOY	PORT	DATE	SERVICE	BUS D20		BUS D40		BUS D45		BUS R40		BUS M20		BUS M40		BUS M45	
TYL	28W	OAK	9/ 9/82	CAO	33	12.0	78	20.6	3	14.7	5	19.8	7	2.0	9	3.0	0	0.0
HOO	29W	OAK	9/24/82	CAO	56	13.1	76	16.7	2	18.5	14	20.0	0	0.0	8	3.0	1	3.0
GRA	29W	OAK	10/ 7/82	CAO	58	12.0	62	17.4	2	19.5	10	19.2	1	2.0	4	6.3	0	0.0
TYL	29W	OAK	10/22/82	CAO	43	15.3	58	17.0	2	17.0	12	20.8	0	0.0	14	3.0	0	0.0
HOO	30W	OAK	11/ 3/82	CAO	69	15.9	83	16.5	3	13.7	5	19.4	0	0.0	1	3.0	0	0.0
GRA	30W	OAK	11/17/82	CAO	55	13.7	75	17.1	2	19.0	11	20.6	12	2.0	6	3.0	0	0.0
TYL	30W	OAK	12/ 4/82	CAO	47	13.2	58	17.4	1	19.0	20	19.5	0	0.0	36	3.0	10	3.0
HOO	31W	OAK	12/16/82	CAO	30	14.2	77	18.3	1	10.0	0	0.0	0	0.0	6	3.0	4	3.0
TOTAL FOR BUS					391		567		16		77		20		84		15	
AVERAGE FOR BUS					48	13.7	70	17.6	2	16.4	9	19.9	2	2.0	10	3.2	1	3.0

Appendix 2

Glossary of containership stowage terms

Bay. Longitudinal division of shipboard container slots.
Cell. Belowdeck space comprising a complete stack of slots.
Cell guide. Vertical structural member of the vessel designed to guide containers stowed in cells by restraining them at the cornerposts.
D&H. Dangerous and hazardous cargo requiring special stowage.
Dry. Container stowed with dry (nonrefrigerated) cargo.
Empty. Container which is not currently stowed with cargo.
Lashing. Means for securing containers stowed on deck.
Lid. Vessel hatch cover.
Overstow. Container which is stowed in a location such that its discharge will be required prior to its destination in order to access nearer destination cargo.
Port restriction. Limitations on container stowage dictated by crane or berth limitations particular to a port.
Port rotation. Ordered list of ports to be called by vessel on its voyage.
Preplan. Target or objective stow plan which will be followed as closely as possible in loading the vessel.
Reefer. Container built for transport of refrigerated cargo.
Rehandle. Container which is discharged and reloaded.
Row. Longitudinal division of shipboard container slots.
Slot. Shipboard stowage location for a single container. Each slot is numbered by its row (longitudinal), tier (vertical) and stack (transverse) location.
Stow plan. Graphical plan of the vessel giving information and location of the containers stowed on board.
TEU (FEU). Twenty-foot (forty-foot) equivalent unit. A measure of container volume. One 20-ft container comprises one TEU. A 40-ft container comprises two TEU's.
Tier. Vertical division of shipboard container slots.
Void. Slot below deck which is not stowed with a container and is unaccessible due to containers on the hatch cover above.

Errata

Johnson, James E., Rogers, A. C., and Bass, Robert L., "An Assessment of Shipboard Tank Level Indicating Systems," MARINE TECHNOLOGY, Vol. 21, No. 3, July 1984, pp. 277–289.

The editor has received the following corrections to the above paper:

- Page 279, Table 1, footnote *b*, last word should be "qualify."
- Page 282, right-hand column, line 19 from the top, the sentence should read, "The unit is certified . . . ."
- Page 284, left-hand column, paragraph (*e*) should begin, "To ensure high reliability . . . ."
- Page 284, left-hand column, paragraph (*f*), third line, should read "+140°F" (not ±140°F).