DESIGN BY SIMULATION

Under the same assumed conditions as in the design by queuing theory, the situation depicted in Figure 2 was simulated by using the general purpose simulation system (GPSS/360) language for 200 terminations (i.e., 200 vehicles passed through the complex).

The service rate at the security gate was random with a mean of 60 sec and a spread of 10 sec (i.e., 50 to 70 sec). The service rate at the main gate was random with a mean of 300 sec and a spread of 60 sec (i.e., 240 to 360 sec). The results are almost identical to those shown in Tables 1-3.

Productivity at Marine-Land Container Terminals

JOAN AL-KAZILY

Productivity at marine terminals can be viewed from several different points of view. To the owners of vessels, terminal productivity implies the rate at which containers can be discharged and loaded. On the national level, productivity may be viewed as the number of containers or tonnage of freight handled per year by a terminal. This is also influenced, both directly and indirectly, by the container handling rate, which is the aspect of productivity reviewed in this paper. The effect of the container handling rate on system costs and productivity is first demonstrated. Data for container handling rate are presented to demonstrate how widely it varies. The need to be able to model container handling rates is suggested and a model is presented. The model is used to demonstrate how the wide variation in container handling rates can occur. The variables used in the model are discussed. Data for some of the variables are not readily available. Some need to be modeled themselves. The importance of models for system components to aid in modeling entire systems is stressed.

The transportation researcher is frequently called on to analyze the operations of a transportation system. In marine transportation, the system involves the collective functioning of a set of ports and the vessels that operate between them. It is clear that fast turnaround of vessels in port is a major factor in the optimum operation of this transportation system. The researcher needs to be able to model the time the vessel spends in the port and is therefore obliged to study terminal productivity and attempt to analyze all of the factors that affect that productivity.

Productivity at marine terminals can be viewed from several different points of view. To the operators of vessels, terminal productivity implies the speed with which loading and discharge are implemented. On the national or regional level, productivity of a terminal might be viewed as the number of containers or tonnage of freight handled per year by a container terminal. The point of view of terminal operators would be a combination of both of these.

There are several separate, although interactive, components in the operation of an intermodal terminal. Each of these components can individually limit productivity. This concept--the modular approach--has been used by Moffatt and Nichol (1) to predict terminal capacity in the Port Handbook for Estimating Marine Terminal Cargo Handling Capability. The modules or components defined by Moffatt and Nichol are ship size and frequency, ship and apron transfer, apron and storage transfer, storage yard capacity, and inland transportation processing capability. For each of these modules there are certain parameters that influence both capacity and productivity.

Although these components are interactive, in that a slowdown in one process can directly affect another process, they can be studied separately. The ship and apron component is examined in this paper. The ship and apron transfer rate directly affects the turnaround time of vessels, which in turn affects system productivity. The efficiency of the ship and apron component may also affect the frequency of vessel calls and hence the overall productivity of the terminal itself.

EFFECT OF CONTAINER HANDLING RATE ON SYSTEM PRODUCTIVITY

The turnaround time of vessels in port has three components: (a) the time taken to get into port, berth the vessel, and later leave the port; (b) the time spent discharging and loading vessels; and (c) the time a vessel is at berth without discharge and loading taking place (idle time). Components b and c are a direct product of the ship and apron transfer module of the terminal. Component a is also included in this paper because it affects the turnaround time of vessels in port.

Productivity of container terminals, as it affects the turnaround time of vessels, can be expressed as the container cargo handling rate, which is the topic of this paper. In order to more clearly define the scope of this topic, the meaning of container cargo handling rate must be clarified. Container cargo handling rate can be expressed in many different ways, including

1. Container moves made per crane hour,
2. Container moves made per gang hour,
3. Container moves made per hour of discharge and loading time,
4. Container moves made per hour of vessel time at berth,
5. Containers discharged and loaded per hour of vessel time at berth,
6. Twenty-foot equivalent load units (TEUs) discharged and loaded per hour of vessel time at berth, and
7. TEUs discharged and loaded per hour of vessel time in port.

Although TEUs per hour is not a measure of container handling rate and is not a direct measure of terminal efficiency, it is a measure that is needed to determine system capacity. The conversion from containers per hour to TEUs per hour is based on knowledge or assumption of the mix of container sizes involved.

For the purpose of research that requires measurement of system capacity in TEUs, four measures of cargo handling rate can be defined:

h = number of container moves made per crane by one crane working alone (base crane efficiency),

h_c = number of containers discharged and loaded per hour by all cranes assigned to a vessel during the time that a vessel is at berth,

h_b = number of TEUs discharged and loaded per hour during the time the vessel is at berth, and

h_p = number of TEUs discharged and loaded per hour of vessel time in port.

In the final analysis, it is the final measure of cargo handling rate (h_p) that determines system productivity and system costs through its effect on ship time in port. The effect of h_p on voyage costs in dollars per TEU carrying capacity is demonstrated in Figure 1. Voyage costs include fuel, vessel capital and maintenance, crew and housekeeping, and container rental. The figures are based on the following unit costs: fuel cost = $160/long ton, all vessel and crew costs = $19/day/TEU capacity, container rental = $2/day/TEU, and specific fuel consumption of 0.4 lb/shaft horsepower-hour. Vessel speeds used were 20 knots for the 2,500-TEU vessel and 18 knots for the 1,000-TEU vessel. Vessels were assumed to be discharged and loaded twice on a round trip.

The comparative costs per TEU of vessel carrying capacity for different cargo handling rates depend on vessel size. If h_p is 40 TEUs/hr, costs are less by $263/TEU for the 1,000-TEU vessel and $525/TEU for the 2,500-TEU vessel. As a percentage of total costs, these dollar values also vary with the round-trip distance. If h_p is 40 and the vessel size is 1,000 TEUs, costs are less than costs with h_p of 10 by 12 percent for a 25,000 nautical mile (nm) round trip and by 34 percent for a 5,000 nm round trip. For a 2,500-TEU vessel, these percentages are 22 and 49 percent, respectively. This is significant and would be higher if vessels discharged and loaded each container slot more than twice on a round trip.

A model for h_p can be developed and will be demonstrated later in this paper. In the model, h_p is a function of the previously defined base crane efficiency (h) and other parameters. In a case study of a container transportation system (2), the effect of variations in base crane efficiency on total costs and system capacity was found to be considerable. The total system costs (vessels, containers, and ports) for h of 10, 15, 20, and 25 containers/hr are compared in Figure 2. There is an average $200 difference, or a 20 percent increase in cost, for h = 10 over h = 25 containers/hr.

Another striking effect that can be seen from this figure is the limit of the system output. For the particular case study, h = 10 containers/hr reduced the system capacity to 50 percent of that for h = 25 containers/hr. The case study represented here is service to five Arabian Gulf ports from Europe, Japan, and the United States. The results in this figure are for direct service to all five ports. All parameters that affect the cargo handling rate were kept constant except the base crane efficiency. This figure is presented to demonstrate the effect of container handling rate on costs and system capacity.

The effect of ship and apron transfer rate on annual terminal throughput is also demonstrated by Moffatt and Nichol [Figure 3 (1)]. Note that here the time frame is terminal operating hours, not vessel hours in port, and the result is therefore somewhat obvious.

TYPICAL CONTAINER HANDLING RATE

Given the importance of container handling rates to system costs and productivity, the next step is to look at data for container handling rates. In a 1976 publication (3), the United Nations Committee for Trade and Development (UNCTAD) published such data, some of which are summarized in Figure 4. These data are the average number of containers discharged and loaded per hour of vessel time at berth (h_b) collected from 21 terminals around the world. The average rate is 442 containers per 24 hr, or 18.4 containers/hr. The range of handling

Figure 1. Effect of cargo handling rate per hour of vessel time in port (h_p) on vessel plus container costs.

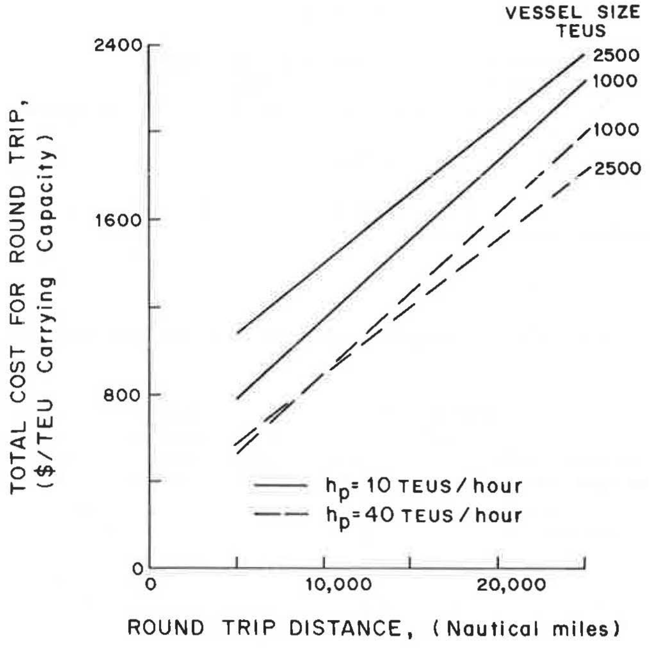
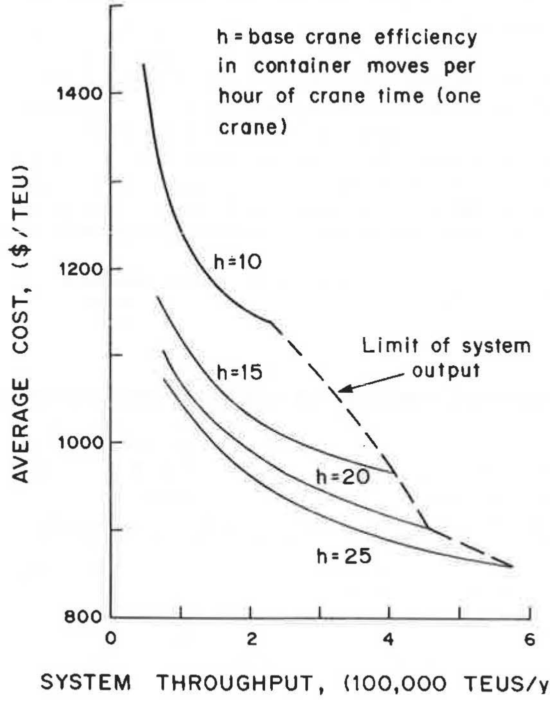


Figure 2. Variation of cost with base crane efficiency.



rates is wide, going from 9.9 to 45.4 containers/hr. All of the terminals involved had two container cranes.

A similar range of container handling rates is demonstrated in data for 1 year of operation of a two-crane container terminal in Oakland, California (Table 1). The average for the terminal is 26 containers/hr of vessel time at berth, and the range is 9.0 to 47.4 containers/hr.

Data collected from ports around the world by Plumlee (4) are also of interest. Several performance indices are defined by Plumlee:

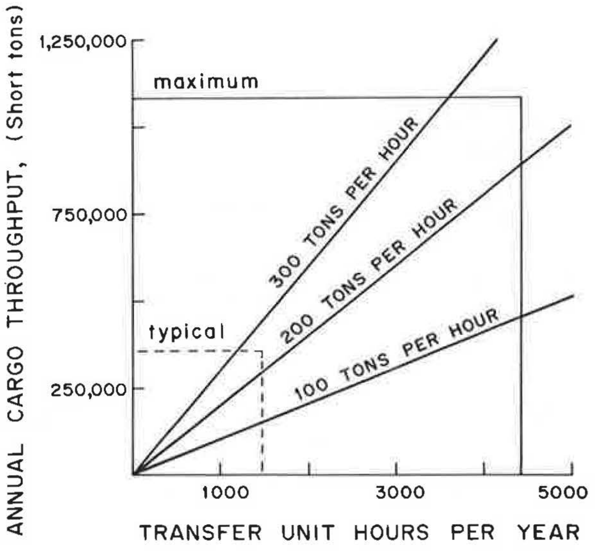
Port PI = tons of cargo loaded or discharged per hour of ship time in port,
Berth PI = tons of cargo loaded or discharged per hour of ship time at berth, and
Cargo PI = tons of cargo loaded or discharged per hour of ship net working time.

There is close similarity between these indices and the container handling rates defined earlier, except that Plumlee uses tons instead of TEUs.

Data are presented by Plumlee for ports in several categories. Large and small ports are separated, and ports in industrialized nations are separated from ports in developing nations. Table 2 (4, pp. 35-39) gives the average performance indices and the upper and lower bounds for each category. Figures are shown in tons and also converted to TEUs, assuming an average of 10 tons of cargo per TEU. This data source, like the previous two, indicates that container handling rates vary over a wide range of values. Plumlee has suggested some basis for classifying terminals, so that variation within the class (industrialized large, industrialized small, and so on) may be less.

When dealing with a widely varying parameter in a systems study, two approaches can be taken. One is to treat the parameter as a stochastic variable without investigating the reasons for the variations. The other is to model the parameter as fully as possible so that variation of the dependent variable of interest is explained by changes in other exogneous variables. These exogenous variables may in turn be predictable or may have to be treated as stochastic events. Modeling systems with stochastic events can be costly because computer simulation is often required. The researcher, therefore, has the responsibility to learn as much as possible about the factors that affect container handling rates so that deterministic models can be used insofar as this is possible. Such a deterministic model has

Figure 3. Effect of ship and apron transfer rate on annual terminal throughput.



Notes: Cargo handling rate = transfer rate, expressed in tons per hour.

Table 1. Container handling rate (h_b) at a single berth: two-crane terminal.

c	h_b	c	h_b	c	h_b
766	36.5	470	33.6	319	13.7
707	26.6	469	47.4	299	27.8
673	31.9	467	29.2	296	28.2
637	38.6	459	36.7	287	17.5
619	11.3	455	31.2	286	22.7
601	19.4	452	33.5	268	24.4
582	28.0	446	33.0	267	24.3
555	37.0	444	23.4	257	20.2
543	23.9	425	24.9	247	21.5
539	30.8	420	23.3	245	22.3
535	36.6	414	20.4	244	11.3
520	35.0	410	17.8	238	23.7
518	25.0	402	17.9	227	13.7
493	24.0	373	28.2	223	17.2
492	27.7	364	22.8	220	16.6
491	26.2	357	17.9	219	29.9
489	27.9	355	17.3	212	20.9
488	10.7	344	21.5	193	26.1
473	31.5	337	29.3	167	9.0

Note: c = number of containers discharged and loaded for one vessel.

Figure 4. Container handling rates at existing terminals.

Notes: 1. Source of data: UNCTAD (Ref 3), from a survey of 21 terminals

2. Container handling rate is expressed per hour of vessel time at berth

3. Mean handling rate = 18.4 containers discharged and loaded per hour

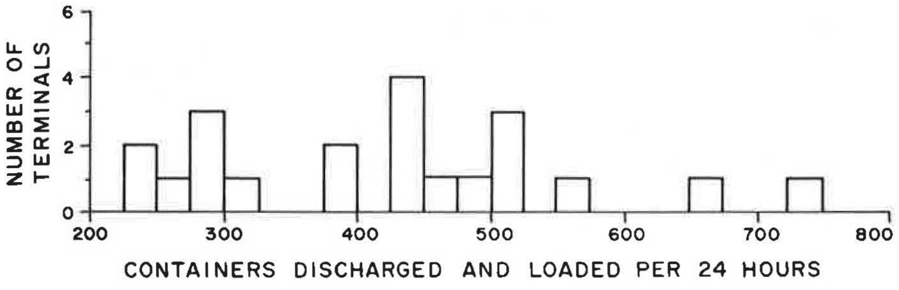


Table 2. Cargo handling rates reported by world ports.

	Cargo and Containers Loaded or Unloaded per Hour of					
	Net Ship Working Time		Ship Time at Berth		Ship Time in Port	
Port	Tons per Hour	Containers per Hour	Tons per Hour	Containers per Hour	Tons per Hour	Containers per Hour
Industrialized						
Large	202	20	219	22	152	15
Small	67	7	67	7	44	4
Developing						
Large	418	42	138	14	92	9
Small	47	5	25	3	27	3
Upper bound, all ports	555	56	436	44	402	40
Lower bound, all ports	44	4	25	3	24	2

Note: Container handling rates are calculated by assuming an average of 10 tons/container.

Table 3. Range of container handling rates per hour of vessel time at berth predicted by model.

Stage	Predicted Handling Rate (containers/hr)
One crane alone (h): lost time assumed to range from 10 to 50 percent	15-27 per crane-hour
Multiplied by the number of cranes (n), ranging from 1 to 2	15-54
Multiplied by the crane interference factor (k), where k = 0.85 for 2 cranes and 1.0 for 1 crane	15-46 per hour of working time
Multiplied by the ratio of working time to berth time, ranging from 0.4 to 0.9	6-41 per hour of berth time
Multiplied (1-R), where R (the proportion of container moves that are restow moves) ranges from 0 to 20 percent	5-41 per hour of berth time

been developed and is demonstrated in the following section.

MODELING THE CONTAINER HANDLING RATE

If n represents the number of cranes assigned to a vessel during a working period and h is the base crane efficiency as described earlier, then nh is the number of container moves per hour made during the working time. If a crane is used during only part of the working period, n can be expressed as a fraction. For example, one crane working for a full working period and a second crane working for only one-third of the working period results in n = 1.33.

Because two or more cranes working together may interfere with each other, the number of container moves made during a working period must be modified, where knh is the modified number of container moves per hour made during the working time, and k is the crane interference factor ($k = 1$ for one crane, and $k < 1$ for more than one crane).

Because the vessel time at berth is usually longer than the working time, a variable (w) is defined as the ratio of working time to berth time. Thus, knhw is the number of container moves made per hour of vessel time at berth.

Finally, because some container moves are not productive but are restow moves,

$$h_c = knhw(1 - R) \tag{1}$$

where R is the proportion of container moves that are restow moves, and h_c is the number of containers discharged and loaded during vessel time at berth.

For the purpose of transportation system analysis, the model is expanded to

$$h_b = h_c(1 + P) \tag{2}$$

where h_b is the number of TEUs discharged and loaded per hour during the vessel time at berth, and P is the proportion of containers that are 40-ft boxes (assuming only 20- and 40-ft boxes), and

$$h_p = c/(c/h_b + t) \tag{3}$$

where

h_p = number of TEUs discharged and loaded per hour during the vessel time in port,
c = number of containers discharged and loaded per port visit, and
t = time vessel spends entering and leaving port (hours).

The independent variables were arrived at through discussions with terminal operators. It was assumed that the time taken to discharge or load a 40-ft box is the same as that for a 20-ft box. Certain terms are clarified as follows:

1. The base crane efficiency is the rate that can be achieved by a single crane working alone. This reflects the efficiency of operations at the terminal. It is expressed as containers per hour of crane time.
2. Working time is the time that cranes are assigned to work on a vessel; it includes all lost time.
3. Lost time refers to unscheduled breaks in the discharge and loading process. Such breaks may be due to equipment failure, bottlenecks elsewhere in the discharge and loading process, work stoppage due to weather, and slowdown due to labor problems.
4. Idle time refers to the difference between the time a vessel is at berth and the actual working time.
5. Idle time includes scheduled work breaks, breaks between shifts, and the time a vessel is at berth before and after discharge and loading take place.

We now have a set of exogenous variables, some of which can readily be predicted, whereas others must be considered as stochastic events. A deliberate attempt has been made to separate these. For example lost time is unscheduled and largely unpredictable, whereas idle time can be predicted. Idle time depends on the working hours of a terminal, the arrival time of a vessel, and the number of containers to be discharged and loaded.

The cumulative effect of these variables on container handling rate per hour of vessel time at berth (h_b) is given in Table 3. Assuming that a container crane is capable of handling 30 container moves per hour, then allowing for lost time, number of cranes, crane interference, ratio of working time to berth time, and restow moves, results in handling rates of 5 to 41 containers/hr of vessel time at berth. This explains how the wide range of values for container handling rates occurs; by comparing this range of values with data in Table 1, the model is to some degree verified.

NEED FOR FURTHER RESEARCH

In Table 3 certain ranges of values have been assumed for the independent variables. These were arrived at through consultation with terminal operators and from the literature. The ranges are believed to be realistic, but more data and research are needed to improve the prediction of values of these variables for specific cases.

One variable that is of particular interest and is by itself a candidate for modeling is R--the proportion of restow moves. More specifically, $R = N_R/(N_R + N_{DL})$, where N_R is the number of restow moves and N_{DL} is the number of containers discharged and loaded. In earlier work (5), the percentage of restow moves was assumed to vary linearly with the number of ports of call as follows: $R\% = 3\ (n_p - 2)$, where n_p is the number of ports of call on a vessel (round trip). Data for modeling R, although undoubtedly in existence, have not been available.

Summarizing the need for further research, the following tasks are identified:

1. Develop a model for the percentage of restow moves (R),
2. Develop a model for predicting base crane efficiency (h),
3. Develop a crane assignment model [i.e., number of cranes assigned (n)], and
4. Develop a model for the ratio of working time to berth time (w).

Other variables such as proportion of containers that are 40-ft boxes (P), time spent entering and leaving port (t), and number of containers discharged and loaded per port visit (c) are specific to the kind of trade and the itinerary of the vessel.

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Handling and Storage of Empty Chassis

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The reasons that intermodalism is growing and will continue to grow are briefly outlined, and the problems inherent in current designs are discussed. One problem—the handling and storage of empty chassis—is identified. Current methods of handling and storing chassis are discussed, and new equipment, which places the chassis in a vertical position, is presented. The methods shown indicate that 65 to 700 ft^2 of land can be used per chassis. Thus, the use of land for chassis storage can vary from 60 to 650 chassis/acre. Brief reference to the economics of this new concept, and the capital investment required, is made.

The intermodal industry comprises several definite and separate individual operating sections. Air transport is an important part of intermodalism, but the intermodal industries considered in this paper are railroads, trucking firms, and water shipping; i.e., where containers and their empty chassis exist.

Each mode has its own functional and mechanical operating problems, and because an individual unit usually operates within its own forum, it often does not come in contact with the other segments. In fact, domestic intermodalism is extremely competitive and often deliberately separate.

There have been efforts at cooperation, such as through the National Railroad Intermodal Association and the Uniform Intermodal Interchange Agreement, but generally it has been each mode--rail, truck, or ship--solving its own problems. And if by chance another mode was helped, it was more by accident than by design. However, in intermodalism, sooner or later each mode comes into contact with other modes, and in doing so is forced to handle an identity that is not compatible with its original terminal design or equipment capabilities.

INTERMODAL GROWTH

The overall industry is a true material handling industry, and because the material is assembled into larger container forms, the physical problems of weight and dimensions necessitated, and still require, the recognition of specialized handling equipment. This industry, despite its rapid expansion, is young in its hardware technology.

There are many internationally recognized manufacturers of material handling equipment, such as LeTourneau, Hatachi, Drott, Raygo Wagner, and Paceco. This list does not cover the entire industry, but it does point out that many capable and competent suppliers are involved.

Thus, tools have been developed and are available to fit into the intermodal segments of the various modes. By rapidly passing over the other individual advances in this industry (i.e., container ships,