A Study of Maritime Container Handling

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osu sea grant

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1. INTRODUCTION

Introduction

The cost of stevedoring containerized cargo in the United States was estimated to be $300 million in 1980. Because the cost of this mode of cargo handling is less than 50% of that for conventional cargoes, this manner of intermodal transfer is expected to continue its rapid growth. This growth in turn will create the need for additional facilities which will require substantial capital investments. Thus, substantial savings may be derived from improvements in the efficiency of container terminal operation by reducing terminal operating costs and the deferment of capital expenditures.

Recognizing the magnitude of the potential savings from improved container terminal operation, the Oregon State University Sea Grant program, in cooperation with the Port of Portland, initiated, in March of 1977, a research project (R/CE-10) to examine various opportunities for improving the efficiency of container terminal operation.

Project Organization

The work performed as a part of this project was conducted in three phases. The first was a familiarization phase in which the OSU researchers became familiar with the operation of a container port. The primary objectives of this phase were to document the material flow patterns through a container terminal and to statistically summarize the export container characteristics.

After the familiarization phase, several meetings were held between the OSU team and Port of Portland (PoP) representatives to define work tasks for the second and third phases of the project. The specific problems selected for the second project phase were the analysis of import container stacking configurations in order to develop optimal stacking configurations, and the development of a model of a container yard for export operations. The latter activity was specifically directed toward developing a simulation model which could be used to analyze container stacking configurations for outbound containers.

The objective of the third phase was to determine the feasibility and benefits of using a computer program to assist manual container ship load planning.

2. INBOUND LOADED CONTAINER STACKING

Introduction

The determination of the appropriate stacking configuration for loaded inbound containers is a problem that is common to all container terminals using either gantry cranes or transtainers for yard operation. The problem arises because, in general, the receiving port does not know in advance the specific order in which containers will need to be retrieved. Therefore, if one container is stacked upon another, it is possible that the bottom container will need to be retrieved first. If this is the case, the top container must be moved in order to retrieve the bottom one, thus necessitating a rehandle. Rehandles are generally viewed as nonproductive effort. For this reason, loaded inbound containers are frequently stacked only one high. This allows direct (random) access to a container without a rehandle.

One-high stacking, however, distributes the containers over a large area which not only maximizes the cost of storage but also the distance a crane must move in order to reach a designated container. If containers are stacked two high, both the area and crane travel time are reduced by approximately half; however, now the containers must be rehandled. The fundamental question is, Does the reduction in space and transtainer movement time justify the additional rehandles? The optimal stacking configuration can be determined if a model providing for trade-offs among the various costs can be developed.

Problem Formulation

To develop the model suggested above, we must make certain assumptions. The following specific assumptions are necessary to develop a manageable model:

a. Loaded inbound containers are off-loaded and transported to a section for storage.

b. This section is used exclusively for inbound (loaded) containers.

c. Rows are cleared before the ship is unloaded. (Containers are placed in rows that are empty at the beginning of unloading.)

d. A row is six slots wide, and containers can be stacked up to 3 high (18 per row).

e. Containers can be lifted four high (so a transtainer is always able to lift the top container out).

f. All rehandles are within a row, and the mean rehandle time is independent of the number of slots moved.

g. Interference with unloading operations is negligible.

h. Containers are redistributed from storage in a random order.

i. A stacking configuration is not influenced by the actual combination of stacks.

Some of these assumptions are more critical than others. For example, the assumption that a row is six slots wide is made simply to match the Port of Portland's system. Similar results may be achieved with other assumptions.

The assumption that the section is used exclusively for loaded inbound containers similarly could easily be relaxed.

The constants and variables used in this paper are defined as follows:

a. S_L = a sextuple denoting the number of containers stored in each slot such that the total number of containers is L. That is, S_7 = (3, 2, 1, 1, 0, 0) would denote three containers stacked in slot A, two in slot B, one each in slots C and D, and none in slots E and F.[1]

b. s_i = the ith component of S.

c. $V(S_L)$ = the value of (S) or the expected number of rehandles until the stack is depleted.

d. C_T = the cost of a transtainer/unit of time ($64.12/hour).

e. C_R = the cost of a row per unit of time.

f. N = the total (maximum) number of containers in storage (= $N_R * L$).

g. N_R = the number of rows to be used.

h. L = the number of containers initially to be stored in a row.

i. T_0 = the fixed time associated with a transtainer move (19.86 seconds).

j. T_1 = the time for a transtainer to move one row number (1.56 seconds).

k. T_2 = the time for a transtainer to rehandle a container (157.92 seconds).

l. T_3 = the time for a transtainer to load a container onto a truck (157.92 seconds).

m. T_4 = the mean time which a row is required for containers.

n. RH(L) = the expected number of rehandles per container for a stacking configuration L.

The average cost per container is then made up of the sum of the space cost, the rehandle cost, the transtainer move cost, and the actual cost of moving the container from storage onto a chassis. This last cost is the easiest to calculate and is simply the time to load the container times the cost of a transtainer, or $C_T * T_3$.

The storage cost per container is the cost of a row per unit of time, times the number of time units it will be occupied, divided by the initial number of containers in the row, or $C_R * T_4/L$. The rehandle cost for a specific configuration is simply the transtainer cost, times the rehandle time, times the expected number of rehandles per container, or $C_T * T_2 * V(S_L)$.

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[1] See the appendix for a description of the physical organization of the PoP T-6 yard.

The transtainer movement time is slightly more complicated. If a transtainer is assumed to be dedicated to the section, then one may assume it moves to a row, loads a container onto a chassis, and then waits at that row until the next container to be loaded is identified. The transtainer then moves to the appropriate row. Thus, one transtainer move per container is required. This movement time comprises a fixed term plus a variable term, dependent upon the number of rows moved. That is, the average transtainer movement time when a move is made is T_0 plus T_1 times (average distance moved) as measured in rows. If the inbound containers are distributed throughout N_R row numbers, where $N_R = k * N/L$, then the average distance moved is $N_R/4$.[2] If the second container is in the same row as the first, then the fixed time, T_0, will also be avoided. The probability of this occurring is k/N_R.

The expected movement time is then

$$T_0\ (1 - L/N) + T_1\ (kN/4L))$$

and the movement cost is given by

$$C_T\ (T_0\ (1 - L/N) + T_1\ (kN/4L))).$$

If the assumption that a transtainer is dedicated to dispatching inbound containers is not appropriate, then the model must be modified slightly. For example, if it is assumed that the transtainer will always need to enter the section from an end and the transtainer must return to the end after loading the container, then the average distance traveled is N_R or kN/L and the average travel time is $T_0 + T_1 * (kN/L)$. The latter assumption would be more favorable to higher stacking configurations. For our purposes, the former assumption will be adopted since this more closely resembles current practice.

The total cost per container then becomes

$$\text{total cost/container} = C_T T_3 + \frac{C_R T_4}{L} + C_T T_2 V(S_L) + C_T T_0 - \frac{C_T T_0 L}{N} + \frac{C_T T_1 kN}{4L}$$

or

$$\text{total cost/container} = C_0 + \frac{C_1}{L} + C_2 V(S_L) - C_3 L,$$

where

$$C_0 = C_T\ (T_0 + T_3)$$

$$C_1 = C_R T_4 + \frac{C_T T_1 kN}{4}$$

---

[2] A 20-foot container requires two row numbers (k=2) while 40-foot containers require four (k=4).

$$C_2 = C_T T_2$$

$$C_3 = \frac{C_T T_0}{N}$$

Solution

Now consider comparing a stacking configuration S_L^* with S_{L+1}^*, where S_L^* is the optimal (best) configuration with L containers/row and S_{L+1}^* the optimal with L + 1. The configuration S_L^* will be preferred if the total cost for S_L^* is less than that for S_{L+1}^*. This may be reduced to the equivalent condition; L* is preferred if

$$\frac{C_1}{C_2} \leq L\ (L + 1)\ \{(V(S_{L+1}) - V(S_L)) - \frac{C_3}{C_2}\ \}$$

Then, to complete the solution, we need to calculate only the expected number of rehandles. Given the assumption that all containers are equally likely to be required first, the expected number of rehandles can be calculated iteratively. In order to simplify the calculations and limit the number of feasible solutions, we made one additional assumption: that the exact slot a container is stored in is not significant. That is, the expected rehandles for the configurations (3, 2, 1, 0, 0, 0) and (0, 3, 0, 2, 0, 1) are equal. Thus,

$$V((3, 2, 1, 0, 0, 0)) = V((0, 3, 0, 2, 0, 1)).$$

More specifically, the expected number of rehandles for all configurations with three containers in one stack, two in a second, one in a third, and zero in the remainder are identical.

To see how the expected number of rehandles may be calculated, consider the (2, 2, 2, 1, 1, 1) configuration. Now consider the expected number of rehandles, given that the bottom container in the first stack (A) is retrieved first. The top container must first be rehandled to another stack (let's assume the shortest one), and then the bottom container is loaded. The resulting configuration is (2, 2, 2, 1, 1, 0). The expected number of rehandles, given this particular container is required first, is then the expected rehandles for the configuration (2, 2, 2, 1, 1, 0), plus the incurred rehandle, or V((2, 2, 2, 1, 1, 0)) + 1. The probability of this container's being required first is 1/9 or 1/L in general. If this procedure is repeated for each of the containers in the configuration and the results are multiplied by the probability of each container's being required first and added, the result is the expected number of rehandles for the configuration (2, 2, 2, 1, 1, 1), which happens to be 1.714.

Obviously, calculating the expected rehandles for configurations with nine containers requires knowing the number of rehandles for configurations with eight containers. This poses no real problems since the calculations begin with the single-container configuration and progress to two containers, three containers, and so on.

A simple computer program (BASIC language) was written to actually perform these calculations. The results for the optimum, least expected rehandles, configuration for a given number of containers per row are given in Table 1.

Table 1. Expected Container Rehandles

Level (Containers per row)	Total Expected Rehandles	Expected RHs Per Container
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	.571	.082
8	1.143	.143
9	1.714	.190
10	2.286	.229
11	2.857	.260
12	3.598	.300
13	4.585	.353
14	5.500	.400
15	6.640	.443
16	7.703	.481
17	8.877	.522
18	10.190	.566

Example

Let's consider an example of a case where we are to accommodate a maximum of 444 inbound 20-foot containers. Assume the operating cost for a transtainer is $64.12 per hour, the total cost per square foot for yard space is $10.00, with a useful life of 20 years, and a row would be required for one week after unloading the containers. The other time values are all as previously given. Only 20-foot containers with a 1½-foot clearance between rows and stacks will be initially considered. As before, six stacks with a truck lane will be assumed. The total square footage for a row is then

$$7 * (8 + 1\tfrac{1}{2}) * (20 + 1\tfrac{1}{2}) = 1430 \text{ ft.}^2,$$

or a total cost of $14,300. Assuming a 20-year life and neglecting maintenance costs and the time value of money gives a weekly cost of $13.75. The cost of a transtainer is $0.0178/second.

Then

$$C_0 = 0.0178 * (19.86 + 157.92) = 3.16$$

$$C_1 = 13.75 * 1 + .0178 * 1.56 * 2 * 44414 = 19.91$$

$C_2 = 0.0178 * 157.92 = 2.81$

$C_3 = \frac{.0178 * 19.86}{2 * 44} = .04$

$C_1/C_2 = 7.09$

$C_3/C_2 = .014$

The C_3/C_2 term is negligible and can usually be neglected. The decision can then be based upon:

$$C_1/C_2 \leq L\ (L + 1)\ (V\ (S_L^* + 1) - V\ (S_L^*)).$$

Table 2. Critical Ratios for Rehandle

If C_1C_2	$L^*=$
3.444	6
3.416	7
3.384	8
3.51	9
3.41	10
5.28	11
8.268	12
8.554	13
9.03	14
9.12	15
11.15	16
13.46	17

Critical values for C_1/C_2 are shown in Table 2 and plotted in Figure 1. From this figure a C_1/C_2 ratio ot 7.09 would suggest the optimum number of containers per row is twelve. This corresponds to uniformly stacking containers two high with an average of 0.3 rehandles per container. The total cost for this configuration is

$$\text{total cost/container} = 3.16 + \frac{19.91}{12} + 2.81 * (.3) - .04 * 12$$

$$= \$5.18/\text{container}$$

compared to

$$\text{total cost/container} = 3.16 + \frac{19.91}{6} + 2.81 * (0) - .04 * 6$$

$$= \$6.24/\text{container}$$

for one-high stacking, or a 16.98% cost reduction.

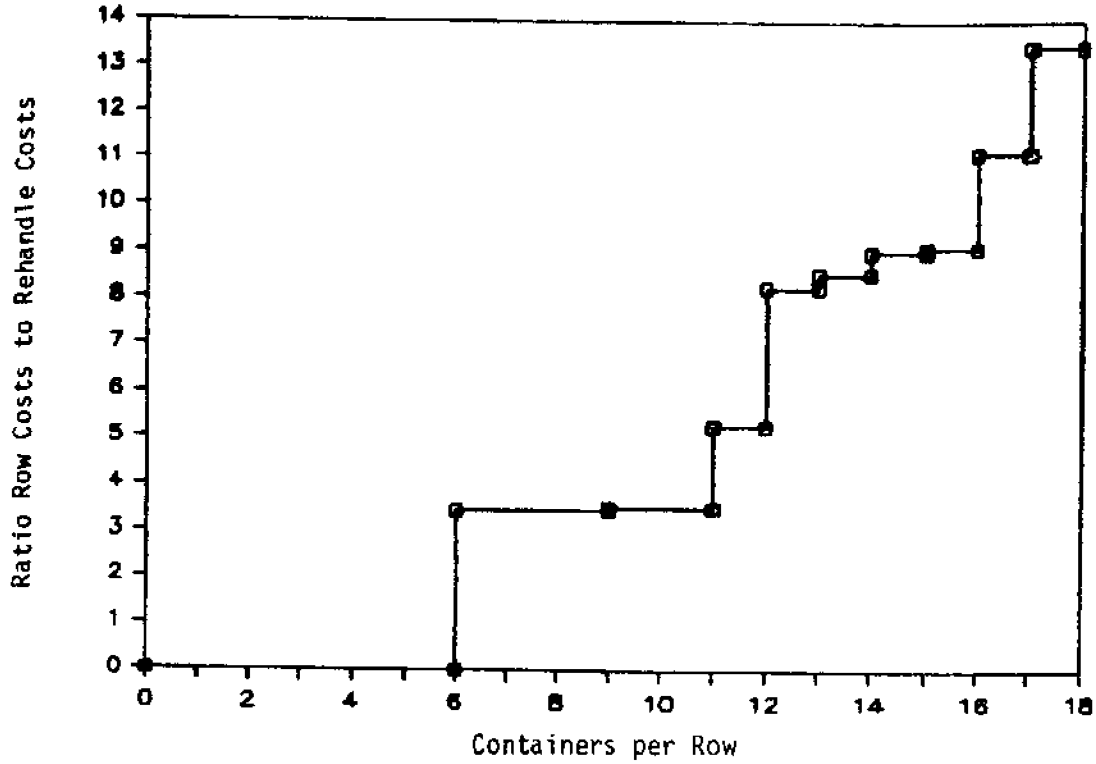

Figure 1. Optimum Containers per Row

Observe that both the space required and the transtainer movement time would double for 40-foot containers. Thus, the C_1/C_2 would double to 14.18, and the optimal stacking configuration would be 18 containers per row. Since the rehandle cost is relatively independent of container length, but space and transtainer movement costs are directly proportional to length, it will generally be more advantageous to stack more 40-foot containers per row than 20-footers.

The mean time to load a container is the sum of the time to load a container, the transtainer response time, and the rehandle time, times the average number of rehandles per container. Thus, the response time, $\overline{T}$, is

$$\overline{T} = T_3 + T_2\ V(S_L^*) + T_0\ (1 - L/(N)) + T_1 * kN/(L/L)$$

or

$$\overline{T} = T_3 + T_2\ V(S_L^*) + T_0\ (1 - k/N_R) + T_1\ \frac{N_R}{4}$$

For our 444-container example stacked two high,

$$\overline{T} = 157.92 + 157.92 * (.3) + 19.86 * (1 - 12/444) + 1.56 * 2 * \frac{444}{4 * 12}$$

$$= 253.48 \text{ seconds,}$$

which corresponds to 4.22 minutes/container, or 14.2 container/hour. For the six containers/row configuration, the mean response time would be

$$\overline{T} = 157.92 + 19.86 * (1 - 6/444) + 1.56 * 2 * 444/(6 * 4)$$

$$= 235.23 \text{ seconds/container,}$$

or 15.30 containers per hour. Although the 12-container-per-row stacking configuration is justified based upon reduced space cost, it does decrease throughput by almost 7.2%.

The time to store containers during ship unloading is relatively easy to calculate. If the incoming containers are stored in contiguous rows, the average time per container is

$$t = T_3 + \frac{T_0 + T_1\ k}{L},$$

or

$$\overline{t} = 157.92 + (19.86 + 2 * 1.56)/12$$

$$= 159.84 \text{ seconds/container,}$$

which is equivalent to a rate of 22.52 containers per hour for 20-foot containers stacked two high.

If the rows are randomly distributed, the average time per container is approximately

$$t = \frac{T_3 + T_0 + T_1 \ kN/L}{L} .$$

For the same case as above with 444 20-foot containers, this would give

$$= 157.92 + (19.86 + 1.56 * 2 * 444/12)/12$$

$$= 169.2 \text{ seconds/container,}$$

or 21.28 containers per hour. Since each container entering the yard must also leave it, then the mean throughput for 444 containers stacked two high would be 3600/(253.48 + 159.84) = 8.71 containers/hour.

This model may be used to assist in deciding the optimum stacking configuration for inbound containers. It should be noted that the appropriate cost figures to use are the shadow costs, not the actual costs. That is, if there is currently spare yard space, then the row cost should be zero dollars per square foot. However, if all yard capacity is being used, then the cost per square foot should be figured at the cost for new construction.

3. COMPUTER-ASSISTED LOAD PLANNING

Significance of Container Ship Load Planning

The work of container ship load planning is important to a container port because it determines how port resources are to be used during loading operations. Furthermore, ship turnaround time, an important criterion of port efficiency and attractiveness to shipping companies, is determined to a great degree by both the speed of load-planning effort and the loading time resulting from such work.

A major portion of this research effort was directed toward developing efficient computer models for container ship load planning. Such an effort was deemed important for the following reasons.

First, as a port's size grows and its business volume increases, manual load planning tends to be more expensive and soon reaches a certain capacity limit. A ship load plan involves using a great amount of data. The advent of efficient and very fast modern computers has made them a viable alternative to manual planning for the load-planning work. The advantages of using computers would be the accuracy of results, speed of work, transportability of data among ports of a region, lower cost for planning, better use of port facilities, and shorter turnaround time.

Second, computerization of load planning opens the door to port automation. Container port automation in Germany and Japan has been reported in Geisler and Trautnitz (1977) and Ninomiya and Nabeshima (1976). The system reportedly installed at Hamburg seems to include a type of load planning which generates yard transport orders so that yard movements are minimized. No literature has been available that gives us an insight into the details of their system. The Tokyo system is for a rail freight terminal, and it is difficult to determine whether the automated system controls ship-loading operations or not. In both systems, material-handling equipment is connected to a central computer so that their movements are coordinated and optimized. Both reports state "considerable" increases in throughput and decreases in unit handling cost.

Containerization was a revolutionary concept in world trade. But containerization requires a high level of capital investment. Port automation is bound to come as a necessity to most of the world's major ports in order to sustain their competitive status in ocean trade. Port automation will be the next revolution. And this automation revolves around the software which generates plans for the optimum use of a system based on requirements of both port-side and ship-side operations.

The Problem

At first, the load-planning process appears quite simple. The basic problem, given a set of containers in the yard and a set of locations on board ship, is to determine the allocation of containers to locations and the loading sequence so that all conditions are satisfied and material handling cost (time) is minimized.

The conditions that must be satisfied include ship stability; requirements for the storage of hazardous cargo; and such special storage requirements as refrigerated units, deck strength limits, container stack height limits, and container length restrictions.

The material handling costs may be divided into two categories: those incurred at the current loading port and those incurred at subsequent ports because of the load plan currently developed. The latter category includes the costs of shipboard rehandles due to unnecessary overstowages and extensions in turnaround time at subsequent ports resulting from improper bay use. An overstowage occurs when a container destined for a latter port is stowed on top of a container for an earlier scheduled port. Thus, the top container must be rehandled in order to unload the bottom container.

Subsequent material handling costs also include delay costs resulting from the improper assignment of containers for a particular port to bays. If containers for a specific port are distributed among many bays, then additional unloading time is required during unloading because the additional hatch covers need to be removed and replaced. Also, if containers are assigned to contiguous bays, it will not be possible to work the ship during unloading operations with two cranes because of crane interference. Again there will be subsequent delays and costs because of poor planning.

Direct loading costs are generally attributable to ship, crane, transtainer, truck, and crew times for loading. Thus, direct loading costs are approximately proportional to loading time. In a one-transtainer to one-crane operating mode, the transtainer is generally the limiting element during the loading operation. Therefore, minimizing transtainer time minimizes loading time.

Transtainer time can be broken down into the time to move containers from storage onto chassis and transtainer movement time. The first of these is independent of the actual load plan, but the second is dependent on it. The transtainer movement time can be considered as the sum of the movement time between rows, the section change time, and the time to rehandle containers stored on required containers.

The general problem, then, was to develop a container loading sequence which would meet all the specific conditions while minimizing overstowages and loading time. Since the transtainer is the limiting factor, the minimization of transtainer movement was of paramount importance.

Other Efforts at Computerized Container Ship Load Planning

A literature search revealed no computer-assisted loading systems designed with a transtainer yard in mind. Some efforts have been made to develop load-planning algorithms for yards which allow random access to containers and for straddle carrier yards. These were useful chiefly in illustrating the difficulty of the task and in confirming the problems associated with using some of the traditional mathematical solutions.

Beliech (1974), of the Naval Postgraduate School, did a study of preload planning with military applications in mind. His model assumed a single container length and random access to containers in the yard. Random access is reasonable if containers are stored on chassis or stored without stacking. This requires a large storage yard.

Beliech considered the use of integer programming for load planning but dismissed the idea because of problems formulating the problem and because the expected solution time was excessive. The solution method he proposed was a heuristic.

Beliech's heuristic attempted to minimize overstows, place hazardous cargo according to U.S. Coast Guard regulations, and preserve ship stability. No other constraints were recognized. Limits on the height or weight of containers in certain bays and on placement of refrigerated (reefer) units were omitted. Avoiding crane interference was not considered either. The emphasis on hazardous cargoes in Beliech's research may be due to the frequency of munitions in military shipments.

No attempt was made to actually code Beliech's heuristic, so no test results are available. Even if it works as designed, Beliech's heuristic will be of limited usefulness. This is due to the assumptions of a single container length and random access in the yard and to the ommission of vessel constraints such as deck strength and location of reefer plugs.

Hydronautics has come out with the most complete computer-assisted load planning system to date (Cojeen and Van Dyke, 1976). The system was first developed for batch runs in the late 1960s. It has since been converted to an interactive program. The program avoids overstow of cargo, can handle containers of different length, and has a system to achieve stable loads. It also recognizes that reefers are restricted to cells with electrical plugs. There are contradictory reports as to whether it considers deck strength, with Hydronautics claiming it does (Cojeen and Van Dyke, 1976) and an evaluation team from Matson Terminals stating it does not (Thoolen, Meade, and Scott, 1978). Special containers such as hazardous cargoes are not placed by the program, but their locations can be specified by the load planner. The program can handle cargo when it is stacked in the yard, but does not consider travel distance for material handling equipment. These assumptions are appropriate for a straddle carrier yard. The objective of the program is to minimize the ballast needed and to prevent crane interference.

A test of the system by Matson Terminals was financed by the Maritime Administration (MARAD) of the United States (Thoolen, Meade, and Scott, 1978). Matson reported that whereas the user interfaces of the system were excellent, erroneous assumptions about the distribution of container weights could cause stability problems. The hydronautics model assumed a uniform distribution of container weights. Matson cargoes tend to have a bimodal distribution. One mode is very light and represents empty containers. The other mode is heavy, a fact which may be due to customers' maximizing container use. The hydronautics model used nearly the opposite of the optimal strategy in this situation, placing heavy containers on top and light containers on the bottom. The resulting lack of stability was considered unsafe.

Since the evaluation of the Hydronautics model, Matson has continued to work on computer-assisted load planning. In the report for MARAD, Matson formulated a constrained assignment model (Thoolen, Meade, and Scott, 1978). The constraints included were for stability, hazardous cargo, deck strength, lashing strength, racking strength, reefers, overheights, container support, and stacking in the yard. Lashing strength is the ability of lashings to hold on-deck cargo firmly and is thus similar to deck strength. Racking strength is the ability of containers to support other containers. Some specialized Matson containers have low racking strength. Container support refers to insuring that each container rests either on the ship structure or another container. The objective function was to maximize profit. This was done by maximizing the number of containers loaded and crane use, and minimizing overstowage and interference between straddle carriers. No attempt was made to solve the problem of constrained assignment.

Matson researchers later concluded the constrained assignment problem was insoluble with present computers because of the large number of variables (Scott and Chen, 1978). They then proposed a simplified model using integer programming. The model recognized all constraints listed for the constrained-assignment model except stability and stacking in the yard. Avoiding overstowage of cargo was also made a constraint. The model uses stability as the objective function, with the intent of minimizing ballast required for a voyage. Cargo with difficult constraints is placed first. Regular containers are first sorted by port, then by general weight using a clustering algorithm. Integer programming is then used to assign containers from the port-weight groups to bays in the ship. If problems occur with stability, containers within the ship are exchanged by a heuristic until acceptable stability is achieved. This model has not been tested.

The Matson model will likely result in feasible load plans, but it currently ignores crane interference and prohibits stacking of containers in the yard. Matson proposes additions to the model which would minimize ship crane interference, and a study of the yard to see if stacking policies could be devised which would be compatible with the model. Even if these studies are successful, the model will be more appropriate to straddle carrier yards than to transtainer yards, because the travel time of equipment is not considered.

Basic Approach

After reviewing all the special container and loading conditions and the frequencies with which they arise, we did not feel that a completely computerized load-planning scheme which could handle all vessels and voyages was appropriate. Rather, an integrated approach, combining the best features of manual and computerized load planning, appeared preferable. Our basic approach was to develop a computer-assisted loadplanning program rather than a fully computerized system.

The analysis of a sample of outbound containers indicated that in excess of 90% of the outbound containers were of either the dry or refrigerated type and that over 80% were shipped on the Asian trade routes. It therefore seemed appropriate to allocate to the computer-assist portion of the load planning system the relatively routine task of planning the loading of the dry and refrigerated containers, while leaving the more complex task of planning the loading of the specials to the manual load planner. It also seemed appropriate to concentrate on the modern ships specifically designed for the container trade, since these ships represented a growing majority of those being served.

The primary emphasis of our study was on developing a computer-assisted load planning system which would plan the loading of 90% of the containers on 90% of the voyages: the 90/90 rule. It was felt this strategy would not only maximize system performance, but also enhance user (load planner) acceptance.

Assumptions

Several assumptions were made before developing a solution to the problem. These assumptions are summarized in Table 3. The first assumption was that container handling equipment would be of the transtainer-yard type. That is, a combination of transtainers, trucks, and ship cranes would be used to transport containers from the dock to the ship. This is, of course, the system used at the PoP.[3] This required a second assumption, that empty containers would not be included in the model. Empty containers at PoP are usually handled with modified fork lift trucks. Transtainers can immediately access the top container of any stack in a section, whereas top loaders can only access top containers nearest to an aisle. Leaving empty containers out of the model should make little difference, since if empties are to be shipped it makes no difference which containers are taken.

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[3] PoP represents the Port of Portland Terminal T-6.

The next assumption involved the ships to be loaded. Older container ships are usually break bulk cargo ships which were modified to handle containers. These ships generally do not have extensive ballast tanks to aid stability. Newer ships have sophisticated tank systems which can do a great deal to adjust stability after a ship is loaded. Since newer ships are rapidly replacing the older variety at the PoP, it was assumed that only the newer ships would be loaded by the computer. This assumption implies that stability will not be difficult to achieve and that the difficult part of load planning is to insure that material handling time is minimized.

The final assumptions were related to the container yard. It was first assumed that all containers for a voyage have arrived and that their yard positions are known. The PoP sets a cutoff time for containers arriving for a voyage, so this assumption is not unreasonable. In addition, it was assumed there would be one transtainer paired with each crane servicing a ship during loading operations and that a ship may be serviced by either one or two cranes.

Table 3. Container Load Planning Assumptions

General:

Yard handling of containers will be by transtainer truck.

Empty containers will not be considered.

Ship stability vs. material handling costs favor material handling cost.

All containers for a voyage are in the yard.

One or two dranes per ship operation.

One transtainer per crane operation.

Operator tasks:

The loading of hazardous and unusual cargoes would be handled manually (less than 10% of all containers).

The sequencing of bays to be loaded would be an operator input.

The assignments of all regions within bays would be an operator input.

Computer tasks:

The assignment of dry and refrigerated containers to location in bays.

The sequencing of containers to be loaded.

The transtainer's movements.

It was also assumed in the interactive system contemplated that the operator would handle the load planning of hazardous and unusual cargoes, the sequencing of the bays to be loaded, and the assignment of container destinations within bays. The last item is generally the prerogative of shipping company officials, and it was felt that they would not want to relinquish this latitude.

The sequencing of bays to be loaded is generally a relatively simple operation. The prime constraints are that underdeck bays must be loaded before the covering on deck bays and that if the ship is being worked by two cranes, minimum crane separation must be maintained.

The computer program would then handle the sequencing of dry and refrigerated containers to be loaded and the assignment of each to a bay location.

Priorities

In developing a container ship load-planning algorithm, we established certain priorities. First, because of their cost of operation and the time involved, it was decided that the container cranes should be moved from bay to bay as infrequently as possible. That is, once you begin loading a bay, it is advantageous to completely fill it, if possible.

After the container cranes, the transtainers are the most critical items. Actually, the transtainers are probably more critical than the cranes, since about 1.3 transtainers are required to meet one crane's capacity. As mentioned previously, a transtainer's time during loading operations can be separated into the time necessary to load containers from stacks onto truck chassis and the transtainer movement time. The first component is productive time which cannot be avoided. Although the movement time cannot be totally avoided, it can be minimized. To achieve this, the following priorities were set. First, minimize transtainer nonadjacent section changes, then minimize container rehandles, and finally, minimize adjacent section changes, transtainer moves, and total distance travelled. These priorities are shown in Table 4.

Table 4. Container Load Planning Priorities

The cranes shall be moved as infrequently as possible. (Once you begin loading a bay it is advantageous to fill it completely, if possible.)

Transtainer nonadjacent section changes should be minimized.

Container rehandles should be minimized.

Transtainer moves should be minimized.

Transtainer distance traveled should be minimized.

Alternative Solutions

As with most problems to be solved by computer, the possible solution algorithms for the load-planning problem can be divided into algorithms which guarantee optimality and heuristics. An optimization algorithm would generally be preferred. Consequently, we made different attempts to formulate the problem so that classical optimization techniques could be applied.

We attempted an integer programming formulation, a transportation or assignment formulation,and a dynamic programming formulation. The problem was formulated as a mixed integer program with variables for each combination of cells and containers. The problem quickly became too large to solve as a linear program, much less as an integer program. Other formulations, such as having variables only for each combination of cells and containers with the same port and length designation, cut the number of variables considerably, but not enough to solve the problem as an integer program.

Formulating the problem as a transportation or assignment problem is not practical because of the objective function. The main goal is to minimize transtainer travel time. Travel time from the transtainer's initial position could be used to develop a cost matrix for a transportation problem. However, after the transtainer had moved once, all the costs would immediately change. The transportation algorithm requires constant costs to find an optimal answer. Even if a way is found to develop an objective function, adding the constraints to the problem would destroy the transportation format.

A dynamic programming formulation also encounters difficulties. The problem can be set up with each successive container selection considered a stage and each possible transtainer location a state. Unfortunately, because of the large number of stages and states involved, one state for each container at each stage, the dynamic programming formulation becomes too laborious to solve to be practical.

Failure to obtain a problem formulation which would allow it to be solved by an algorithm which guaranteed optimality left the variegated realm of heuristics. The two approaches considered were to use a modification of an optimization algorithm or to try and emulate the techniques currently used by load planners at the PoP. There were significant disadvantages to each approach.

Modification of guaranteed optimal algorithms would require overcoming the problem of the number of variables for a linear/integer programming approach, modifying the objective function for transportation problems, or dealing with the dimensionality problem for dynamic programming. In addition, it would require a way to deal with the constraints for the transportation problem or dynamic programming. One suggestion for the latter difficulty would be to solve the unconstrained problem, then modify the solution to bring it to optimality. If such an approach would prove feasible, its potential for generating very good solutions was very good.

The second approach, modifying the load planners' present system, also had pitfalls. It seemed likely that a set of decision rules could be developed in this manner, but such a set of rules would necessarily be incomplete. Planners currently take into account a great many factors which vary widely with each load planned. Any subset of these rules would run the risk of not meeting the goal of loading 90% of the ships adequately 90% of the time. There also was the question of whether a computer could improve upon the plans generated by port personnel using their own techniques.

In the final evaluation, the automation of the load planners' heuristics appeared to have less risk and would more easily accommodate unusual situations. Therefore, a heuristic (NCH) was developed based on the decision roles currently used by PoP load planners.

4. THE NEAREST CONTAINER HEURISTIC (NCH)[4]

Introduction

We roughly applied three principles while developing the heuristic solution to the load-planning problem. The first was to use current procedures when feasible. The second was to assume that stability would be relatively easy to achieve and that more attention should be paid to procedures to achieve good material handling. The last was that when multiple alternatives were available and there was doubt as to which was superior, the simplest option would be tried. These attitudes did much to shape the algorithm.

The first step in the solution process was to decide the order in which in-bay cells would be filled. The starting point here was the load planner's bay sequence plan. It was decided to request some additional information from the load planner at this point. First, the order in which ports would be filled within the bay would also be entered. This does not currently appear on the bay sequence sheets. Furthermore, targets for the number of light, medium, and heavy containers for each bay and port combination would also be input. The planner would decide the targets based on stability considerations. Although it was expected that deviations from the targets would not have a large impact on stability, having a good initial starting point was felt to be important. The operator would also input which crane would be used for each bay and port combination when more than one crane was to be used.

Given that the bay and port combinations were selected as specified, the tiers for that bay-port combination would be taken from bottom to top. Within each tier, cells were selected from river to dock side. When loading on deck, crane operators prefer to start loading from the river side so they do not have to lift later containers over those they have just loaded. Selection of cells was therefore first controlled by the planner's directions, then by two straightforward rules based on crane operator's preference.

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[4] See Martin, G. L., for a more detailed description of the program.

After a cell had been chosen, the next step was to find a container for it. A rough guideline in container selection was to pick the nearest acceptable container. Application of this rule was not consistent throughout the algorithm, however.

Once a cell was specified, there were two cases. The first, or normal condition, was that the weight or height of the container was not of special importance. The weight target for that cell could be applied, but deviation from it would presumably affect stability only slightly. The second case was when the cell was at the top of an on-deck stack and the weight of the container could exceed deck strength limits. In this case there was a strict upper limit on the weight of the container, and special procedures were required. Deviation on the low side would again only affect stability to a small degree. Different methods of container selection were developed for each case.

The method of container selection used for most cells was the one where deck strength limits were not a consideration. These cells had a weight-class target of light, medium, or heavy; but it was not expected that strict adherence to the targets would be necessary. It was decided to expand the weight ranges which would be accepted for a weight class, with the amount the ranges were to be expanded left as an operator input. This would result in overlapping ranges to be used as targets. An operator could try a run with very wide ranges and check stability. If stability limits were exceeded, another run could be tried using narrower ranges. Limits would not change during a run. Therefore, the first actions after selecting a cell were to determine its weight class and to calculate a range for the weight of the container to fill it.

Besides weight, three other factors had to be checked. These were port, length, and sometimes height. Height was checked only if the cell being filled was in a 20-foot, underdeck bay and if no more high cubes could be allowed in that stack. Port and length checks were always required.

With port, length, weight, and sometimes height requirements determined, the algorithm then searched for a suitable container. The first place searched was the transtainer's current position, or the "current" row. If only one of the containers in the current row was acceptable, it would be "loaded" (i.e., assigned to the cell being filled). If more than one container was acceptable, the algorithm selected containers that minimized rehandles, then chose the container nearest the truck lane.

If none of the containers in the current row were acceptable, the search was expanded to other rows in the current section (i.e., the section the transition was currently in). Not all rows were immediately considered, however; candidate rows were selected by the average weight of the containers in the row. The reasoning behind this policy was as follows. Cells for a particular port, length, and weight class usually came in groups. A 40-foot bay that had 32 cells for the port Kobe might have had 12 heavies designated for it. The algorithm would look for a row where the average weight of the containers was also heavy, so several of the cells could be filled from the same row. As with the container weights, the weight range used when searching for a row could be varied for each run by the operator.

When the candidate rows had been determined, the algorithm searched them for an acceptable container. If more than one acceptable container was found, the algorithm first minimized rehandles, then took the shortest travel distance. If no acceptable containers were found, the search proceeded to other sections.

From the current section, the search moved to the adjacent section, if any containers for this voyage were stored there. Candidate rows were developed using the same weight range used for the current section. The candidate rows were then searched using the same criteria of minimizing rehandles and travel distance used before. If the adjacent section failed to yield an acceptable container, the other sections were searched in the same way. As soon as a section was found with an acceptable container, the best container in terms of rehandles and travel distance was loaded and the search terminated. If no acceptable containers were found in any of the candidate rows in any of the sections, the search returned to the original section.

At this point, the allowable weight for a candidate row was changed to any weight outside the original range. Thus, any row not already checked would then be a candidate row. The search of the original section was repeated using the new criteria for candidate rows and the same policy of minimizing rehandles and then distance. If no acceptable container was found, the search would be repeated for other sections, starting with the adjacent section and continuing with the others if necessary. If any section had an acceptable container, it would be located and loaded. If no acceptable container was available anywhere in the yard, the algorithm eventually returned to the original section and the failure to find a container for that cell was noted. Regardless of whether a container was found or not, the algorithm moved to the next cell and began a new search.

The second method of container selection was reserved for cells which were at the top of an on-deck stack. Too heavy a container in this case would result in overloading the deck stress limits. PoP personnel pointed out, though, that the lightest containers might be needed later in other stacks. They therefore recommended that the heaviest container which would not actually exceed the deck strength limits be loaded. This would save the lighter containers for possible later needs.

It was decided to modify this policy to increase flexibility. Instead of using the heaviest container with acceptable port and length, we considered eligible for loading any acceptable container within an operator-specified weight range of the heaviest acceptable container. Of those containers, the choice was narrowed to those which minimized rehandles; then the one which minimized travel distance was loaded. As with the normal search for a container, the search when weight could be critical proceeded section by section. If an acceptable container was located in a section, no other sections were searched. The order of the sections was the same; first the current section was checked, then the adjacent section, and finally the nonadjacent sections. Since all rows in a section were considered candidate rows, each section was checked only once. If no acceptable container was found, that fact was noted as in the regular search routine, and the loading algorithm proceeded to the next cell.

It should be noted that the policies adopted in the two container search procedures further refined the objective function. The result is a mixed policy of minimizing the number of transtainer moves, the transtainer distance traveled, and the number of rehandles. In the regular search routine, the number of moves is first minimized. If a move is necessary, the number of rehandles is minimized next and finally the distance traveled. In the critical weight search routine, the number of moves is ingored; rehandles are minimized first, then transtainer distance, within the limits of finding a container of acceptable port, length, and weight.

It may be noted that no consideration was given to reefers, refrigerated containers, in the algorithm. This omission was not accidental. When steamship line representatives give PoP personnel directions on where to locate cargo for different ports in the vessel, they distinguish between reefers and regular cargo. Different portions of the vessel are set aside for each. In effect, reefer cargo and regular cargo for the same destination port can be considered as cargo for two different ports. PoP personnel currently distinguish between reefer and regular cargo for the same bay. It was thus decided to make no special arrangements for reefers but to simply handle it with the algorithm's provisions for separate ports.

When all cells of the vessel have been checked by the algorithm, and as many as possible have been filled, the matter of stability remains. No way could be devised while developing the algorithm to check stability as loading progressed, so it was decided to follow current PoP procedures and check it after the loading was finished. The final step in the algorithm was therefore to calculate stability. If the calculations were within tolerance, the plan could be used. If they were out of tolerance, parameter changes would have to be made to the ranges used when searching for a row or a container and the algorithm rerun from the beginning. The first run with acceptable stability calculations would be used.

Evaluation of the Nearest Container Heuristic

Now that the subject of how the algorithm works has been dealt with, the remaining major topic is how well does it work? Naturally, this question must be broken down into measurable criteria. The first thing that must be established is whether the algorithm works at all. Given containers and a ship, can the program successfully match the two? The second criterion is feasibility of the load plan. Are constraints regarding stability, deck-stress limits, and high-cube limits met? The third criterion to be considered is whether the material handling efficiency of the program is acceptable. It should be remembered that one of the original objectives was to be at least as good as the current method in terms of time to load the vessel. The final criterion is what resources are required by the program? How much management and computer time will be needed for program operation? Reducing the management time needed to plan loads is of great interest to the Port of Portland. After the aggregate results have been evaluated, pertinent points from the results for individual voyages will be discussed.

Testing Procedure

Two vessels were selected for testing. These were the Japan Apollo and the Alaska Maru. The basis of selection was simply that both are large modern ships constructed for containers and having good ballast systems. They are part of a fleet of six ships belonging to a consortium of steamship lines that handle a large proportion of the container traffic in Portland.

Two voyages were tested for each of the two ships. These were voyages 5 and 10 for the Japan Apollo, and voyages 89 and 93 for the Alaska Maru. Information on the containers to be loaded and the status of the vessel before loading was obtained from the PoP. The assignments of ports to cells for the voyage and sequence for loading the bays were also provided. This information was used to prepare the yard file and run file to be used by the program to develop a load plan.

Once the files were prepared, several program runs were made using different parameters for row and container weight ranges. Only stability results and material handling summaries were obtained for these runs. The run with the best material handling results and adequate stability was then selected. An additional run was made using these parameters to obtain the complete load plan. For one voyage--Alaska Maru V93--the program failed to load two containers. This occurred because light containers for a port were loaded early in the loading process and were not available for a later on-deck bay. As a result, the operator was not able to meet deck stress limits for two stacks. The load plan was adjusted by the operator so that all containers were loaded. This required changing the positions of six containers.

The load plan and stability calculations prepared by the PoP were also obtained for each of the four voyages. In some cases, the stability calculations by the port contained errors. These were corrected and stability was recalculated for their plan. The material handling necessary for the PoP load plans was also calculated. Material handling for the computer load plan is calculated by the program. This was adjusted for any containers that were placed by the operator and for a different starting position. The program uses an arbitrary starting position for all transtainer movement. Since the transtainer position before loading is not known, the position of the first container loaded by each crane was used instead. Comparisons between PoP load plans and the computer load plan were made with these adjusted figures.

One problem with testing involved rehandling of containers from the ship. Some voyages required that containers which were aboard ship when the vessel reached the PoP be moved to other points on the vessel. Some of these moves were made directly, but in some cases, the containers were first placed in the yard, then loaded with the other cargo. Information obtained from the PoP did not include which containers were stored in the yard or what their locations might have been. These containers were therefore ignored in the analysis. The effect these containers would have had on the load plans is not known.

Stability Results

Whether a load plan's stability is adequate or not must be decided by ship's officers. They have the ultimate responsibility for the vessel and its cargo. They also know how much the ship's ballast system can modify the stability for the load plan supplied. The load planners, however, do have targets and ranges for stability which they try to achieve. These vary with the season. Table 5 shows the targets and ranges used by the PoP for summer and winter. Whether or not a load plan meets these limits, the vessel's officers make the final determination of acceptability.

Table 5. Stability Ranges

	GM	TRIM
Target	1m.	1m.
Winter range	0.8 - 1.9	0 - 1.5
Summer range	0.65 - 2.0	0 - 1.5

Stability calculations for the four voyages were not always within the desired limits. However, calculations for the computer load plan were within a few percent of those for the PoP plan. (Table 6). GM calculations ranged from 3.7% to 1.1% under the PoP's. Trim calculations ranged from 1.9% to 7.1% under the PoP's. Consultation with PoP load planners revealed that this range is considered acceptable for all voyages.

Table 6. Stability Results for Test Voyages

Voyage	PoP Plan	Computer Plan	Diff.	% Diff.
Japan Apollo V5	GM 1.77	1.75	- 0.02	- 1.1
	Trim 0.95	0.96	+ 0.01	+ 1.1
Japan Apollo V10	GM 1.98	1.92	- 0.06	- 3.0
	Trim 2.06	2.02	- 0.04	- 1.9
Alaska Maru V89	GM 1.64	1.58	- 0.06	- 3.7
	Trim 0.57	0.59	+ 0.02	+ 3.5
Alaska Maru V93	GM 1.32	1.29	- 0.03	- 2.8
	Trim 1.04	1.12	+ 0.08	+ 7.1

The stability results obtained by the program are especially surprising given the weight ranges used in the runs. The program is designed to allow the load planner to emphasize or de-emphasize stability by tightening or loosening the weight ranges used in row and container searches. The weight ranges used for the four test voyages were very wide, especially for individual containers. Table 7 shows the parameters used. The figures for row and container range increases are the amount the range is increased in both directions. Thus, if a range is from 15 to 23, increasing the range by 10 changes it to 5 to 33. The critical weight range is the maximum difference between two container weights that will still be considered the same weight by the critical weight container search subroutine. It has only a small effect on overall program performance.

Table 7. Parameters Used in Test Voyages

Voyage	Row Range Increase	Container Range Increase	Critical Weight Range
Japan Apollo V5	3	11	2
Japan Apollo V10	5	11	2
Alaska Maru V89	4	12	2
Alaska Maru V93	5	11	3

The effect of the parameters used is perhaps better illustrated by Table 8. This shows the ranges that resulted for row and container searches from the parameters used for *Japan Apollo* V10 and *Alaska Maru* V93. For 20-foot containers any weight would be accepted for light and medium cells. Only very light containers would be rejected for heavy cells. For 40-foot containers, containers would be excluded for every weight class, but only the heaviest and lightest containers are excluded.

Table 8. Row and Container Ranges for *Japan Apollo* V10 and *Alaska Maru* V93

Weight Class	Basic Range		Row Range		Container Range	
	20	40	20	40	20	40
Light	0-10	0-15	(-4)-14	(-4)-19	(-11)-21	(-11)-26
Medium	10-15	15-23	6-19	11-27	(-1)-26	4-34
Heavy	15-21	23-31	11-25	4-32	4-32	12-42

The ease of achieving stability even with wide weight ranges may be due to a preponderance of heavy containers for the four voyages. Table 9 shows the number of containers in each weight class. For all voyages heavy containers account for at least 60% of all containers loaded. Less than 10% of the containers loaded were classified as lights. It may be that narrower weight ranges would be needed if container weights were more heterogeneous. The weight distribution of containers for the test voyages is not typical for the PoP, however. A study of export containers at the PoP's terminal 6 (Cho, 1980) found 8% of the containers were lights, 34% mediums, and 58% heavies. Problems with stability at the PoP are thus not expected.

Table 9. Number of Containers in Each Weight Class for Four Voyages

Weight Class	Japan Apollo V5		Japan Apollo V10		Alaska Maru V89		Alaska Maru V93	
	No.	%	No.	%	No.	%	No.	%
Light	8	3	8	2	17	7	5	2
Medium	64	25	120	36	55	21	46	22
Heavy	186	72	201	61	189	72	160	76

Material Handling Results

The influence that a load plan can have on material handling time can be attributed to five discrete factors. Four of these have to do with movement of the transtainer (yard crane). The last is the number of containers for the voyage that must be rehandled. The four elements of transtainer movement are the number of moves, the distance traveled within yard sections, the number of times the transtainer moves between adjacent yard sections, and the number of times it moves between nonadjacent yard sections.

The number of moves made is significant because each one requires the transtainer to accelerate, decelerate, and position itself. The distance is of course significant because transtainer speed is finite. Changes between adjacent yard sections are really just added distance. These are changes where the transtainer can drive across the center aisle into the next yard section. The analysis distinguishes between these moves and distance traveled within sections because it was simpler to keep track of them this way. Changes between nonadjacent section changes require much more time. These section changes require the transtainer to stop in the center aisle, turn the wheels 90°, travel down the center aisle, turn the wheels back, and then move into the new section. Nonadjacent section changes are thus counted separately.

Time studies were used to measure the influence of the five factors on loading time. The times recorded were move times for various distances, time to change between nonadjacent sections, and time to load containers out of a row to the truck. These were then used to develop time estimates for each of the five factors (Table 10).

The first step in developing times was to distinguish between the time needed to accelerate, decelerate, and position the transtainer, and the time to travel various distances. This was done by recording times for various distances and then regressing time against distance. The correlation coefficient for these points is 0.9783. Regressing time against distance gives the model:

time = 19.8622 seconds + 1.56236 seconds/row number traveled

Row numbers were used as the distance unit since locations at the PoP are recorded this way. Row numbers are 10.8 feet apart. This model gives a constant time of 19.86 seconds for every move and additional time of 1.56236 seconds for every row number traveled by the transtainer. This figure for speed corresponds to 415 feet/minute. Maximum transtainer speed according to equipment specifications is 440 feet/minute. Once the transtainer speed is known, the extra time needed to travel between adjacent yard sections is easily calculated. The center aisle is 104.3 feet wide or the equivalent of 9.66 row numbers. The time to cross the center aisle is thus 15.09 seconds.

To calculate the time for nonadjacent sections changes, the time to turn the wheels, move down the aisle, and turn the wheels back was needed. Observations of eight nonadjacent section changes yielded an average time of 218.50 seconds with a standard deviation of 48.10 seconds. When making nonadjacent section changes, the transtainer will on average traverse the width of the center aisle once. The time to cross the center aisle--15.09 seconds--is thus added to the nonadjacent section change time. In addition, the transtainer makes a complete move out of the original section and a second move into the new section. Only one of these moves is counted in the number of moves statistics, so the time for the second move--19.86 seconds--is added to the nonadjacent section change as well. The total time for nonadjacent section changes is thus 253.46 seconds. There is another consideration, however. Not all nonadjacent section changes actually take place. During normal business hours, the PoP has four transtainers manned to service trucks delivering and picking up containers. When a vessel is being loaded, transtainers are placed in all areas where containers for the vessel are located. Instead of actually moving transtainers between sections, the port simply switches from one transtainer to another. Many nonadjacent section changes never take place. To account for this, it was assumed that no nonadjacent section changes take place during regular business hours and all changes take place at other times. Standard practice is to work a vessel two shifts a day every day it is in port. Thus, nonadjacent section changes can be expected during nine shifts out of every 14, or 64.3% of the time. Rather than try to determine when ships were loaded, we multiplied the time for nonadjacent section changes by .643 to get an expected time for section changes over the long run. The figure obtained is 162.94 seconds per nonadjacent section change.

Perhaps the most difficult time to obtain was for the fifth material handling factor-rehandles. When a container is rehandled, two things can happen. If the container can be placed somewhere else in the same row without blocking another container for the same voyage, this will be done. If all stacks in the row still have containers for the voyage, the transtainer will move to a nearby row and place the container there. Times for this are difficult to obtain because there are few rehandles per voyage.

To develop a time for rehandles we made two assumptions. The first was that the rehandled container would always be placed in the same row and no transtainer movement would be necessary. The second was that it takes the same amount of time to move a container from point to point within the row as it does to move it from the row to the truck. Since the transtainer operator usually pauses and verifies the container he is to take by radio when a rehandle is needed, this may result in underestimating the time needed for rehandles. Given these two assumptions, the data needed is the time to move a transtainer from the row to the truck.

While it is difficult to tell when individual containers are moved by the transtainer, it is easy to tell when a transtainer begins picking containers from a row and when it stops. It was thus possible using a load plan to calculate the average time to take containers from each row. Weighting these average times yielded an overall average time of 157.92 seconds to move a container from its position in the row to the truck. This is the figure used for rehandles.

Table 10. Times Used for Material Handling

Transtainer Moves	19.86 seconds/move
Distance Traveled Within Sections	1.56236 seconds/row number
Adjacent Sections Changes	15.09 seconds/change
Nonadjacent Section Changes	162.94 seconds/change
Rehandles	157.92 seconds/rehandle

With times for the five material handling factors, variable material handling time for the load plans can be calculated. Table 11 gives the results for both the PoP and computer load plans for the four vessels. Results for the Alaska Maru's voyage 93 are given both before and after adjustment to show what effect the manual alterations had. As can be seen in the table, there was significant variation between the PoP and computer load plans, but in no consistent direction. The program did the best for the Japan Apollo's voyage 5, bettering the PoP's plan by more than 25 minutes. Its worst performance was for the Alaska Maru's voyage 93 where loading time was nearly 15 minutes longer. The vessel involved makes no apparent difference, as two voyages where the program did better were for different ships.

Table 11. Material Handling Results by Voyage

	Results			Time (sec)			
	PoP	Computer	Diff	Pop	Computer	Diff	% Diff
Japan Apollo V5 (258 containers loaded)							
Moves	54	52	-2	1072	1033	-39	-3.7
Distance (rows)	1677	1330	-347	2620	2078	-542	-20.7
Adj Sec Chgs	9	8	-1	136	121	-15	-11.1
Nonadj Sec Chgs	11	9	-2	1792	1466	-326	-18.2
Rehandles	7	3	-4	1105	474	-631	-57.1
Totals				6725	5172	-1553	-23.1
Japan Apollo V10 (329 containers loaded)							
Moves	58	59	1	1152	1172	20	1.7
Distance (rows)	1651	1743	92	2579	2723	144	5.6
Adj Sec Chgs	7	9	2	106	136	30	28.5
Nonadj Sec Chgs	8	10	2	1304	1629	325	25.0
Rehandles	0	0	0	0	0	0	0
Totals				5141	5660	519	10.1
Alaska Maru V89 (261 containers loaded)							
Moves	70	64	-6	1390	1271	-119	-8.6
Distance (rows)	2473	1978	-495	3864	3090	-774	-20.0
Adj Sec Chgs	15	11	-4	226	166	-60	-26.7
Nonadj Sec Chgs	14	14	0	2281	2281	0	0
Rehandles	4	3	-1	632	474	-158	-25.0
Totals				8393	7282	-1111	-13.2
Alaska Maru V93--Before Adjustment (209 containers loaded)							
Moves	54	56	2	1072	1112	40	3.7
Distance (rows)	1630	1864	234	2547	2912	365	14.4
Adj Sec Chgs	11	8	-3	166	121	-45	-27.3
Nonadj Sec Chgs	7	13	6	1141	2118	977	85.7
Rehandles	6	1	-5	948	158	-790	-83.3
Totals				5874	6421	547	9.3
Alaska Maru V93--After Adjustment (211 containers loaded)							
Moves	54	59	5	1072	1172	100	9.3
Distance	1630	2018	388	2547	3153	606	23.8
Adj Sec Chgs	11	11	0	166	166	0	0
Nonadj Sec Chgs	7	13	6	1141	2118	977	85.7
Rehandles	6	1	-5	948	158	-790	-83.3
Totals				5874	6767	893	15.2
Grand Total*				26133	24881	-1252	-4.8

*Uses after adjustment figures for Alaska Maru V93

The major conclusion that can be drawn from the data is that there is no evidence that use of the program would result in increased material handling time at the PoP.

Another way of looking at the material handling results is by the material handling factors. Table 12 breaks down the material handling results by factor. The second, third, and fourth factors show a similar pattern to the results by vessel. If the program did well for a voyage, it does well for the number of moves, distance, and adjacent section changes. It should be noted that the deviations for the number of moves are relatively small, always less than 10% either way.

Table 12. Material Handling Results by Material Handling Factor

	Results			Time (sec)			
	PoP	Computer	Diff	PoP	Computer	Diff	% Diff
Containers Loaded							
Japan Apollo V5	258	258	--	40743	40743	--	--
Japan Apollo V10	329	329	--	51956	51956	--	--
Alaska Maru V89	261	261	--	41217	41217	--	--
Alaska Maru V93	211	211	--	33321	33321	--	--
Total	1059	1059		167237	167237		
% of Grand Total				86.5	87.0		
Moves							
Japan Apollo V5	54	52	-2	1072	1033	-39	-3.7
Japan Apollo V10	58	59	+1	1152	1172	+20	+1.7
Alaska Maru V89	70	64	-6	1390	1271	-119	-8.6
Alaska Maru V93	54	59	+5	1072	1172	+100	+9.3
Total	236	234	-2	4687	4647	-40	-0.8
% of Grand Total				2.4	2.4		
Distance (rows)							
Japan Apollo V5	1677	1330	-347	2620	2078	-542	-20.7
Japan Apollo V10	1651	1743	+92	2579	2723	+144	+5.6
Alaska Maru V89	2473	1978	-495	3864	3090	-774	-20.0
Alaska Maru V93	1630	2018	+388	2547	3153	+606	+23.8
Total	7431	7069	-362	11610	11044	-566	-4.9
% of Grand Total				6.0	5.7		
Adj. Sec. Chgs.							
Japan Apollo V5	9	8	-1	136	121	-15	-11.1
Japan Apollo V10	7	9	+2	106	136	+30	+28.5
Alaska Maru V89	15	11	-4	226	166	-60	-26.5
Alaska Maru V93	11	11	0	166	166	0	0
Total	42	39	-3	634	589	-45	-7.1
% of Grand Total				.3	.3		

Table 12. (Continued)

	Results			Time (sec)			
	PoP	Computer	Diff	PoP	Computer	Diff	% Diff
Nonadj. Sec. Chgs.							
Japan Apollo V5	11	9	-2	1792	1466	-326	-18.2
Japan Apollo V10	8	10	+2	1304	1629	+325	+25.0
Alaska Maru V89	14	14	0	2281	2281	0	0
Alaska Maru V93	7	13	+6	1141	2118	+977	+85.7
Total	40	46	+6	6518	7495	+976	+15.0
% of Grand Total				3.4	3.9		
Totals							
Japan Apollo V5	--	--	--	47468	45915	-1553	-3.3
Japan Apollo V10	--	--	--	57097	57616	+519	+0.9
Alaska Maru V89	--	--	--	49610	48499	-1111	-2.2
Alaska Maru V93	--	--	--	39195	40088	893	+2.3
Grand Total				193370	192118	-1252	-0.6

The figures for nonadjacent section changes and for rehandles do not follow the same pattern. Furthermore, deviations between the PoP and computer load plans are much greater--as high as 85%. In the case of nonadjacent section changes, the computer load plan resulted in fewer changes only once. Examination of the PoP load plan for that voyage shows that a simple change would have eliminated the need for two of the sections changes. If this had been done, the PoP would have been as good as or better than the program for every voyage. That this was not the case can be attributed to human error. Analysis of the two voyages where the PoP was better than the program for these section changes shows that the program's weakness is its inflexibility in certain situations.

The last factor is rehandles. Here the program does better in every case except for Japan Apollo V10, where neither method resulted in rehandles. For the Alaska Maru V93, the PoP load plan resulted in six rehandles while the program had only one. For the four voyages, the program had 59% fewer rehandles than the PoP. This is by far the largest difference of any of the factors. Studies of the load plans do not suggest a reason for the difference. In a few cases the PoP rehandles may have been due to a greater emphasis on stability, but most do not appear to be caused by this.

The possible trends for nonadjacent section changes and for rehandles are interesting, but it should be stressed that with the small sample size the results have no statistical significance. Any suggestion of a trend comes as much from a detailed comparison of the load plans as from the overall statistics for these four voyages. Further testing would be needed before any patterns could be given statistical backing.

Summary of NCH Program Evaluation

The results from the NCH program evaluation are positive. Although not exceeding the manual load plans in material handling efficiency in every case, the computer-assisted load plans did reduce on the average, nonproductive transtainer time by 4.8% and over all time by 0.6%. It would appear that the computer-assisted load plans are, on the average, as efficient as manually prepared plans. Furthermore, it is estimated that the computer-assisted load plans can be prepared in half the time or less than that required for manually prepared load plans. The results of the evaluation indicate the NCH program has met the objectives originally established for it.

From the results of the evaluation, it is estimated that further development of the NCH program could improve its efficiency by as much as 10% of the nonproductive time or about 1.5% of the total loading time.

It should also be noted that the evaluation of the computer program was conducted in such a way that one of the program's best features was not used. The preparation of a manual load plan is such a laborious task that once a feasible plan is obtained, no attempt is made to improve the material-handling efficiency by generating alternative plans. This is not the case with the computer-assisted system. Once a feasible load plan has been developed using NCH, alternate plans may be developed in four to six minutes by changing certain program parameters.

For example, the load planner could try three or four different bay-loading sequences, then pick the sequence which gives the best results. This possibility was not examined in the evaluation of NCH.

Port Load-planning Efficiency

The summary results in Table 11 provide an estimate of the total transtainer time, in seconds, required to load each ship. These estimates are translated into hours and into container handling rates in Table 12. For example, a total of 16.00 transtainer hours would be required to load the Japan Apollo on voyage 10. This estimate is based upon two transtainer operations, but managers should be aware that it is usually not possible to distribute the work equally between the two transtainers. In other words, the results do not imply that two transtainers, each working eight hours, could complete the task.

It should be observed that the estimated average containers per hour per transtainer of 19.78 containers/hour given in Table 13, is based upon continuous, uninterrupted transtainer operation. It is also based upon the PoP's current operating procedures. Changes in these operating procedures could significantly affect this rate. This rate also assumes a loading only mode of operation and does not include unloading time.

Although it wasn't possible to obtain an estimate of the magnitude and frequency of the unavoidable delays that a transtainer might encounter, a customary figure would be about 15%. This would provide an estimated rate of 16.81 containers/hour, which should provide a good target value. It should be emphasized that no attempt was made to measure the actual operating efficiency.

Table 13. Performance Indices

Voyage	Loading Time (Comp.) Sec.	Hrs.	Number of Containers Loaded		Containers per hour loaded
Japan Apollo V5	45915	12.75	258		20.24
Japan Apollo V10	57616	16.00	329		20.56
Alaska Maru V89	48499	13.47	261		19.38
Alaska Maru V98	40088	11.14	211		18.94
Total	192118	53.36	1059	Mean	19.78 (.75)

It is informative to compare the actual performance to the theoretically best possible performance. Here, the theoretical performance assumes no rehandles, no section changes, and the minimum possible number of moves and distance traveled by the transtainer. It also assumes a 50/50 mix of 20- and 40-foot containers and no-specials. The tabulated results in Table 14 would indicate that the current manually developed load plans are operating at 87% of the maximum theoretical efficiency, as measured by transtainer time. Thus, the maximum possible reduction in transtainer time would be 13%, and this assumes perfectly arranged containers and no specials! It's not clear exactly how much of this 13% potential savings could possibly be realized. Most likely, no more than 6% or 7% could actually be realized under current operating procedures.

Table 14. Theoretical Performance (Sec.)

Voyage	Theoretical	Actual (PoP)		% Efficiency
Japan Apollo V5	41111	47468		86.60
Japan Apollo V10	52422	57097		91.81
Alaska Maru V89	41585	49610		83.82
Alaska Maru V93	33615	39195		85.76
Total	168733	193370	Mean	87.00

Once again, Table 11 indicates that about 8% of the total, or over 60% of the nonproductive time, is spent on movement time within sections. This would then appear to offer the greatest potential for possible reduction.

Nonadjacent section changes account for 25% or more of the nonproductive time and represent another area for potential improvements. An examination consisting of a sample of load plans, Table 15 suggested that these nonadjacent section changes are necessary to load a small percentage, 17.2%, of the containers. Of these "out of section" containers, 78% are refrigerated units. The possibility of prestaging these containers immediately presents itself. By this we mean moving these containers out of their current sections to the primary sections just prior to loading the ship. If this could be accomplished during the first-shift idle time at no additional cost, then there would be nearly a half hour per ship reduction in loading time. However, if this staging could not be achieved as background work which could be accomplished at very little cost, it would probably not be cost effective.

Table 15. Container Distribution by Section

	SECTION				
Container Type	42	52	44	54	57
Regular	616	567	14	1	36
Refrigerated	0	0	65	116	0
Total	616	567	79	117	36
%	43.5	40.1	5.6	8.3	2.5

During the evaluation of the NCH, two possibilities for improving terminal operation were identified. The first involves the estimated 157.92 seconds, or 2.63 minutes, to load a container from a stack onto a chassis. This time appears excessive. Since about 85% of the total loading time is due to this single factor, it should be carefully examined. If this time per container can be substantially reduced, the total time could also be similarly reduced.

Current port operating procedures are for the ship to be unloaded, then loaded. During the unload operation the crane spreader travels empty from the dock to the ship. During loading operations, the spreader travels empty from the ship to the dock. This empty travel time represents a significant wasted effort. If these two operations, loading and unloading, could be interleaved, there could be a substantial improvement in efficiency. When interleaving, the crane would pick up a shipbound container and then place it on a chassis on the wharf. The crane would then pick up an export container from a shore side chassis and load it in the ship bay. This pattern would continue as long as there was an adequate supply of both inbound and outbound containers. Obviously this scheme would not always work for on-deck bays. It does, however, offer the potential for a 20% or more improvement in efficiency, and we recommend it be given serious consideration.

5. DEVELOPMENT AND TESTING OF THE YARD SIMULATION PROGRAM

Introduction

Because of its highly capital-intensive nature, a container port calls for the maximum use of its equipment and manpower. The primary objectives in developing the model are reduced overall operating cost and increased customer satisfaction, including minimum possible ship turnaround time. The actual changing of physical layouts, operating procedures, and other factors influencing operational effectiveness would be a very expensive means of testing various proposed improvements. Such is not the case in computer-based simulation models where it is possible to test various proposed changes without affecting actual yard operations. Granted, no simulation model exactly represents all the parameters and their interactions of a system as complex as a container facility, but a well-developed model does allow tests to be run on significant aspects of the operation. The technique of computer simulation provides the manager analyst with an economical means of evaluating changes and their effects on overall port efficiency.

The overall port design was assumed to consist of the following general areas:

1. Gate--for processing paperwork of incoming and outgoing trucks.

2. Yard area--provides stowage and staging area for both outgoing and incoming containers.

3. Dock area--loading and unloading operations take place here.

4. Container freight station--packing and unpacking of containers when necessary.

5. Administrative and maintenance support area.

The following types of material handling equipment operate in the port system under consideration:

1. Ship cranes--mounted on rail trucks along the deck and load and unload containers onto and off of ships.

2. Transtainers--rail-mounted gantry cranes that ride across the breadth of a yard section. They stow containers to slots in a section or take them out to place on truck chassis.

3. Yard trucks--trucks with specially designed container chassis. They provide the link between transtainers and ship cranes.

4. Others--regular highway trucks that bring in or take out containers, fork-lift trucks that handle empty containers, and so on.

The yard consists of a number of "sections" of equal size. A typical section contains 37 rows and six columns of 20-foot storage slots. Containers can be stacked to a maximum of four high in each slot.

Simulation Objectives

The primary objective is to develop a simulation model using the GASP-IV simulation language which will enable the user to test and compare the merits of the following operational parameters and policies of a container port.

1. Various values of maximum stack height.

2. Loading from a randomly stacked yard section vs. loading from a pre-ordered section.

3. Implementation of any initial yard stowage pattern through input data to provide the flexibility of being able to handle various policies of partial preload yard stowage.

4. Number of yard trucks to use.

5. Loading from a single section vs. loading from two sections.

The measures of effectiveness are the total operation time and expected annual equivalent cost.

The model should enable the user to establish the relationship of total loading time in terms of the number of containers, the number of yard sections, and the number of cranes employed.

Model Structure

The general structure of the simulation model is based upon a mathematical representation of the primary characteristics of the system being studied. The basic variables of this representation fall into three groups: entities, or the physical components of the system; activities, or the action taking place within the system; and events, or significant points signifying the beginning or end of critical activities.

Additionally, specific technical components of the model must be developed in order to allow the computer to perform simulated activities and keep track of relevant statistics. These components are subroutines, variables, and data arrays, and a complete list of those statistics to be collected. The specific program components for YARDSIM are detailed in this section.

A. Entities

1. Permanent: Cranes
   Transtainers
   Yard trucks
   Ship, yard sections

2. Temporary: Containers

B. Activities

1. Ship loading operations

- Transtainer loads container on truck chasis.
- Truck chasis transports container to crane.
- Crane loads container onto ship.
- Truck returns to transtainer area.
- Transtainer handles rehandling of containers in section.
- Transtainer changes position.
- Crane changes position.

2. Pre-ordering operation

- Transtainer loads desired container onto truck chassis.
- The container is transported to pre-order section.
- The container is stowed in pre-order section.

C. Events

The following events represent key operational points in both yard activities and the simulation model of those activities.

- Truck arrives at transtainer
- Transtainer completes position change
- Transtainer completes truck loading
- Truck arrives at crane area
- Crane completes position change
- Crane completes ship loading

Model Logic and Input Data

The general logic of YARDSIM is actually condensed into a three-phase program of inputting data specifying yard layout, ship characteristics, and equipment operating parameters; executing the GASP package to monitor and perform the various simulation activities; and printing various statistics called for in the output. The 20 subroutines used in the YARDSIM program are listed in Table 16. This interrelationship is shown in Figure 2.

Table 16. YARDSIM Subroutines

Name	Function
YARDSIM	Reads in some data and calls GASP.
INTLC	Sets initial conditions.
RDMZE	Makes random assignment of initial container locations.
PRESQ	Constructs job sequence file for pre-ordering.
LDSEQ	Constructs job sequence file for ship loading.

Table 16. (Continued)

Name	Function
EVNTS	Transfers control to appropriate subroutine.
DISCR	Generates random movement times.
UERR	Prints out error messages.
TARRV	Enjoins the arriving truck to queue and calls TRANS.
TMOVE	Updates transtainer position and calls TRANS.
TLOAD	Sends off truck from queue and calls TRANS.
TRANS	Truck-loading operation.
TKOUT	Computes transtainer move time to take out container.
SERCH	Looks for an empty slot to move rehandle container.
PRODR	Stows container in pre-order section.
CARRV	Adjoins arriving truck to queue and calls CRANE.
CMOVE	Updates crane position and calls CRANE.
CRANE	Ship-loading operation.
OTPUT	Output of results.
CLOAD	Finishes loading into ship and calls CRANE.

The execution of YARDSIM requires the user to supply data pertaining to the following variables.

1. Ship characteristics
2. Yard equipment time distribution
3. GASP operational details
4. Layout of yard sections

After the various input files are read into YARDSIM, a printout is made of each of the specific data groups to allow the user to check the inputs prior to executing the main body of the program. At the end of the prespecified simulation exercise, the GASP package releases to YARDSIM all statistical data requested, and these figures are then provided to the user in a summary table. In case of an input error in either equipment time specifications, container ID codes, or yard location parameters, the simulation is terminated and an error code is printed.

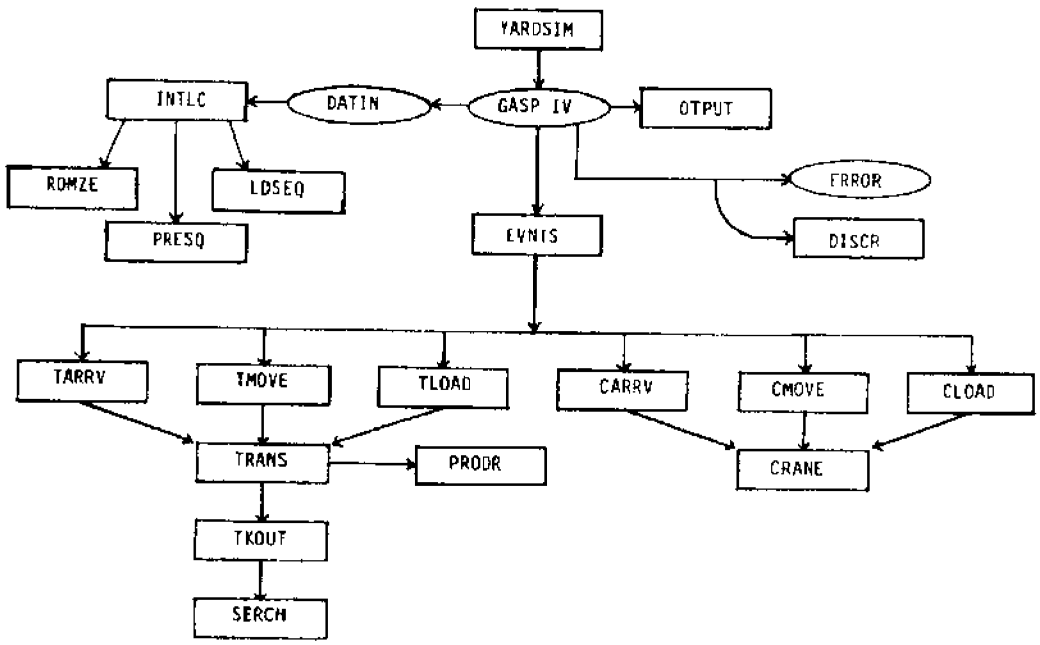

Figure 2. YARDSIM Program Organization

Examples

The model will now be used to simulate various combinations of policies and operating procedures. However, in order to obtain a common measure of comparison between various situations, it was necessary to develop some equivalent hourly operating costs for the various pieces of equipment being modeled.

Estimated hourly equivalent costs in 1979 dollars were calculated for the ship cranes, transtainers, and yard trucks, using a combination of inputs from Port personnel and general industrial assumptions. These costs are not to be construed as accurate estimates of the true costs at the Port of Portland, but rather are simply synthetic estimates of operating costs. Their development was strictly for the purpose of illustrating how representative costs would be employed in the analysis of data provided by the simulation model.

Development of these cost estimates are as follows:

1. Ship crane costs of $318/hour.

2. Transtainer costs of $64/hour.

To demonstrate how the simulation program may be employed, we conducted three exercises using the cost estimates described above. These exercises consisted of the following simulations:

Case 1: A loading operation involving 400 containers from a single randomly stacked yard section with each container being specifically sequenced into an assigned ship bay. Overstacking did exist in the yard prior to the loading operations. One ship crane and one transtainer were used, but the number of yard trucks was varied to test the effect on total load time and total equivalent cost.

Case 2: Identical to Case 1 except that containers in the yard section were pre-arranged in exact load sequence. Again, one ship crane, one transtainer, and a variable number of yard trucks were employed.

Case 3: A pre-ordering operation involving the moving of 400 containers from a randomly arranged section to one which would be arranged to a predetermined ship load plan. In other words, determining the time and cost required to change the initial conditions in Case 1 to those in Case 2. Two transtainers and a variable number of yard trucks were used.

It should be noted that these exercises are intended only as an illustration of how the YARDSIM package can be employed, not as a recommendation for instituting current operating procedures.

RESULTS AND CONCLUSIONS

The simulation results for the three cases cited above are shown in Figures 3 and 4. From Figure 4 we can see that two trucks are optimal for loading from a random stack or pre-ordering and three trucks are optimal for loading from an ordered stack. The results give the cost per container

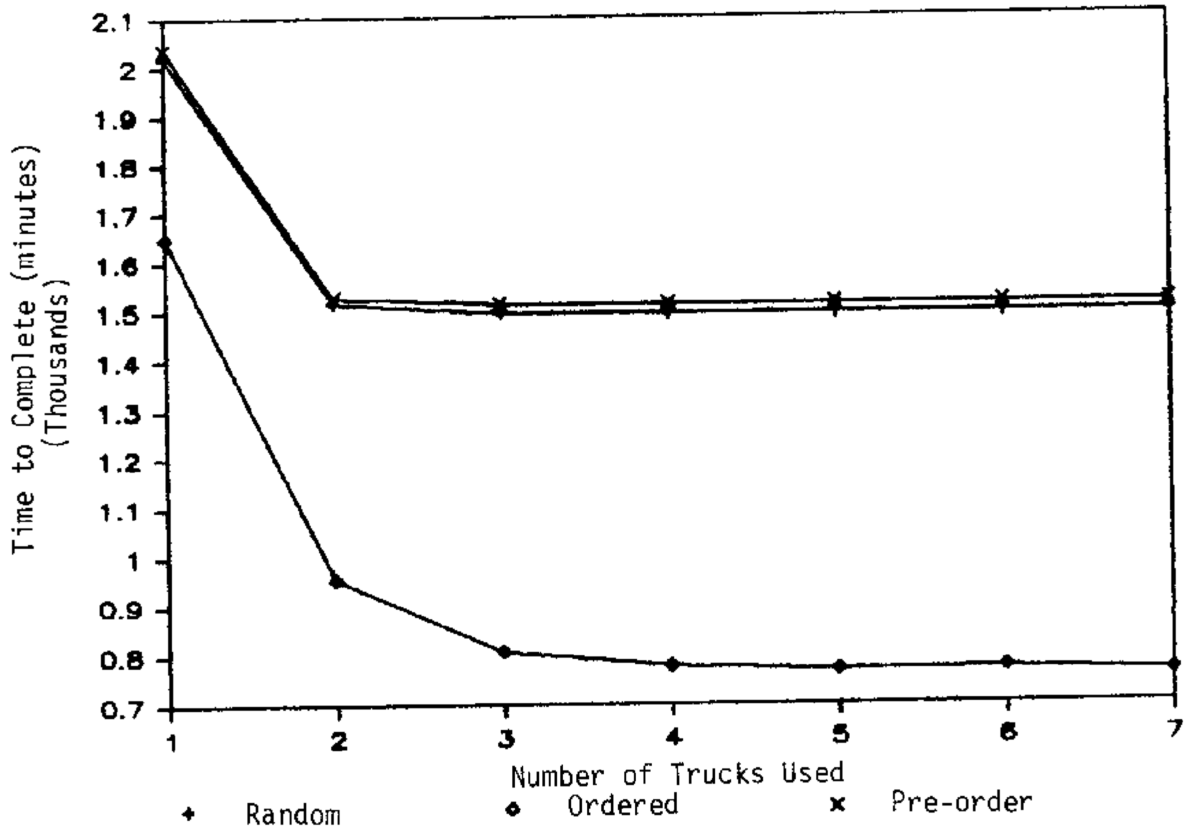

Figure 3. Time for Operation

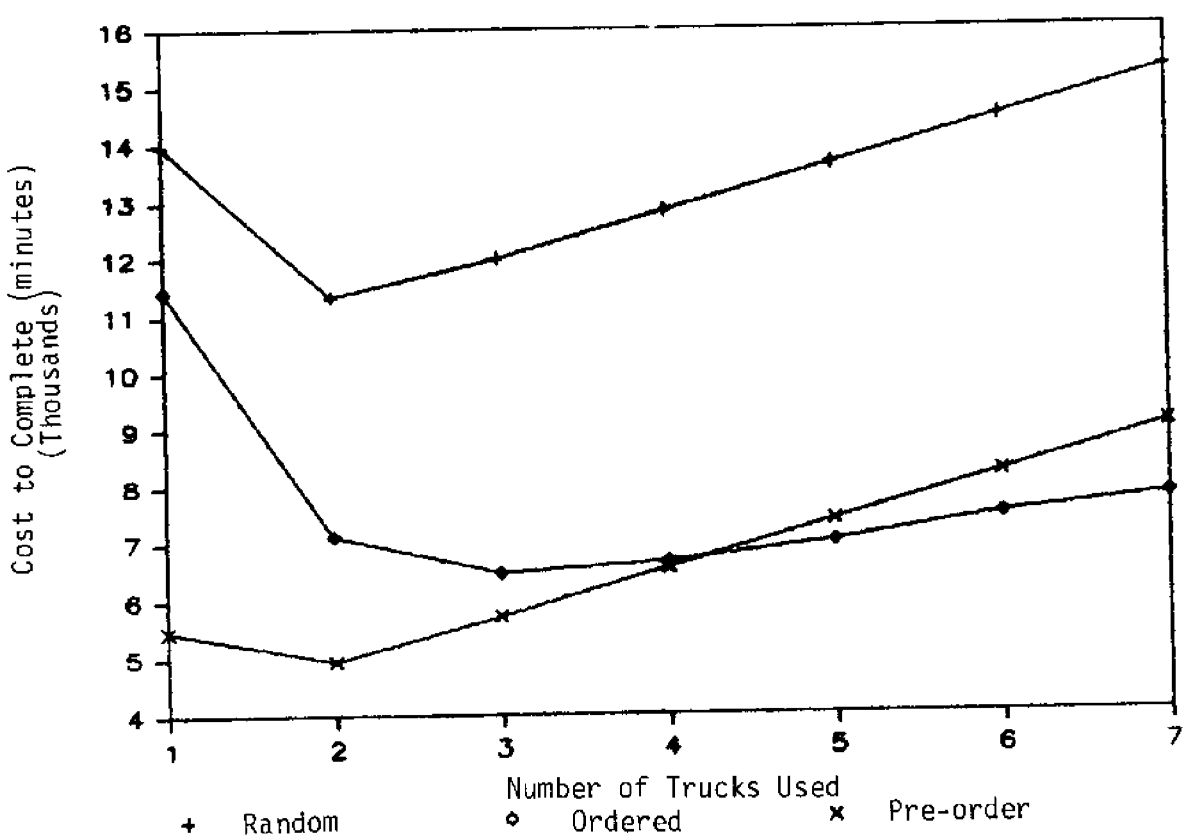

Figure 4. Cost for Operation

as $28.33 for a random load, $16.18 for an ordered load, and $12.53 per container for a pre-order. The total cost to pre-order and then load from the ordered stack would be $28.53 per container, or a 0.7% increase. Figure 3 indicates this would reduce ship loading time by 12.2 hours. At an approximate cost of $1,000.00 per hour for a container ship in port, this would save the steamship company $12,200, or $30.50 per container loaded. This savings, if it could actually be realized, is substantial. We therefore recommend the PoP seriously consider a change in their mode of operation.

The most serious obstacle to pre-ordering is the lack of timely information. The port would need a reasonably accurate list of containers to be loaded and a load plan. Currently the bay loading plan necessary to develop a load plan arrives with the ship. If pre-ordering were to be used, this information would need to be obtained far enough in advance of the ship's arrival to allow the pre-ordering. Given the current state of electronic communications this should be easily accomplished.

The use of an accurately designed simulation program can provide management with a tool which allows the testing of numerous ideas for operation and procedure without actually interfering with operations. However, it should be remembered that the basic simulation model is a simplified view of reality and any information it provides is only as valid as its original design and the validity of the input data it uses.

In building and testing YARDSIM, we have incorporated numerous assumptions into the design. Overall, the model seems to represent container loading and other yard operations very well. It will, however, need updating as time and cost parameters as well as yard procedures change.

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APPENDIX

CONTAINER TERMINAL OPERATION

I. Structures

A. Check-in Station: Yard controlled from this point. Here, exports are checked in, imports are checked out, and assignments of yard slots are made. In addition, master records of which container is in which yard slot are kept here. The dispatcher for yard trucks and customs is here.

B. Dock Office: Loading and unloading of ships supervised and controlled from here.

C. Administration Building: Administrative functions, planning of stowage, and computer center found here.

D. Maintenance: Equipment and containers repaired here.

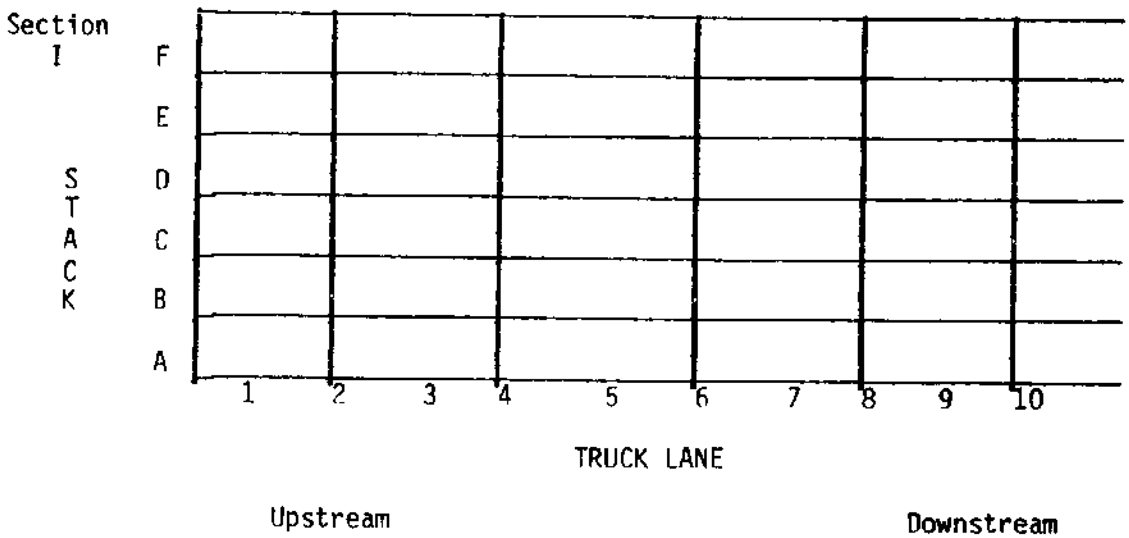
II. Yard

A. Physical Layout: There are 14 sections.

1. Three sections (45, 46, and 47) are for empties only and can only be serviced by side and top loaders. Containers here are packed as close together as possible--two high (block storage).

2. Sections 41 through 44 and 51 through 57 are transtainer sections. Containers are stacked in rows of six across up to four high. About one and one-half feet separate containers. Each section can accommodate 37 rows of 20-foot containers. Numbering of rows goes from 1 to 73. Lines are painted every 20 feet on the ground. Odd numbers are in the space between the lines and even numbers are on the lines. The row number is the number in the middle of the container. Twenty-foot containers then have odd row numbers, and 40-foot containers have even row numbers. The six positions in a row are denoted A through F. The height of a container in a stack is denoted by bottom, center, top, and zulu for the first, second, third, or fourth container off the ground. Complete designation of a container is given by the section number, row number, stock number, and height in the stack (tier number). For example, 5215DB would denote a 20-foot container on the bottom in stack D of row 15 in section 52.

3. Refrigerated units (reefers) can be accommodated at the ends of sections 44 and 54, which are nearest the check-in station. There are plug-ins at these points for the refrigeration units.



B. Organization

1. Sections 41, 42, 51, 52, and 53 are used primarily for export cargo. Sections 41 and 51 have cargo for the six-company Japanese consortium. Each line has an area of the yard reserved, more or less, for its exports within these areas; cargo is arranged by ship and by voyage number. Cargo is also segregated by weight and by commodity when possible. If there are a large number of containers, an attempt is made not to place cargo for the same voyage in one spot. This way, two or more transtainers could work at one time.

2. The ship's cargo (imports) is usually discharged into sections 55 and 56. Cargo is stacked one high when possible to make every container accessible when a truck picks it up.

3. Section 55 is used primarily to discharge empty (MTY) containers from ships. Sections 44 and 54 are also MTY discharge except for the reefer areas.

C. Traffic Patterns

Trucks always travel down lanes between sections from the upstream to the downstream side. (The check-in station is downstream.) Two-way areas surround the yard and cut between sections 41, 42, 43, 44, 45, 46, and 47, and 51, 52, 53, 54, 55, 56, and 57, perpendicular to the river.

Traffic from the check-in station usually passes on the land side of the containers when traveling in the upstream direction. Traffic on the dock underneath the Hitachis usually travels in the upstream direction. Traffic flow, then, is roughly circular from check-in through the yard or from ship through the yard.