TANDEM: Marine and Rail Container Terminal Simulation Model

PETER J. WONG, ANDREW R. GRANT, AND ROBERT G. CURLEY

SRI International's terminal analysis, design, and evaluation model (TANDEM) is a computer-based tool that assists designers in the planning, design or rehabilitation, and operational evaluation of marine or rail container terminal facilities. The unique characteristics of each terminal facility dictate that engineering judgment and past experience be augmented by systematic analysis methods such as TANDEM. The use of TANDEM permits the designer to evaluate and explore alternative designs and methods of operation for intermodal terminals so that the optimum design can be selected. An example is presented of the use of TANDEM to determine the effect of a change from a two-ship-a-week to a three-ship-a-week schedule on operations at a hypothetical terminal.

In the 1950s, full container ships were introduced and the use of trailers-on-flatcars (TOFCs) and containers-on-flatcars (COFCs) became widespread. To take advantage of the economies made possible by these intermodal operations, ports, shipping lines, and railroads modified their old facilities or designed and constructed new ones. Little prior experience existed at that time to guide designers, and tools for economical iterative analysis of design alternatives were unavailable. The manner of conducting operations changed constantly as improved methods evolved through experience. Consequently, most existing intermodal facilities have been designed--unwittingly but necessarily--for less-than-optimum operational and economic results.

The cost of rehabilitating an old container terminal facility or constructing a new facility can be tens of millions of dollars. Furthermore, after the facility has been constructed or modified, its design will influence operations, and hence the profit and loss of the operating company, for decades. Thus, design trade-off analysis and operations planning studies must be performed before construction or modification to ensure that the design will meet forecast demands.

Engineering judgment and experience in designing similar terminal facilities have been the primary bases for designing a new terminal. In many instances, however, because of different land constraints and traffic demands, terminal facilities must be custom-tailored. Engineering judgment and experience therefore must be supported by systematic analysis methods.

To provide analytical support for terminal design decisions, some designers developed rules-of-thumb that were encoded into simple formulas, tables, or graphs. For example, Frankel and Liu (1) developed simple formulas to estimate the requirements for a marine terminal storage area and the number of pier cranes as a function of traffic to be handled by the terminal.

The modern computer now enables the terminal designer to develop a model of a proposed terminal design and to perform experiments and modify the design rapidly. The terminal designer thus can use the computer model to develop the optimum design for a particular site location and traffic condition. Such a computer simulation model--the terminal analysis, design, and evaluation model (TANDEM)--which is useful for the design, rehabilitation, or operational improvement of either a marine container or a rail piggyback terminal, is described in this paper.

DESIGN AND OPERATIONAL TRADE-OFF ISSUES

The fundamental issue in terminal design is to ensure that the capacity is sufficient to handle the projected demand. Beyond that basic consideration are many design and operational trade-off issues that must be addressed in the planning or rehabilitation of a terminal. These issues concern

1. Storing containers on chassis or stacking,
2. Basic terminal operating method,
3. Terminal layout, and
4. Quantity and types of materials handling equipment.

Often the trade-off is between a capital-intensive design with lower operating costs and a less-capital-intensive design with higher operating costs.

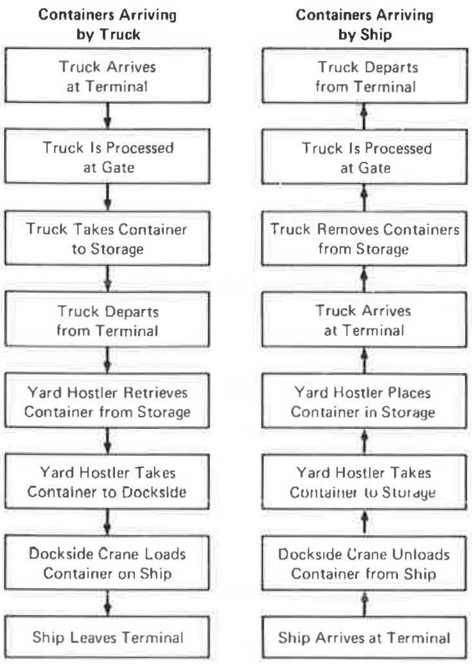
In many cases, land is extremely expensive or its availability is limited. Consequently, a major consideration is whether the containers are to be stored on chassis or whether they are to be stacked and how high. The chassis system is the least complicated and least expensive to operate; the relative capital investment in land and chassis, however, is high. Alternatively, the stacking system is more complicated and can be more expensive to operate unless automated, and it requires more expensive materials handling equipment; but, the relative land costs are less. In many situations, the land constraints dictate the method of operation.

Once the decision to store on chassis or to stack has been made, many alternative operational methods are available that apply different layouts and need different operational equipment to accomplish the same end. For example, in the chassis system, the highway tractors can move directly to and from the dockside (or railside) to pick up or deliver containers, or the highway tractors can stop in a temporary parking area to transfer the container and chassis to a yard hostler. In the latter alternative, the operational consideration is to minimize the movement of highway tractors within the terminal area because the drivers' lack of familiarity with the terminal layout might cause disruption of operations.

In a stacking operation, movements between the dockside (or railside), the storage area, and the gate can be accomplished with various types and combinations of materials handling equipment, including jib cranes, gantry cranes, transtainers, straddle carriers, side-loaders, and yard hostlers. [For example, Matson Terminals, Inc., has designed a highly automated and sophisticated stacking system for its facilities at the Port of Richmond and the Port of Los Angeles (2).]

Fouliard (3) analyzed the operation of four types of materials handling systems for a hypothetical terminal, Port Utopia. This article is useful as a guide for evaluating and selecting a materials handling system. The circumstances that favor the recommended materials handling system for Port Utopia, however, may or may not apply to a specific terminal because of different land and labor costs, availability of capital, and the operating and service philosophy of the operating company.

Figure 1. Example of processing in a marine terminal.



The trade-off issues in the design and operation of a terminal clearly are complex; each terminal must be analyzed in its own right. Because design and operational decisions can affect the financial performance of the operating company well into the future, the designer must use the best analytical tools available. The use of a computer simulation model enables the designer to try alternative designs in the computer and select the best alternative. In this way, the likelihood that the most cost-effective and efficient design will be developed is maximized.

DESCRIPTION OF TANDEM

The operations of a terminal can be viewed abstractly as the processing of containers through various queues (e.g., waiting area, storage area) by servers (e.g., gate, materials handling equipment). The network of queues and servers corresponds to the processing of containers to and from the gate and the ship (or railcar), as depicted in Figure 1. Such an abstract representation is called a queuing system. The computer simulation language [general purpose simulation system (GPSS)] was originally developed by IBM to easily construct models that could be represented as a queuing system. The TANDEM model is constructed by using GPSS and is a fully stochastic model to account for randomness in processing rates, traffic demand, and the like.

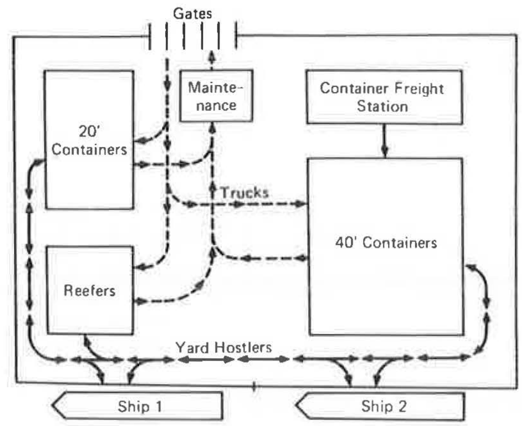
Types of Containers

TANDEM is capable of monitoring the processing of and requirements for many separate categories of containers; e.g., 20- and 40-ft containers, refrigerated containers (reefers), flats, and containers for dangerous cargo. The user can specify up to 16 different container types in the model.

Terminal Layout

To represent the terminal layout in TANDEM, the designer identifies all the activity areas in the terminal; these include dockside (railside), storage areas for various types of containers, container freight station (CFS), and gates. The designer must specify the average travel distance from the center of gravity of each activity area to that of every other activity area. This travel distance must reflect the specified route of travel, which depends on the planned traffic circulation pattern (see Figure 2).

Figure 2. Sample layout of marine terminal.



Inaccuracies arise when the travel distance to the center of gravity of a large storage area is used to represent the travel distance to a particular spot; the inaccuracies can be compensated for in TANDEM in one of two ways. First, the storage area can be subdivided into smaller areas so that the travel distance to the center of gravity more nearly represents the travel distance to any spot in the storage area. As the number of storage areas increases, however, the computer requirements also increase exponentially. At one extreme, each spot can be represented as a separate storage area in the model; in this case, the computer requirements would be considerable. The other way to overcome the inaccuracy problem is to add or subtract a random component to or from the average travel distance to represent the distance associated with traveling to a random spot in the storage area.

In the marine version of TANDEM, the position of the dockside crane is essentially represented as a stationary point on the dock. In the rail version, the position at which containers (or trailers) are removed from the train is represented as a moving point along the railside.

Processing Rates and Specification of Materials Handling Equipment

The number of entry and exit gates must be specified. The processing rates of highway vehicles at the entry and exit gates are represented by probability distributions, which must reflect not only nominal processing rates but also occasional lost papers.

The user must specify the quantity and types of materials handling equipment. The capability must be specified for each type. The user specifies the capability of stationary materials handling equipment, such as dockside cranes, in terms of a container lifting or cycle rate. The capability of mobile materials handling equipment, such as yard hostlers, is specified in terms of a container lifting or cycle rate and the speed along the ground. If containers are to be stacked in storage, a random component must be added to the basic cycle rate to account for the time necessary to access the container in the stack; the position of the container is also chosen randomly. A randomness can also be added to the average travel time of the materials handling equipment to account for random delay due to conflicts in the traffic pattern.

The user also must specify the operational strategy for the materials handling equipment. In a specialized operation, one type of equipment might operate from the dockside (railside) to the storage area, and another type might operate from the storage area to a point of transfer to a highway tractor. Alternatively, an operation might be specified in which all pieces of equipment can work throughout the terminal. The specialization of equipment is specified in terms of the routes and activity areas where the equipment can work.

Terminal Demand and Traffic

The TANDEM user specifies the arrival schedule of ships (or trains) into the terminal and the total container-carrying capacity of each ship (or train) by container type.

The number of trucks arriving at the terminal during each time increment of the day (currently at 10-min increments) must be specified. For each arriving truck, the user indicates the container type and the assigned departing ship (or train).

TANDEM begins with an empty terminal. The container inventory is built up over the first few days of arriving and departing ships (or trains) and trucks. Output statistics are therefore meaningful only after buildup of the inventory.

The active elements in the TANDEM model are computer entities that represent the physical entities in the system being simulated, that is, trucks, materials handling equipment, ships (or trains), and containers. The program generates these entities at the proper moment in simulated time and then proceeds in a manner that simulates the handling of the physical entities in the real system. The program prescribes the events that will take place and the length of simulated time needed for the appropriate action. For instance, the computer entity that represents a truck would be generated to appear at the entry gate at a particular simulated time. The truck would spend some time there for processing and then might proceed to the storage area, taking a certain amount of simulated time to do so. Whatever action was taken at the storage area would take additional simulated time. The disposition of the truck would depend on the overall situation at the time, as determined by the program. The operating rules are built into the program, with varying levels of choice available at each moment and place in the program.

Output Statistics and Utilization Reports

The TANDEM model provides utilization statistics for each type of materials handling equipment, both stationary and mobile. By adjusting the quantity and types of equipment, the user can determine the optimum number and mix of equipment to keep the equipment utilization rate high and still process containers through the terminal in a timely manner.

Statistics are provided on the use of storage for each type of container. This information will enable the user to determine the optimum storage space for each category of container.

TANDEM provides information on the total terminal detention time of each type of container. Furthermore, the time waiting in storage or in a queue waiting to be processed is indicated.

The time to load or unload a ship (or train) is output from the model. Also indicated are the waiting time of highway tractors and where they are waiting.

USING THE MODEL: PARAMETRIC ANALYSIS

TANDEM simulates in the computer the operation of the terminal as specified by the input data. Each run of the model is a performance evaluation of a particular set of terminal design and operational characteristics. Thus, to find the optimum set of terminal characteristics, the user must make a series of runs in which the input parameters are varied systematically. This process is called parametric analysis or sensitivity analysis.

In parametric analysis, the designer must establish criteria for terminal improvement; this is likely to include cost calculations performed manually by using model data. The designer makes small incremental changes to the model input parameters and evaluates the results. The direction and magnitude of change in a parameter for the subsequent model run are dictated by the change in terminal improvement from the preceding model run. When no further improvement can be obtained, the model provides the optimum terminal characteristics.

By varying the appropriate parameters to the model, numerous questions concerning the terminal design and operation can be answered, including,

1. How much space is needed for containers? How much space is required for each category of container?
2. What type and how many of each type of materials handling equipment should be provided?
3. What should be the terminal layout?
4. How many cranes are needed?
5. What is the effect of work shift variations?
6. Can the results be improved by changing the arrival rates or the arrival patterns of trucks or by varying the schedules of ships (or trains)?
7. What is the effect of irregularity in ship (or train) arrivals?
8. What is the effect of changes in operating procedures, such as storing on the ground instead of on chassis?
9. How many entry and exit gates are needed?

The TANDEM program requires a GPSS V package on the computer. On a CDC 6400 or the equivalent, the cost of a complete run for a given set of operating parameters would be between $15 and $35, depending on the number of entities involved and the length of the simulated time period.

CASE STUDY OF HYPOTHETICAL TERMINAL FACILITY

Central Bay Terminal is operated by a large shipping company. The company is interested in determining the effect on the terminal of changing from a two-ship-a-week schedule to a three-ship-a-week schedule, where each ship has a capacity of 700 containers.

The terminal has two berths and two dockside cranes. Containers are stored on chassis. Three types of container storage areas are provided in Central Bay Terminal: 40-ft containers, 20-ft containers, and reefers. The terminal has six gates, which can be used interchangeably as entry and exit gates, depending on demand. The maintenance facility has three lanes where departing trucks with containers can check gasoline, oil, tire pressures, and the like before arriving at the exit gate. Figure 3 is an approximate layout of the hypothetical terminal.

After processing and checking for bad papers at the gate, inbound trucks are directed to a proper storage spot where they either unload or pick up a container (and chassis); then they leave the yard via an exit gate. (We assume that the percentage of trucks that both off-load and on-load a container on the same trip to the terminal is low.) Trucks do not serve the ships directly; yard hostlers are used to move containers between the storage areas and the ships. A container arriving by ship is placed on a chassis, which is brought to the ship by a yard hostler; the yard hostler then moves the container to a storage location. Containers to be shipped out are picked up by a yard hostler and delivered to the ship, at which point the container is removed from the chassis and the chassis is returned to a storage area. Off-loading and on-loading activities at the ship proceed simultaneously as soon as a sufficient number of containers have been off-loaded so that space is available for containers to be on-loaded.

We assume that containers begin arriving at the terminal about 6 days before the arrival of the assigned ship and that the arrival rate increases inversely with the time remaining until the ship arrives. (The container arrival rate increases rapidly as the ship's arrival time nears.) Container types are determined randomly, but we assume that about 65 percent are 40-ft containers, 25 percent are 20-ft containers, and the remaining 10 percent are reefers. Figure 4 shows the arrival rate of containers for both the two- and three-ship-a-week schedules.

Table 1 gives the maximum, minimum, and median travel distances between the activity areas in the terminal (see layout in Figure 3). In the model, the actual probability distributions of each spot in the various storage areas are used. Table 2 gives some of the operational parameters assumed for the case study.

Table 3 summarizes the quantitative results of the computer analysis. These results indicate that

Table 1. Container travel distances.

	Container Travel Distance (ft)		
Route	Median	Maximum	Minimum
Gate to 20-ft container storage	575	1,100	300
Gate to 40-ft container storage	760	1,100	150
Gate to reefer storage	790	900	650
Dock to 20-ft container storage	350	1,100	300
Dock to 40-ft container storage	750	1,500	350
Dock to reefer storage	930	1,400	600

Table 2. Hypothetical terminal operation parameters.

Parameter	Value
No. of yard hostlers	20
Avg time dockside crane handles containers (sec)	140
Avg yard hostler speed (ft/sec)	15
Avg time yard hostler handles containers (sec)	100
Avg time for trucks at entry gate (sec)	250
Avg time for trucks at exit gate (sec)	300
Bad papers (%)	5
Avg delays for bad papers (sec)	300
Avg time for trucks at maintenance (sec)	300

Figure 3. Layout of hypothetical case study marine terminal.

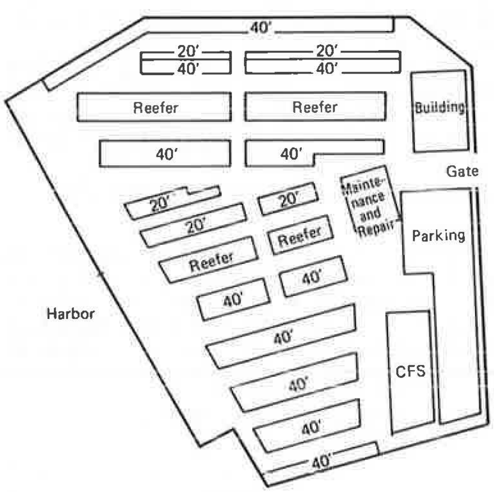
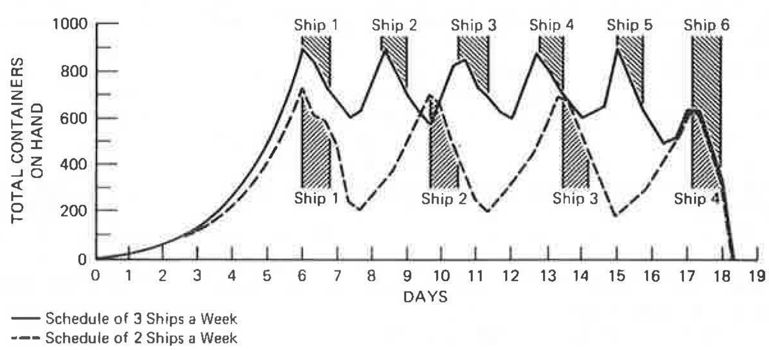


Table 3. Results of case study analysis.

	Ships per Week	
Item	Two	Three
Container storage requirements		
Maximum 40-ft containers on hand	484	621
Maximum 20-ft containers on hand	202	241
Maximum reefers on hand	89	98
Total	775	960
Avg time containers are in terminal (hr)		
Containers arriving by truck	47	47
Containers arriving by ship	24	24
Availability of yard hostlers		
Containers waiting for hostlers (%)	11	12
Avg wait time of containers, if waiting (min)	9	10
Gate processing		
Trucks waiting at entry gate (%)	1	1
Trucks waiting at exit gate (%)	47	48
Avg wait time at exit gate (min)	5	5
Maintenance processing		
Trucks waiting for maintenance (%)	0	0
Avg wait time of trucks, if waiting (min)	0	0
Avg time to load and unload ship (hr:min)	17:51	17:55

Figure 4. Total containers on hand as a function of time.



the principal effect on operations of changing from a two- to a three-ship-a-week schedule would be that the maximum requirements for container storage would increase by 25 percent. The case study also revealed that, under either schedule,

1. Containers arriving by truck would spend approximately 2 days in the terminal, whereas containers off-loaded from the ship would spend approximately 1 day;
2. More than 10 percent of the containers would be delayed, on average, 10 min because of waiting for a yard hostler; more yard hostlers might be required during peak periods when the ships are in the terminal;
3. Truck delays at the entry gate would be minimal, but almost half of the departing trucks would be delayed at the exit gate; consequently, providing more gates may be appropriate.
4. The maintenance facilities appear to be more than adequate to service the traffic; and
5. The time to load and unload a ship would be approximately 18 hr.

This case study demonstrates only one type of parametric study that can be performed by using TANDEM. The purpose is to illustrate the type and quality of data produced from the TANDEM computer model. In a full-scale analysis effort, all parameters of the terminal would be varied to develop the optimum terminal operating characteristics. For example, the following terminal characteristics would be varied: the number of gates; the number of yard hostlers; the rate, volume, and mix of arriving containers by truck; the size of ships; the arrival schedule of ships (assumed to be equally spaced during the week); and the layout of the terminal.

CONCLUSION

A computer simulation model such as TANDEM offers the terminal designer the opportunity to plan, design, or modify container terminals with less risk and more confidence. Specifically, the designer can use the model to develop the optimum system design and then to test the response of the design to various traffic levels and operational scenarios. Because the cost of capital is high, and because the terminal design can affect the profitability of the operating company for decades, terminals must be planned and designed by using the latest available techniques.

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Simulation of Railway Piggyback Terminals

LOUIS DUBÉ

The computer model described in this paper simulates trailer handlings in railway top-lift piggyback terminals. It allows a fast and accurate evaluation of operating trade-offs by quantifying the use of tracks, storage areas, cranes, and tractors. The input comprises key physical characteristics, machine schedules, and train and trailer arrivals and departures according to specified distributions. Output tables describe the machine time spent in loading, unloading, traveling, or idling, and they also describe an hourly distribution of cars on each track and trailers in storage. Time-distance charts of machine positions on each track give a detailed log of operations performed for each trailer. The simulation has been used to evaluate modifications to existing terminals and for the design of proposed terminals. It has general applicability to a wide variety of terminal configurations, equipment types and speeds, and traffic volumes. It is written in Simscript II.5 and requires 400-600 K of core and 1-5 sec/simulated day to execute, depending on the size of traffic.

A computer simulation model of operations in a railway piggyback terminal, where trailers are lifted on and off railcars, is presented. Such terminals provide the link between the long-distance haul of trailers on railway cars and the delivery of those trailers by road to customers.

The following points are covered in this paper:

1. Objectives of simulation,
2. Events simulated,
3. Events not simulated,
4. Inputs required,
5. Outputs generated,
6. Technical considerations, and
7. Applications for (a) modification of an existing terminal, and (b) design of a proposed terminal.

OBJECTIVES OF SIMULATION

Simulations of operations have always been a powerful tool in designing intermodal terminals. They allow a systematic evaluation of various designs under different traffic levels and operating conditions. Two major difficulties have held back the full use of simulations: (a) the high level of detail required to model reality adequately, and (b) the long time spent in performing simulations manually and recording pertinent information for further analysis.

The computer simulation described here attempts to overcome these difficulties. It includes the most relevant features of a piggyback terminal, simulates its activities in detail, and produces reports on its performance, thus allowing many alternatives to be analyzed quickly. It may be used to evaluate changes in loading tracks, handling equipment, traffic volumes, and train schedules.

EVENTS SIMULATED

In a piggyback terminal, trailers change modes of transportation from road to rail and vice versa.