Figure 2. Sample report of processing times for an arriving train.

```
                   DISPOSITION OF TRAIN TV-11

                  SCHEDULED ARRIVAL TIME 19:30

  1 2 3 4 5 6 7 8 9101112131415161718192021222324     HOUR
 -+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|
|                                      ********       ARRIVAL
|
|                                         *******>    PLACED ON
|***                                                  YARD TKS
|
|                                              **>    TRAILERS
|*********                                            GROUNDED
|
|      *******************                            PARKING
|
|       *************************                     TRAILERS
|                                                     DISPATCHED
|
|
|
|
-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  1 2 3 4 5 6 7 8 9101112131415161718192021222324     HOUR
               <TIME OF DAY>

   -90%        AVG.     +90%
   18:35       20:15   21:45    ARRIVAL TIME
   20:33       22:50   01:20    YARDED
   22:30       02:00   04:18    TRAILERS GROUNDED
   02:55       06:00   12:30    TRAILERS PARKED
   03:30       07:10   15:20    TRAILERS DISPATCHED
      25          40      60    TRAILERS/TRAIN
```

start and stop times for the various processes needed to receive, unload, and dispatch onto the street the traffic of a single train. This type of information is especially helpful in evaluating the impact on service commitments (getting the trailers on the street) that result from changes in the terminal operation, train schedules, and so on.

MODEL DEVELOPMENT AND TESTING

TSM was designed around and patterned after Pennsylvania Truck Lines' (PTL) Kearny, New Jersey, TOFC facility. PTL provided data on yard layout, processing rates, train schedules, and volumes. Although the initial intent was to develop the model to simulate a simpler terminal, it was found that testing the model's treatment of the interreaction of the various terminal work functions could best be explored in a complex, busy terminal. Therefore, Kearny was chosen. PTL has been reviewing the results of the simulation to determine if it predicts and simulates terminal performance accurately.

Setting up the Kearny model required building up a fairly detailed description of the current traffic and operations at the terminal. Descriptions of the current train schedules and traffic volumes and types were assembled in standard input table format for TSM. The physical description of the terminal was converted to a queue description. The various shifts and their equipment resources were also encoded. The actual construction of these tables took only one afternoon. The key data to be captured are the tasks performed and the cycle times for various processor activities. This site-specific information is best accumulated through an industrial engineering field study of the terminal, but default cycle times are available, which can be checked quickly for local validity. These default times can also be used when evaluating a proposed new terminal.

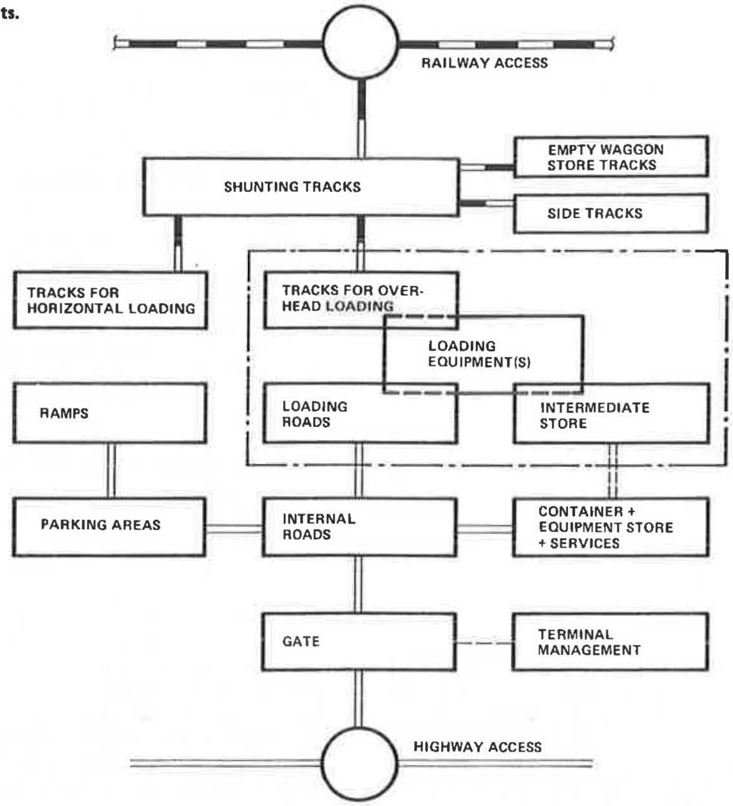
Once the basic terminal description has been captured in the series of TSM input tables, use of the model becomes a simple matter of identifying the change to be made to trains and traffic, to terminal layout, or to work crews and work schedules, and making this change in the input table. A separate table exists for each train and for each processor. To facilitate these changes, the tables are well annotated. The model can be rerun as a batch program because no interaction is required. The results of the new run can be compared with either the base run for the terminal or some other run to establish the impacts on traffic schedules, processor productivity, or facilities use. For example, the sample report in Figure 1 could be used to compare packer utilization under two different sets of train schedules. The sample report in Figure 2 might be used to compare the service provided to trailers that arrive on one train (TV-11) with different numbers of packers or cranes on duty.

Applications of Computer Model Techniques for Railroad Intermodal Terminal Configuration, Equipment, and Operational Planning

PETER BOESE

Although apparently simple, the intermodal transshipment process is quite complex. The intermodal terminal has to coordinate the interface of two (or more) transportation systems of very different operational characteristics and company organizations. With the rapid growth of container and piggyback transportation volumes within the last decade, most road and rail intermodal terminals in large urban agglomerations of Western Germany ran into bottleneck situations. Capacities, economics, and service qualities of the intermodal transportation systems can only match future demands through substantial investments in existing and new terminal sites. The efficiency of these investments depends on the development and implementation of new terminal design concepts together with improved operational systems. Planning for optimum terminal layout, equipment, and operation for future demands can no longer rely on mere rule-of-thumb methodologies. Computer modeling of terminal functions becomes crucial for testing of new technical design and control concepts under near-realistic requirements before their practical implementation. The developed model contains a number of program modules for the different functional parts of a terminal. Under given cargo volume fluxes, types of load units, train schedulings, and selected rail operational strategies, the daily train operation is simulated in coordination with equipment capacities. The road counterpart is formed by Monte Carlo simulation of the stochastic properties of vehicle arrivals at the terminal, according to different truck operating patterns. The core module consists of the simulation of the single movements and actions of the transshipment equipment on the basis of the geometry of the given loading track, truck and storage lane configuration, and the dynamic properties of equipment. A dispatch control module decides on the transshipment sequences prescribed by train operation and truck arrivals, trying to maximize equipment productivity and minimize truck waiting times. A sample of practical results is presented, which shows alternative layout and equipment configurations and the influence on terminal throughput capacity, equipment productivity, and service levels. Some conclusions for terminal economies, improved operational strategies, and computer-aided control systems for future high-capacity terminals are made, together with an outlook on further model refinements.

Figure 1. Terminal functional elements.



The rapid growth of intermodal transportation has brought about bottleneck situations for many intermodal terminals, especially those in large urban agglomerations. This situation leads to low levels of service quality for the user and to high operating costs. Nevertheless, the intermodal market share is still growing, which may prove the inherent attractiveness of this system.

Until the beginning of the intermodal age, the equipment for loading operations had been installed mainly on existing rail yards. Although gradual adaptions of the infrastructure and installations have been performed, the planning and operation concept as a whole has not yet been improved in a systematic approach.

Long-term national transportation policy aims to multiply the intermodal cargo volume and to reach full cost to cover the federal railway company. The transshipment activities will be concentrated at about 50 terminals (today there are 40), with capacities currently ranging from 60,000 to 120,000 load units per year for the 10 largest terminals (which means 240 to 480 per statistical mean day).

The major part of the terminals must operate the different existing intermodal techniques, i.e.,

1. Deep-sea container (ISO) and European inland container-on-flatcar (COFC),
2. Swap-body from 6 to 12 m on flatcar, and
3. Trailer and whole trucks on low floor flatcars (horizontal loading).

Part of these terminals also contain service functions around the container.

In a pilot project for the city of Bremen, the intermodal terminal will be integrated in a new regional distribution center with private and cooperative cargo handling and consolidation services.

CONCEPT

For the expansion of existing terminals and the planning of new ones, the design and operation concept must be improved systematically. Many technical and organizational questions still need to be answered, such as

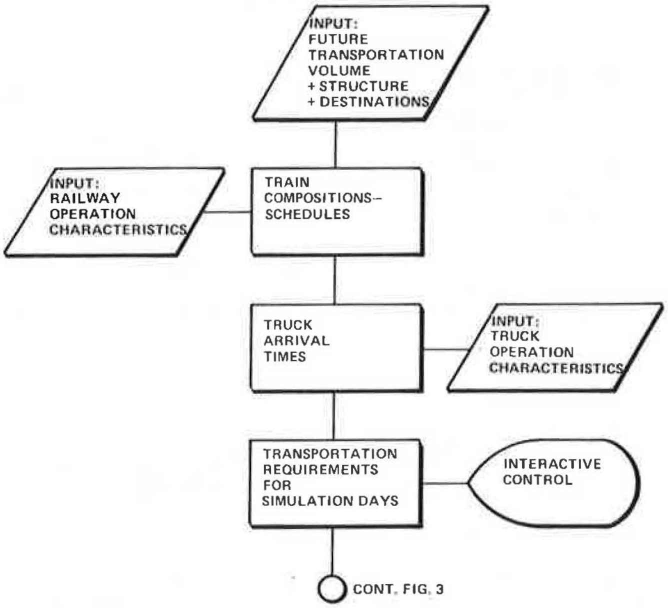
1. How far can the capacity of existing terminals be raised where there are limits to spatial capacity concentration?
2. What is the optimum relation between capacity and main design parameters, such as number and length of loading tracks, road lanes, and type, dimension, and number of equipment types?
3. How can the capacity, handling cost, and reliability of existing equipment be improved? What is the optimum mix of equipment types for a given terminal?
4. How can the terminal operation be improved to reach higher capacity, better service levels, and better economics?
5. How does the optimum design and operation concept of terminals depend on external factors such as structure of cargo volume, rail network and train operation characteristics, truck operation patterns, terminal site restriction, and so on?
6. How can future computer-aided control and information systems improve terminal operation? How do they influence terminal configurations?

Obviously, these questions are interrelated and can only be answered if the functional relations between the components of the terminal and its internal and external requirements are analyzed in a systematic approach.

The main functional elements of an intermodal rail and road terminal are shown in Figure 1. The core elements are the transshipment equipment, the loading track system, the loading roads for the trucks, and eventually the intermediate storage areas for the load units. These elements form a close unit (module) with a wide variety of possible configurations, depending on the type of equipment and the chosen design philosophy. In a recent paper (1), a number of module configurations, with specific suitability for rail-mounted cranes, tire-mounted cranes, rail- and tire-mounted side-lifters, and front lifters have been shown.

The complexity of the interrelations of the functional elements of the terminal and the dynamic character of terminal operation can only be treated in detail by computer simulation techniques.

Figure 2. Structure of terminal simulation model—transportation requirements.



The model described below has been developed and applied to actual planning tasks for a number of terminals. Along with its application, further questions about new design and operation possibilities arose; as a result, the model had to be continuously refined and extended. This process is still going on.

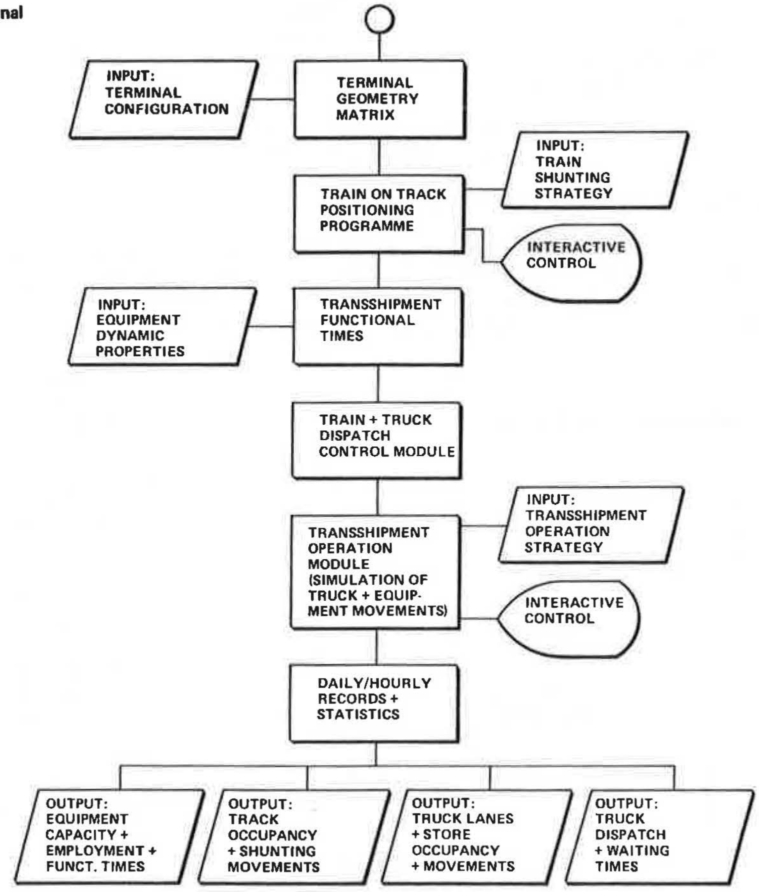
The program is of strictly modular design. It runs on a medium-sized process computer. A number of design alternatives can be tested at reasonable cost.

THE MODEL

Figures 2 and 3 provide the macrostructure of the terminal simulation model. From transportation projections or company marketing aims, the annual cargo volume and structure (number and type of container and piggyback load units) must be given for the terminal catchment area and for the different rail transport destinations. The dimensioning (peak) days must be derived from observed or assumed seasonal and weekly cargo fluctuations. The schedules and loads of the inbound and outbound trains are composed according to given railway network operation, and marshaling strategies form the railside model input.

The truck operating characteristics that form the roadside input for the model must be determined by typical patterns for pickup and delivery tours between the rail and road terminal and consolidation ramps or customer ramps located in the region. The truck operation can be performed by the intermodal or terminal operation company (in West Germany, for

Figure 3. Structure of terminal simulation model—operational simulation.



the container railroad subsidiary) or by the individual trucking companies (for the different types of piggyback transportation alternatives). Each form of pickup and delivery organization results in different requirements on the terminal operation and possibilities to harmonize them with the train and transshipment operation.

Due to the stochastic elements in road transportation (traffic congestions, dispatch irregulations, and so on), the arrival of pickup and delivery trucks at the terminal gate is a random process, which is simulated by the computer model. The Poisson-distributed arrivals are normally linked to the train schedule; just after train arrival they give a peak frequency and then decrease for the following hours. For deliveries of outbound loads, there is the inverse statistical pattern.

The schedules and compositions of inbound and outbound trains and the truck arrivals of every simulation day are compiled for the transportation requirement data sets for the operation simulation module. All requirements can interactively be controlled and adapted.

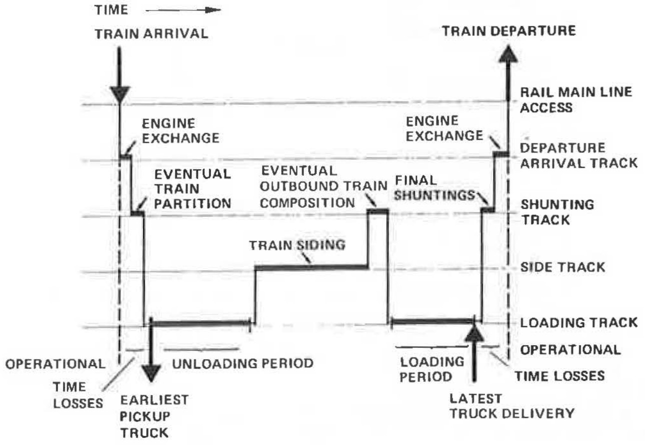
The given terminal configuration geometry, with its track system, loading road lanes, and storage positions, is imaged in a terminal area matrix. According to daily train arrival and departure times and train length, the trains are positioned by the computer onto the loading tracks under given shunting strategies.

The dynamic properties of the selected type of equipment, and the velocity and acceleration parameters for crane traveling, trolley, and spreader (including positioning and gripping times), determine the transshipment functional time data file.

During the simulation run, the time needed for any transshipment cycle is computed according to terminal geometry and actual positions of the load units on the wagons of the track, on the vehicles in the road lanes, and on the storage spots. Thus, the movements of the equipment are simulated as realistically as possible to include the major stochastic elements (e.g., time losses due to imprecise spreader positioning).

The control core of the transshipment model is formed by the train and truck dispatch control module. According to an externally chosen transshipment operation strategy, this module coordinates the simultaneous loading phases of the trains, the sequence of load units to be loaded on the trucks as they arrive or queue up on the road lane, and the storage movements. The priority selection of all transshipment actions is programmed by decision matrix techniques, thus enabling maximum flexibility in adopting and testing different operational strategies.

Figure 4. Typical train operating characteristics.



These strategies vary from the simple first-come, first-serve principle to more sophisticated strategies aimed at simultaneously minimizing truck waiting times and unproductive equipment movements, especially at peak hours. According to the loading and unloading sequence prescribed by the dispatch control module, the actions of the equipment are performed in the transshipment operation module, where time consumption is computed.

The degree of sophistication that can still be realized by conventional terminal organization and communication means as well as the possibility of new dispatch control systems and of semiautomation or full automation of equipment control can be tested by introducing different types and combinations of operational strategies. The output of the simulation runs consists of daily and hourly records and statistics for

1. Equipment maximum capacity, employment, and functional times;
2. Track system occupancy and shunting movements;
3. Truck lanes and storage area occupancy and movements; and
4. Truck dispatch and waiting times.

These results give the quantitative criteria for the assessment of design and operation alternatives under technical, economic, and service aspects.

OPERATIONAL SCHEMES

Figure 4 shows a typical train movement inside the terminal track system. In West German terminals, the (electrical) engine must be exchanged for a shunting engine after train arrival. At present, new types of train operations are under consideration in order to avoid excessive shunting. But, the ideal concept of whole trains always moving directly between the loading tracks of two corresponding terminals is difficult to realize within the dispersed West German intermodal transportation network and within the space restrictions of the terminal sites in the urban agglomerations.

When the train is longer than the free loading tracks (which is the case in most existing terminals), the train must be divided. Then, after some time losses, the train stands ready for unloading. For the "stand" type of train operation, the train remains on the loading track until its departure. The simplest type of operation enables nearly exclusive direct unloading and loading, which means transshipments between wagon and truck without intermediate storage on the floor. The unloading and loading sequence is dictated mainly by truck arrivals at the terminal ("truck service" strategy).

In most terminals the capacity of the loading track system is not sufficient to receive all arriving trains. In these cases, some trains, after an unloading or loading phase of some hours, must be removed from the loading tracks and shifted to the side tracks to make space for new inbound trains. This calls for a more sophisticated shift operation with another type of transshipment strategy. At some period of time before being removed from the loading track, the remaining train load (which has not yet been picked up by arriving trucks) must be unloaded onto the intermediate storage area. This stripping "clear-the-train" operation leads to a significant number of indirect transshipments and thus to higher equipment capacity demand. In addition, more terminal space for intermediate storage and side tracks is needed. On the other hand, the

Figure 5. Typical unloading and truck pickup operation.

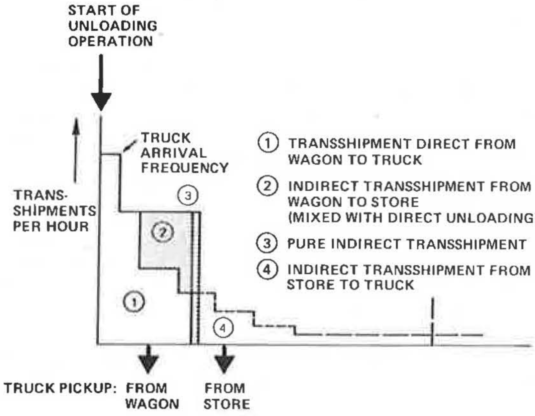
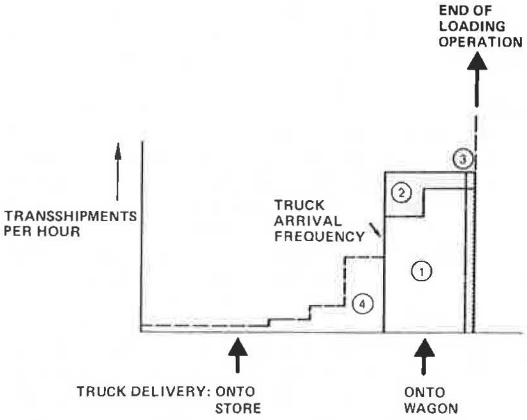


Figure 6. Typical truck delivery and loading operation characteristics.



throughput capacity of the loading track can be raised by a factor of 2 or more, as will be shown later.

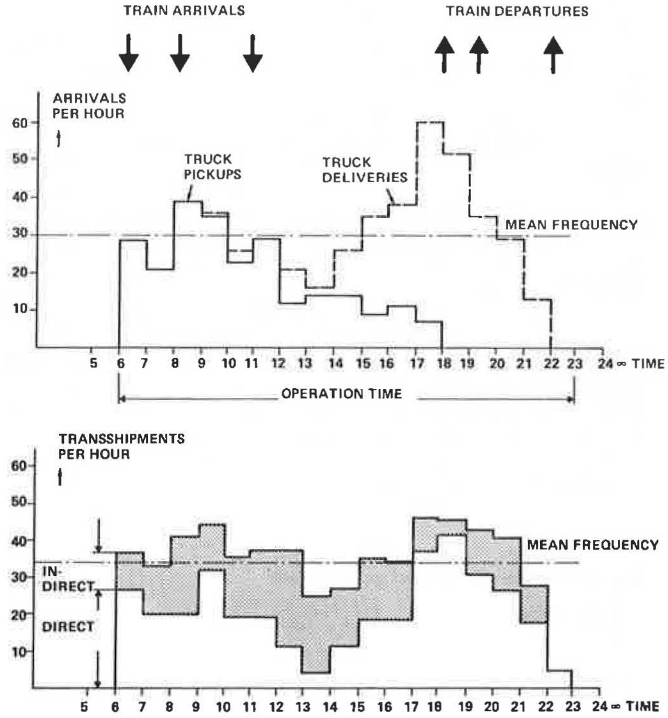
Figure 5 shows a typical unloading operation scheme. Just after train marshaling to the loading track, most of the load is unloaded directly onto the arriving trucks ("serve-the-truck" phase). Approaching the end of the standing time with less trucks to be served, parallel stripping of the train onto the storage area starts ("mixed-operation" phase). Finally, just before the train must be shunted to the side track, the remaining load units must be exclusively stripped off (clear-the-train phase) onto the storage area. The units that have been placed into storage can be picked up by the trucks during the rest of the day, independently of the train.

Figure 6 shows the reverse procedure for the loading process of outbound trains.

When the units are stored on the floor (swap-bodies) or stacked (containers), equipment must always be available to serve the trucks on their arrival if waiting times are to be avoided. If the load unit consists of a trailer, the truck can autonomously pick up the unit without the help of equipment. The same type of operation is possible if the containers are always loaded directly on a semitrailer and moved to a parking area by a terminal trucker. This explains the main difference between the continental European and the American type of intermodal terminal operation.

As explained earlier, piggyback transportation of semitrailers on recess wagons holds a small but growing fraction of the whole intermodal market in Europe. The dominating types of intermodal units are the swap-bodies that belong to the road transportation companies or firm consortia that operate their trucks independently of the rail and terminal operator. This type of terminal operation could obviously be improved by better coordination between train marshaling and truck operation by using new information and communication systems or differentiating tariff systems.

Figure 7. Daily truck arrival and transshipment frequency characteristics for four-track module with two cranes.



SIMULATION RESULTS

The model described above has been applied to a number of projects for the expansion of existing terminals and for the design of new ones, ranging from medium (300-900 load units/peak day) to large capacity (1,000-2,000 load units).

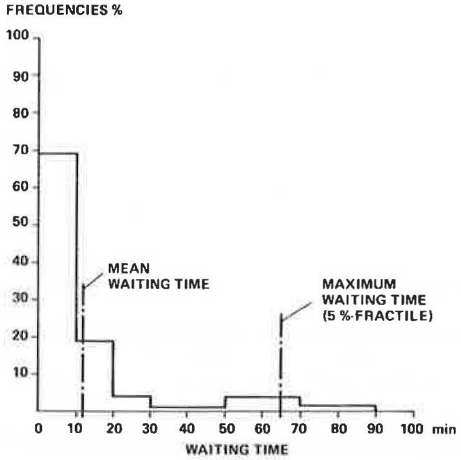
Figure 7 shows the simulation results for the hourly frequencies of truck arrivals and transshipments for a terminal of a four-track module of 700-m length (equal maximum train length) with two rail-mounted high-speed cranes. The combined effects of train arrivals concentrated in the morning and departures in the evening together with the truck arrival characteristics (see Figures 5 and 6) lead to pronounced peak frequencies in the morning and evening, which can be twice as high as the daily mean frequency. This effect leads to strong fluctuations of the required number of transshipments per hour (see the lower histogram in Figure 7).

In the case described above, the total inbound and outbound train length is three times the total track length, which results in a high amount of clear-the-train operational phases. Consequently, the fraction of indirect transshipments is quite high (40 percent of the total terminal throughput). These double handlings are effected mainly outside the peak hours, but they still call for additional equipment capacity (or cause more truck waiting times during terminal rush hours).

Figure 8 shows a typical truck waiting time frequency distribution histogram. Short waiting times (10 or 20 min) are frequent, but long waiting times of more than 1 hr can occur in the worst case. Thus, not only the mean value but also the maximum waiting times (e.g., 5 percent-fractile) must be assessed as a terminal service quality criterion. The longer waiting times are caused by truck queues during peak hours and by service breaks when the clear-the-train operation has absolute priority for train marshaling reasons. By means of more sophisticated operation strategies, this negative effect can be minimized by early train stripping-off operations that make use of equipment idle periods during serve-the-truck phases.

Figure 9 answers questions about the maximum terminal throughput for a given tolerable service quality (maximum truck waiting times) and about the amount of equipment required for a typical two-track module configuration of 700-m length. The maximum waiting times show a steep ascendance with a growing number of transshipments. If we take the maximum tolerable waiting time of, for example, 30 min, the maximum throughput for a one-crane configuration of this terminal would be about 220 load units/day. The second and the third crane would always give smaller capacity increments.

Figure 8. Frequencies of truck waiting times.



The reason for this functional relation between crane number and capacity is as follows. Only one crane for the total module length has low productivity due to time losses for traveling between the random unloading and loading spots during the serve-the-truck operational phases. With more equipment working at the same track length, equipment travel distances become shorter and their productivity rises. But with rising throughput, more trains must be marshaled to the loading tracks. The track load factor (overall train length) rises from 1.5, which enables the stand operation, to 4 and 5. This means that the shift operation, with an always higher rotation of inbound and outbound trains, is necessary. Thus, the amount of indirect (double) transshipments rises, which lowers the effective terminal capacity increments. Other handicaps for this type of operation are the rising productive time losses due to train shunting and also the rising coordination problems between the cranes. This effect obviously limits the amount of equipment for a given track length, depending on the type of control system.

For terminal area demand, the rising throughput also requires more side tracks for the stripped trains and more intermediate storage space. Also, at a certain point, traffic congestion at the truck road lanes beside the loading tracks calls for more road lanes. A computer traffic control system is conceivable, which coordinates the truck flow to the loading positions with the transshipment process of the cranes. But how far can such a control system count on the participation of the truck drivers?

For any type of module configuration, there is an optimum amount of equipment and thus a maximum throughput capacity. This optimum can be found for any specific terminal project by economic analysis on the basis of simulation results.

In the search for more efficient terminal concepts, the number of loading tracks under the cranes has been raised. The traditional concept was based on two tracks. Now cranes of the portal or cantilever type that have four tracks are under construc-

Figure 9. Truck waiting times over terminal throughput and crane number (two-track module).

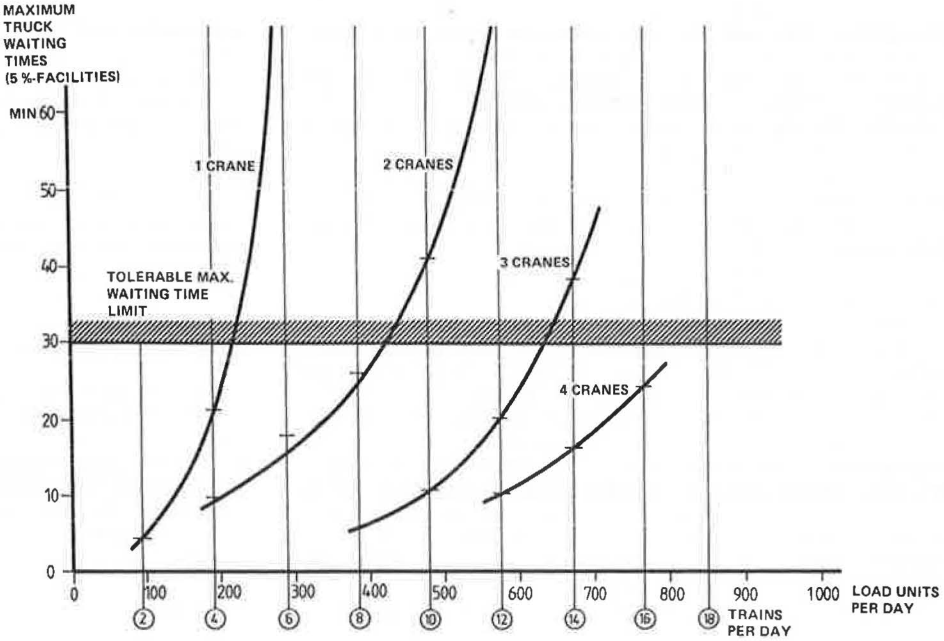
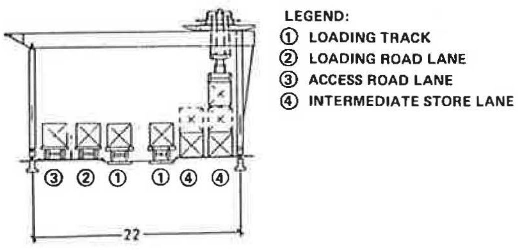
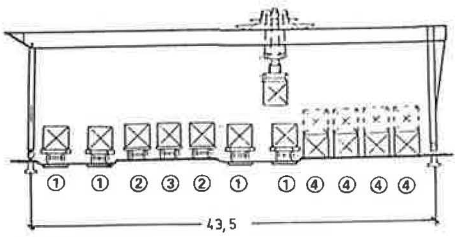


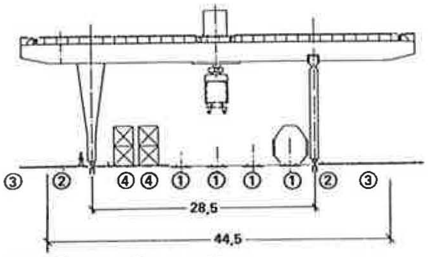
Figure 10. Typical configurations for rail-mounted cranes.



TWO-TRACK PORTAL CRANE

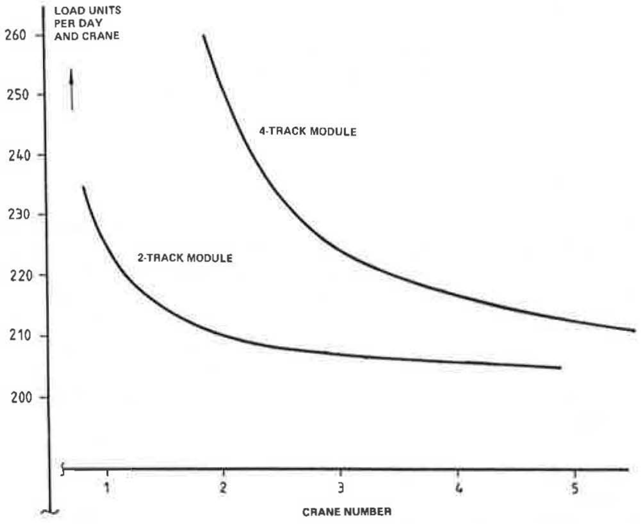


FOUR-TRACK PORTAL CRANE



FOUR TRACK CANTILEVER CRANE

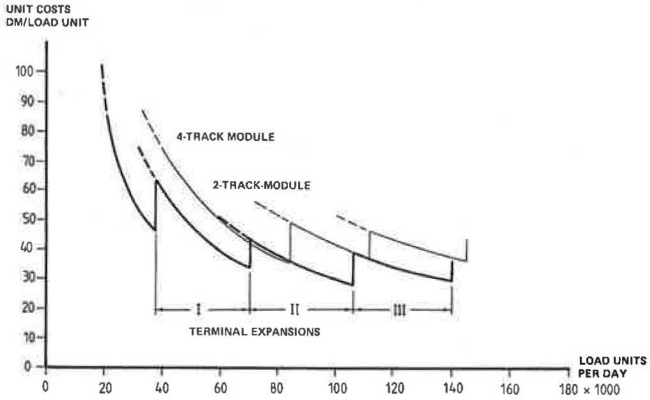
Figure 11. Terminal capacity over crane number for two different configurations.



tion in the larger terminals of West Germany (see Figure 10). Cranes of even higher spans for six or eight tracks are planned for new terminal projects.

The idea behind this concept is that the transshipment capacity of the terminal must be concentrated on one module with a high number of parallel-working (computer-controlled) cranes. The trains must be marshaled to these cranes by the appropriate high capacity of the loading track system. By this procedure, the productivity of the cranes will be raised through shorter traveling distances along the trains and more even capacity use through the high number of parallel trains.

Figure 12. Terminal unit costs over throughput for different terminal capacities.



But with the bigger crane span, the transversal velocity of the trolley must be raised in order to compensate for the longer transversal ways, which, along with the higher structural weight of the crane, requires a much more powerful installation. Consequently, costs for equipment, including infrastructure (crane rails and power supply), will be two to three times higher than for the small crane type.

From practical experience in Britain with the Freightliner terminals, Howard (2) found that the average unit costs for the larger terminals are not lower than the smaller ones; sometimes the opposite is the case. The smaller terminals, with up to 40,000 containers/year, are equipped with cranes spanning only 4 lanes (2-3 tracks), whereas the terminals of 60,000 containers/year and more have cranes of the cantilever type, which can span 10 or more lanes (5 tracks).

The simulation results reported here show that the capacity of, for example, 4-track cranes is only 5 to 20 percent higher than that of 2-track cranes (Figure 11). This effect does not compensate for higher investment and energy cost, as shown in Figure 12. The unit cost function for different capacity levels is significantly higher for the larger crane modules than for the smaller ones.

CONCLUSIONS

The following conclusions are based on computer simulations from the study in West Germany on intermodal capacity expansion. The concentration of the entire capacity of larger terminals on one high throughput system will not reduce unit costs and may also bring operational problems caused by lack of redundancy. In addition, there is little flexibility in the step-by-step adaptation of investment to cargo volume development.

In the alternative concept, where the whole terminal capacity is split into two or more parallel modules, the investment risk can be reduced.

Currently, this alternative appears to be significant because the future development of the volume and the participation of intermodal techniques is still uncertain. For instance, the swap-body places different requirements on the terminal than COFC or the trailer on recess wagons. Also, the future participation of horizontal loading techniques is still uncertain. Therefore, the best design philosophy is to plan for maximum future flexibility.

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