At least one section of the loading tracks of a terminal should be suitable for vertical as well as horizontal loading. The configuration should also enable the employment of the more flexible mobile equipment of the front-, side-, or overhead-loader type. This would reduce initial investment cost at the starting phase of a terminal.

The parallel employment of mobile equipment to the cranes increases flexibility in reacting to peak periods and improves terminal redundancy. This concept has been applied successfully to terminals where the equipment can otherwise be employed in additional container services (long-time empty container storage and repair).

All of these different terminal design and operational concepts can be tested and optimized with the help of simulation techniques. As pointed out earlier, the terminal cannot be treated as an isolated system. The railroad network operation must be closely coordinated with the terminal operations. Therefore, the main direction of future model development is to incorporate rail network simulation into the terminal model described here.

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Gate Requirements for Intermodal Facilities

GEORGE C. HATZITHEODOROU

Intermodal facilities require large capital and operating expenditures for their construction, maintenance, and operation. They also serve daily a large number of vehicles and containers that move in and out or through them. It is therefore imperative that an intermodal terminal operates optimally. For the purpose of this paper, optimal terminal operations imply least total cost operations; namely, that the sum of costs to the terminal operator and users is as low as possible. The optimization of the gate complex of a container terminal is considered. By using the queuing theory equation [$\rho = (\lambda/S\mu)$] and other related equations and a computer program [where λ is the arrival rate, μ is the service rate, and S is the number of servers (lanes and corresponding booths)], tables have been written for various rates of arrival (λ) and various S values for the security and for the main gate, respectively. These tables may be used as a quick way to find the required size of each gate as to the number of lanes and space required for waiting vehicles in designing new or altering existing container terminals. The marginal cost of adding (or subtracting) a lane is compared with the marginal benefit to the terminal and its users. When benefits exceed costs, then the lane is added (or subtracted). The optimum number of lanes is obtained for each gate sequentially, and thus the entire gate complex is optimized. An application of the methodology to an actual container terminal is also presented.

The big changes that containerization has brought about require careful design for new intermodal terminals. Construction of intermodal facilities requires large capital expenditures. Large sums of money are also needed for their maintenance and operations. It is therefore imperative that an intermodal terminal operates optimally. For the purpose of this paper, optimal terminal operations imply least total cost operations; namely, that the sum of the costs to the terminal operator and users is as low as possible.

Although the methodology presented here could be applied to any intermodal facility, it is assumed that the objective is to optimize the operation of a marine container terminal, hereinafter referred to as terminal. Such a terminal is an area of interface between land and water transportation modes and, for the purpose of its analysis and optimization, it can be considered as a system composed of the following three subsystems:

1. The landside [the gate entrance complex and less-than-container-load (LCL) buildings, if any],
2. The waterside (wharf and cranes), and
3. The container marshaling area, which can be considered as the link between the landside and the waterside.

The number of containers that move through the terminal, and the number of land and waterborne vehicles that use it, are factors that affect the operation of all three subsystems, as shown in Figure 1. However, for the analysis of each subsystem, additional information and data are required that may or may not be subsystem specific. Due to lack of space, the optimization of the terminal gate complex is dealt with exclusively. Throughout the paper, any point within the terminal where vehicles must stop for a transaction [weighing, vehicle inspection station (TIR), customs inspection, security check, and so on] shall be referred to as a gate.

GATE COMPLEX

One of the most important facilities in the landside of a modern terminal is the gate complex. Its adequacy and efficiency assure an uninterrupted flow of vehicles in and out of the terminal. It must be designed in such a manner so as to provide the optimum number of lanes needed at peak, or close to peak, hours of traffic through the terminal. Each lane must be reversible in direction in order to avoid overconstruction.

The number of gates that a terminal consists of may vary from terminal to terminal. For example, a terminal that exclusively handles domestic cargo will not need a customs gate. For the purpose of illustrative simplicity, it is assumed that the complex consists of two gates only.

This assumption is supported by operating practices of most major terminals in the United States, which divide their entrance gate facilities (at least for the vehicles that enter the terminal carrying containers) into a security gate and a main gate, as shown in Figure 2. The security gate is located outside of the terminal. It serves the purpose of checking the identification of the driver and the vehicle to assure the legitimacy of their visit to the terminal. The main gate is located further inside the terminal. It serves the purpose of completing the transaction for the transfer of responsibility for cargo and equipment, which includes weighing the vehicle and checking the accompanying papers.

Figure 1. Flow diagram for optimization of a container terminal.

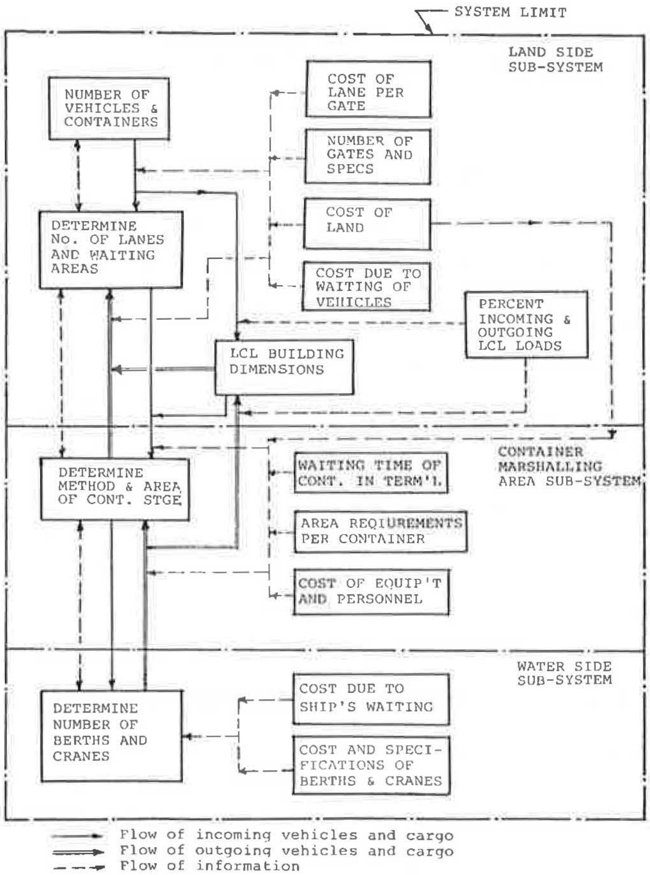
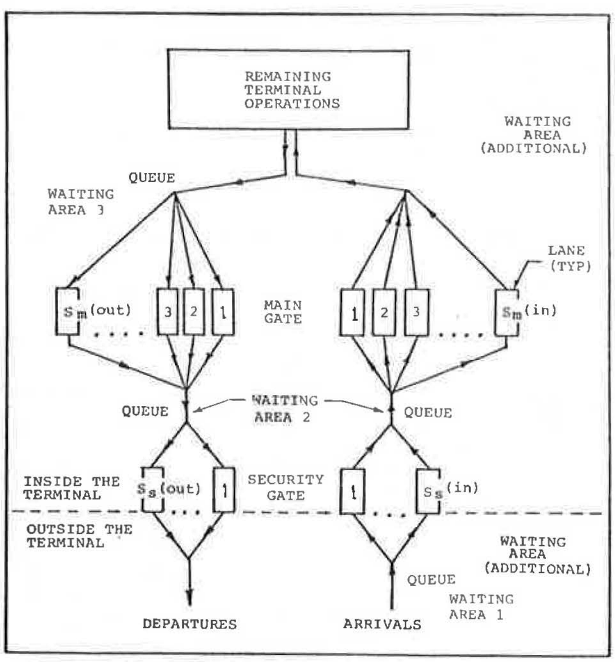


Figure 2. Terminal gate flow representation.



The purpose of the procedure that follows is to determine the number of lanes and waiting areas required at each gate (security and main) for a variety of traffic volumes. It is assumed that the gates are reversible and that there is no delay in terminal operations caused by space unavailability, seasonal variations, cargo handling equipment, personnel, and other factors. The following conditions also are assumed:

1. The traffic generated at the gate and the checking time required are independent of the container handling and marshaling system or systems within the yard and the sizes and types of containers accepted by the terminal;
2. With the exception of service and private vehicles, the gate complex serves all exiting vehicles; empty containers and bobtails (tractors without trailers) use separate entrances, which do not affect the design;
3. The arrivals of vehicles are random and Poisson distributed; and
4. The service rate at both gates is random and exponentially distributed.

DESIGN BY QUEUEING THEORY

The above assumptions, which have been verified with actual time measurements at a major terminal, indicate that a queuing model would be ideal for the situation depicted in Figure 2.

According to the queuing theory, delays and queues at a service station depend mainly on the following ratio:

$$\rho = \lambda/S\mu \tag{1}$$

where

λ = arrival rate,
μ = service rate, and
S = number of servers.

As ρ approaches 1, service deteriorates rapidly, and when $\rho = 1$, there is a complete service breakdown with infinitely long queues and delays.

For instance, if each lane of a main gate serves 1 vehicle every 5 min, or 12 vehicles/hr, and vehicles arrive at the rate of 100/hr, then at least 9 service lanes are required [100/12 = 8.88]. Eight lanes would serve up to 96 vehicles, which is less than the arrival rate, and will make $\rho = 1.04$.

As a general rule, ρ should never be allowed to exceed (roughly) the value of 0.9. Also, letting ρ fall below 0.5 will make the service facilities unnecessarily underused, as will be seen later.

The probability that a facility is idle is

$$P_o = 1/\left\{\sum_{n=0}^{S-1} [(\lambda/\mu)^n/n!] + [(\lambda/\mu)^S/S!] \cdot [1/(1-\rho)]\right\} \tag{2}$$

The total time (in minutes) that a unit (vehicle) spends in the system (waiting and in service) is

$$T = [P_o\,(\lambda/\mu)^S/S!\,(1-\rho)^2\,\mu S] + (1/\mu) \tag{3}$$

The total number of units in the system (being served and queued up) is

$$L = \left\{[P_o\,(\lambda/\mu)^S \cdot \rho]/S!\,(1-\rho)^2\right\} + (\lambda/\mu) \tag{4}$$

COMPUTATIONS AND RESULTS

A computer program was written in order to perform the calculations necessary for obtaining P_o, T, and L as shown in Equations 2-4 for arrival rates

(λ) between 60 and 180 vehicles/hr in increments of 10 and for a variety of service lane numbers for the security and main gates.

The computation results are tabulated in Tables 1-3. The output variable (T_t) is the total time (in minutes) that a vehicle needs to pass through both gates (waiting time included) as it enters or leaves the terminal.

The waiting areas listed in Tables 1-3 are as follows:

1. The area required to accommodate the queue of the entering vehicles in front of the security gate (outside the terminal);
2. The area required to accommodate the queues between the two gates, i.e., exiting vehicles waiting before the security gate and entering vehicles waiting before the main gate; and
3. The area required to accommodate the queue of the exiting vehicles before the main gate (inside the terminal).

Table 1 is produced under the assumption that the security gate consists of 3 lanes and the main gate

Table 1. Values for waiting line at entrance of container terminal as function of arrivals or departures of vehicles (λ), with values set at 3 lanes for gate A and 14 lanes for gate B.

Arrivals or Departures, λ (vehicles/hr)	Entering									Exiting											
	Gate A				Gate B					Gate B				Gate A					Waiting Areas		
	ρ	L	T	P_o	ρ	L	T	P_o	T_t	ρ	L	T	P_o	ρ	L	T	P_o	T_t	1	2	3
60	0.333	1.1	1.2	30.8	0.357	5.0	5.0	0.67	6.17	0.357	5.0	5.0	0.67	0.333	1.1	1.2	30.8	6.17	1	6	5
70	0.389	1.3	1.2	25.2	0.417	5.8	5.0	0.29	6.23	0.417	5.8	5.0	0.29	0.389	1.3	1.2	25.2	6.23	1	7	6
80	0.444	1.6	1.3	20.7	0.476	6.7	5.0	0.13	6.31	0.476	6.7	5.0	0.13	0.444	1.6	1.3	20.7	6.31	2	8	7
90	0.500	1.9	1.4	17.0	0.536	7.6	5.0	0.05	6.42	0.537	7.6	5.0	0.05	0.500	1.9	1.4	17.0	6.42	2	9	8
100	0.556	2.2	1.5	13.9	0.595	8.5	5.1	0.02	6.51	0.595	8.5	5.1	0.02	0.556	2.2	1.5	13.9	6.57	2	11	8
110	0.611	2.6	1.6	11.3	0.655	9.4	5.2	0.01	6.79	0.655	9.4	5.2	0.01	0.611	2.6	1.6	11.3	6.79	3	12	9
120	0.667	3.1	1.8	9.1	0.714	10.6	5.3	0	7.12	0.714	10.6	5.3	0	0.667	3.1	1.8	9.1	7.12	3	14	11
130	0.722	3.7	2.1	7.2	0.774	12.0	5.6	0	7.65	0.774	12.0	5.6	0	0.722	3.7	2.1	7.2	7.65	4	16	12
140	0.778	4.7	2.5	5.5	0.833	14.0	6.1	0	8.57	0.833	14.0	6.1	0	0.778	4.7	2.5	5.5	8.57	5	19	14
150	0.833	6.2	3.2	3.9	0.893	17.7	7.2	0	10.44	0.893	17.7	7.2	0	0.833	6.2	3.2	3.9	10.44	6	24	18
160	0.889	9.2	4.7	2.5	0.952	29.5	11.5	0	16.22	0.952	29.5	11.5	0	0.889	9.2	4.7	2.5	16.22	9	39	30
170	0.944	18.2	9.1	1.2	1.010	∞	∞	0	∞	1.010	∞	∞	0	0.944	15.2	7.6	1.5	∞	18	∞	∞
180	1.000	∞	∞	0	1.070	∞	∞	0	∞	1.070	∞	∞	0	1.000	15.2	7.6	1.5	∞	∞	∞	∞

Table 2. Values for waiting line at entrance of container terminal as function of arrivals or departures of vehicles (λ), with values set at 3 lanes for gate A and 15 lanes for gate B.

Arrivals or Departures, λ (vehicles/hr)	Entering									Exiting											
	Gate A				Gate B					Gate B				Gate A					Waiting Areas		
	ρ	L	T	P_o	ρ	L	T	P_o	T_t	ρ	L	T	P_o	ρ	L	T	P_o	T_t	1	2	3
60	0.333	1.1	1.2	30.8	0.333	5.0	5.0	0.67	6.17	0.333	5.0	5.0	0.67	0.333	1.1	1.2	30.8	6.17	1	6	5
70	0.389	1.3	1.2	25.2	0.389	5.8	5.0	0.29	6.23	0.389	5.8	5.0	0.29	0.389	1.3	1.2	25.2	6.23	1	7	6
80	0.444	1.6	1.3	20.7	0.444	6.7	5.0	0.13	6.30	0.444	6.7	5.0	0.13	0.444	1.6	1.3	20.7	6.30	2	8	7
90	0.500	1.9	1.4	17.0	0.500	7.5	5.0	0.05	6.40	0.500	7.5	5.0	0.05	0.500	1.9	1.4	17.0	6.40	2	9	7
100	0.556	2.2	1.5	13.9	0.556	8.4	5.0	0.02	6.53	0.556	8.4	5.0	0.02	0.556	2.2	1.5	13.9	6.53	2	11	8
110	0.611	2.6	1.6	11.3	0.611	9.3	5.1	0.01	6.71	0.611	9.3	5.1	0.01	0.611	2.6	1.6	11.3	6.71	3	12	9
120	0.667	3.1	1.8	9.1	0.667	10.3	5.2	0	6.97	0.667	10.3	5.2	0	0.667	3.1	1.8	9.1	6.97	3	13	10
130	0.722	3.7	2.1	7.2	0.722	11.4	5.3	0	7.38	0.722	11.4	5.3	0	0.722	3.7	2.1	7.2	7.38	4	15	11
140	0.778	4.7	2.5	5.5	0.778	12.8	5.5	0	8.03	0.778	12.8	5.5	0	0.778	4.7	2.5	5.5	8.03	5	17	13
150	0.833	6.2	3.2	3.9	0.833	14.7	5.9	0	9.17	0.833	14.7	5.9	0	0.833	6.2	3.2	3.9	9.17	6	21	15
160	0.889	9.2	4.7	2.5	0.889	18.1	6.9	0	11.58	0.889	18.1	6.9	0	0.889	9.2	4.7	2.5	11.58	9	27	18
170	0.944	18.2	9.1	1.2	0.944	27.3	10.0	0	19.10	0.944	27.3	10.0	0	0.944	18.2	9.1	1.2	19.10	18	45	27
180	1.000	∞	∞	0	1.000	∞	∞	0	∞	1.000	∞	∞	0	1.000	∞	∞	0	∞	∞	∞	∞

Table 3. Values for waiting line at entrance of container terminal as function of arrivals or departures of vehicles (λ), with values set at 3 lanes for gate A and 16 lanes for gate B.

Arrivals or Departures, λ (vehicles/hr)	Entering									Exiting											
	Gate A				Gate B					Gate B				Gate A					Waiting Areas		
	ρ	L	T	P_o	ρ	L	T	P_o	T_t	ρ	L	T	P_o	ρ	L	T	P_o	T_t	1	2	3
60	0.333	1.1	1.2	30.8	0.312	5.0	5.0	0.67	6.17	0.312	5.0	5.0	0.67	0.333	1.1	1.2	30.8	6.17	1	6	5
70	0.389	1.3	1.2	25.2	0.365	5.8	5.0	0.29	6.23	0.365	5.8	5.0	0.29	0.389	1.3	1.2	25.2	6.23	1	7	6
80	0.444	1.6	1.3	20.7	0.417	6.7	5.0	0.13	6.30	0.417	6.7	5.0	0.13	0.444	1.6	1.3	20.7	6.30	2	8	7
90	0.500	1.9	1.4	17.0	0.469	7.5	5.0	0.05	6.39	0.469	7.5	5.0	0.05	0.500	1.9	1.4	17.0	6.39	2	9	8
100	0.556	2.2	1.5	13.9	0.524	8.4	5.0	0.02	6.51	0.524	8.4	5.0	0.02	0.556	2.2	1.5	13.9	6.51	2	11	8
110	0.611	2.6	1.6	11.3	0.573	9.2	5.0	0.01	6.67	0.573	9.2	5.0	0.01	0.611	2.6	1.6	11.3	6.67	3	12	9
120	0.667	3.1	1.8	9.1	0.625	10.1	5.1	0	6.90	0.625	10.1	5.1	0	0.667	3.1	1.8	9.1	6.90	3	13	10
130	0.722	3.7	2.1	7.2	0.677	11.1	5.1	0	7.24	0.677	11.1	5.1	0	0.722	3.7	2.1	7.2	7.24	4	15	11
140	0.778	4.7	2.5	5.5	0.729	12.3	5.3	0	7.78	0.729	12.3	5.3	0	0.778	4.7	2.5	5.5	7.78	5	17	12
150	0.833	6.2	3.2	3.9	0.781	13.6	5.5	0	18.70	0.781	13.6	5.5	0	0.833	6.2	3.2	3.9	8.70	6	20	14
160	0.889	9.2	4.7	2.5	0.833	15.5	5.9	0	10.53	0.833	15.5	5.9	0	0.889	9.2	4.7	2.5	10.53	9	25	15
170	0.944	18.2	9.1	1.2	0.885	18.6	6.7	0	15.78	0.885	18.6	6.7	0	0.944	18.2	9.1	1.2	15.78	18	37	19
180	1.000	∞	∞	0	0.937	26.1	9.0	0	∞	0.937	26.1	9.0	0	1.000	∞	∞	0	∞	∞	∞	26

of 14. As ρ increases and approaches 1, the queues, delays, and waiting area requirements increase drastically and P_o drops quickly to zero. When λ reaches 180 (ρ = 1), the service breaks down completely.

When the number of service lanes is increased to 3 and 15, the terminal can handle up to 170 arrivals or departures and service breaks down at λ = 180, as can be seen in Table 2.

It is therefore imperative that all gates operate close to the same value for ρ, because improving service conditions in one of them alone will simply create bottlenecks in the other. In general, the ratio of the number of service lanes in each facility should be equal to the inverse ratio of their service rates; namely, $(S_s/S_m) = (\mu_m/\mu_s)$, where s refers to the security gate and m to the main gate. For the case in discussion, $(\mu_m/\mu_s) = (12/60) = (1/5)$. Therefore, the number of main gate lanes should be five times that of the security gate lanes.

If the relation $(S_s/S_m) = (\mu_m/\mu_s)$ does not hold, then service at one of the gates will break down before the other, as indicated in Tables 1 and 3, where the security and main gate lanes are 3 and 14, and 3 and 16, respectively.

All of the above calculations were made for constant rates of arrival, which should be the peak demand for the terminal regardless of time of day, day of the week, or season of the year during which it occurs.

OPTIMIZATION OF GATE COMPLEX

With the aid of Tables 1-3 it is now possible to optimize the operation of the gate complex, i.e., to determine the number of lanes at each gate that will minimize the overall cost for the terminal operators and users. The flow diagram of the optimizing algorithm is presented in Figure 3. Starting at the first gate and given the arrival rate (λ) and the service rate (μ) per lane, the number of lanes (S) is determined in such a way that $\rho = (\lambda/S\mu) \approx 0.9$. Then an attempt is made to reduce or increase the number of lanes by one. If the overall savings (S) from the subtraction or addition of the lane are greater than the overall costs (C), then the action is taken and further subtractions or additions are investigated. Otherwise, the analysis proceeds with the next gate until the lane requirements for all gates have been determined.

The lane subtraction or addition is determined by the following factors:

1. The difference in total annual cost from the delay of vehicles (Δ_{CT}), which may be expressed as follows:

$$\Delta_{CT} = \pm [\Sigma V_i \cdot T_i \cdot HW \cdot D \cdot CD \cdot (1/60)]_S \mp [\Sigma V_i \cdot T_i \cdot HW \cdot D \cdot CD \cdot (1/60)]_{S\pm 1} \quad (5)$$

where

V_i = number of vehicles that pass through gate i,
T_i = average delay at gate i (min),
HW = number of working hours per day,
D = number of work days per year, and
CD = cost of delay per vehicle per hour.

When adding a lane, the upper signs are used and the value of Equation 5 shows the yearly difference of savings from the decrease in delays. When subtracting a lane, the lower signs are used, and Equation 5 shows the yearly difference in cost from an increase in delays. Therefore, the value of Equation 5 is always positive.

2. The difference in total annual cost of land for the waiting areas, which may be expressed as follows:

$$\Delta_{CL} = \pm (\Sigma Q_i \cdot A \cdot CL)_S \mp (\Sigma Q_i \cdot A \cdot CL)_{S\pm 1} \quad (6)$$

where

Q_i = average queue of waiting vehicles in gate i,
A = area occupied by one vehicle, and
CL = cost of land per unit area.

The upper signs are for the addition of a lane, and the lower signs for the subtraction. Therefore, the value of Equation 6 is always positive and shows the yearly savings when a lane is added and the yearly cost when a lane is subtracted.

3. The difference in total annual cost of the idling gates (Δ_{CIG}), which may be expressed as follows:

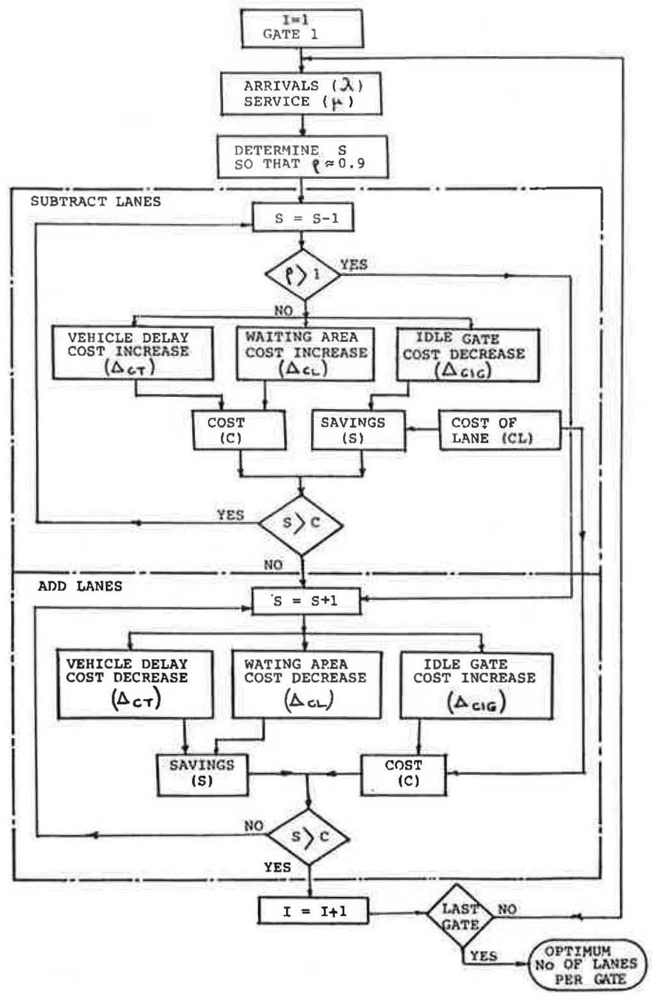
$$\Delta_{CIG} = \mp (\Sigma P_{oi} \cdot S_i \cdot CPL_i)_S \pm (\Sigma P_{oi} \cdot S \cdot CPL_i)_{S\pm 1} \quad (7)$$

where

P_{oi} = percentage that gate i will be idle,
S_i = number of lanes in gate i, and
CPL_i = cost of each lane in gate i.

Noteworthy is the fact that Equation 5 refers to users of the terminal, whereas Equations 6 and 7

Figure 3. Flow diagram of algorithm for analysis and optimization of landside subsystem of a container terminal.



refer to the management of the terminal. Also, Equations 5 and 6 move as a function of the number of lanes in a direction opposite of that of Equation 7. When lanes are added, the savings that result for users from Equation 5 and for the terminal from Equation 6 increase, whereas Equation 7 shows increasing cost for the terminal. When lanes are subtracted, the increasing costs for the users and the terminal are shown by Equations 5 and 6, whereas Equation 7 shows the increasing savings for the terminal.

4. The cost of the added or subtracted lane is a function of the cost of its construction and maintenance, the salaries of its personnel, and all of its necessary equipment. The cost must also be taken into consideration.

The four cost components presented here are summarized schematically in Figure 4. The optimal number of lanes in a gate is the one that produces the smallest total cost for the terminal and its users.

NUMERICAL EXAMPLE

For this example, the algorithm of Figure 3 will be applied to the situation depicted in Figure 2. Observations and time measurements made at a major container terminal of the Port of New York gave a service rate (μ) of 12 vehicles/hr for gate B (main gate) and 60 vehicles/hr for gate A (security gate). Assuming an arrival rate (λ) of 160 vehicles/hr, the lane requirements for $\rho \approx 0.9$ become

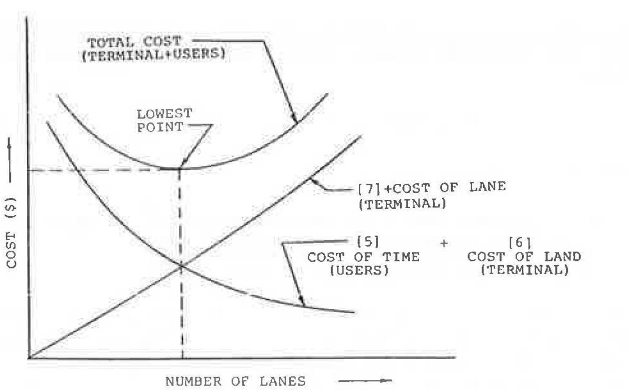
$S = 160/(0.9 \times 12) = 14.81$, or 15 lanes for gate B,

and

$S = 160/(0.9 \times 60) = 2.96$, or 3 lanes for gate A.

At this point we must examine the possibility of adding or subtracting one lane in gate B.

Figure 4. Cost of gate activities of container terminal as function of number of lanes in gate.



Note that the reduction to 14 lanes at the main gate is permissible because if S = 14, then ρ = 0.952, which is less than 1. In the case of gate A, the reduction by one lane in gate A (S = 2) is impossible because ρ = 1.33.

The table below gives the necessary information extracted from Tables 1-3. [Note that the table gives the results from varying the number of lanes (S) by 1 for gate B (main gate); arrival and departure frequency (λ) is taken as 160 vehicles/hr].

No. of Lanes (main gate)	Total Time (min)	No. of Waiting Places	Idle Gate Time (%) Gate A	Gate B
14	16.22	44	2.5	0.0
15	11.58	18	2.5	0.0
16	10.53	11	2.5	0.0

The total time corresponds to the total time a vehicle needs to pass through both gates A and B. The waiting places are the total number of places that correspond to the numbers of waiting vehicles shown in Tables 1-3, minus the number of corresponding lanes, because Equation 4, which refers to the number of units (vehicles) in the system, counts the waiting vehicles as well as those being served. The percentage of time that a gate remains idle is the probability P_0.

It is apparent from the above table that, by increasing the number of lanes, the total passing time and the necessary waiting time are decreasing. The percentage of idle time varies also but not to the accuracy of decimals shown in Tables 1-3. Therefore, by adding a lane, the cost for waiting decreases but the cost of service increases.

Furthermore, suppose that the marginal cost of one lane is $40,000/year and we want to find out if the addition or the subtraction of one lane in gate B is economically justified. Also assume that

1. The terminal gate works 260 days/year and 8 hr/day,
2. Each vehicle needs an area of 500 ft² (10x50 ft),
3. The cost of land is $2.00/ft²/year, and
4. Vehicle delay costs are $20.00/hr.

Table 4 is based on the basis of the above assumptions. As can be seen in this table, the total marginal savings of service from adding one lane is $123,480, and the total marginal cost from subtracting it is $90,341. Because the cost of the lane is $40,000, the lane should not be subtracted. However, the addition of a lane is economically justified because the marginal savings are greater than the marginal cost.

To complete the analysis, one should investigate whether one more lane should be added. All remaining gates in the terminal should be examined with the same method. The landside will operate optimally when the analysis of all gates is completed.

Table 4. Costs or benefits from adding or subtracting one lane.

Item	No. of Lanes	Total Time (min)	Waiting Places	Difference in Time per Vehicle	Difference in Space	Yearly Cost for Time Difference[a] ($)	Yearly Cost for Land Difference[b] ($)	Yearly Cost for Difference of P_0 ($)	Total Cost of Difference[c] ($)
Base	15	11.58	18	0	0	0	0	0	0
Addition	16	10.53	11	-1.05	-7	-116,480	- 7,000	0	-123,480
Subtraction	14	16.22	44	+4.64	+26	+ 64,341	+26,000	0	+ 90,341

[a]Yearly cost for time difference = [(difference in time per vehicle x 160 x 8 x 260)/60] x $20.
[b]Yearly cost for land difference = difference in space x 500 x $2.
[c]Total cost of difference = yearly cost for time difference + yearly cost for land difference + yearly cost for difference of P_0.

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

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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: