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Authors of the Papers in This Record

Al-Kazily, Joan, Department of Civil and Environmental Engineering, University of Rhode Island, Kingston, RI 02881
Boese, Peter, Dornier-System GmbH, Postfach 1360, 7990 Friedrichshafen 1, West Germany
Corbett, Scott S., Jr., Corbett Consultants and Multi-Sort, Inc., P.O. Box 30075, Portland, OR 97230
Curley, Robert G., SRI International, 333 Ravenswood Avenue, Menlo Park, CA 94025
Dubé, Louis, Industrial Engineering, Canadian National Railways, P.O. Box 8100, Montreal, Quebec, Canada H3C 3N4
Golden, Douglas S., Transportation and Distribution Associates, Inc., 1818 Market Street, Philadelphia, PA 19103
Grant, Andrew R., SRI International, 333 Ravenswood Avenue, Menlo Park, CA 94025
Hatzitheodorou, George C., City of New York, Department of Ports and Terminals, Battery Maritime Building, South Ferry, New York, NY 10004
Héjj, Erwin, Krupp Research Institute, Munchener Strasse 100, 4300 Essen 1, West Germany
Howard, S.G., Freightliners Limited, 43 Cardington Street, London NW1 2LR, England
Muskin, Jerold B., Department of Transportation and Marketing, Drexel University, 32nd and Market Streets, Philadelphia, PA 19104
Radzikowski, Phillip, Booz-Allen & Hamilton, Inc., 4330 East West Highway, Bethesda, MD 20014
Smith, Douglas P., Department of Civil Engineering, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1
Staley, Richard A., R.A.S. Consulting, 1221 South Buchanan Street, Arlington, VA 22204
Wong, Peter J., SRI International, 333 Ravenswood Avenue, Menlo Park, CA 94025
Wood, Carlton F., Transportation and Distribution Associates, Inc., 1818 Market Street, Philadelphia, PA 19103

Land Use Constraints in Locating Intermodal Terminals

RICHARD A. STALEY

Intermodal freight terminals are land intensive, in that each requires a substantial dedicated land area, and they are usually sited within urban areas. Some are locationally constrained due to mode dominance (e.g., a container port must be located at waterside). For these reasons, developers and users of new intermodal freight terminals may find themselves limited in their choice of locations. Existing facilities may also have limited opportunities for redevelopment or expansion or both. In addition to natural locational constraints on intermodal freight terminal site selection, there can also be a number of social or environmental constraints. Noise and around-the-clock operation are but two examples. Existing intermodal terminal facilities are often only tolerated in urban areas, and the land may be rezoned to a higher use by those who advocate urban redevelopment. Thus, due to possible zoning restrictions based on environmental or other similar constraints, developers and users of intermodal freight terminals may find their locational and operational options severely limited, or exercisable only at drastically reduced levels of efficiency. Special land use zoning or urban land development under the joint-use concept is recommended in order to assure user viability of new or expanded intermodal freight facilities to serve all forms of goods transport. Community education and involvement may also be required to prevent unwarranted restraints.

Applied to freight transport, the term intermodal may have become one of the most used--and misused--of terms. To a water carrier, intermodal means transferring goods to or from ships at dockside. To the railroads, intermodal normally connotes piggyback [trailer-on-flatcar (TOFC)], which involves rails and motor trucks.

The people who draft intermodal cargo container standards have adopted a broader definition of the term. They define intermodal as "the carriage of goods by two or more modes of transport" (1). From this, it would appear that intermodal terminals may be defined as locations where freight is transferred between any two or more freight modes, including airports, piggyback (TOFC) yards, pipeline terminals, and sea, lake, and river ports. The freight modes that use such facilities would be any appropriate mix of trucks, railroads, ships, barges, aircraft, or pipelines.

In real-world operations, some intermodal transfers are unlikely (e.g., pipeline to aircraft) while others are encountered frequently (e.g., ships to trucks or railroads). However, any transfer of freight between two or more transport modes is intermodal, and where such a transfer occurs is, in fact, an intermodal terminal.

INTERMODAL FREIGHT TERMINAL REQUIREMENTS

The requirements for viable intermodal freight terminals, in and of themselves, provide insight into why such facilities may face locational or operational constraints. Therefore, it is essential that these requirements be categorized and classified. Some intermodal terminals are basically mode dominant in that their location or function is determined primarily by a single transport mode. Ports fall within this category because their location is dictated by the presence of navigable water. To a lesser degree, the same may be said of airports, where the primary consideration is unencumbered space to accommodate aircraft operations. Pipeline terminals, too, represent a marginal form of a mode-dominant facility.

At the other extreme, trucking operations can adjust to nearly any locational environment. Therefore, intermodal terminals that involve trucking may be considered unconstrained insofar as that mode is concerned. Occupying a middle ground, so to speak, are piggyback terminals operated by railroads. Although these must be adjacent to rail trackage, some latitude can be provided by constructing spur or feeder tracks that connect the terminal to main rail lines.

Regardless of the modes involved, intermodal terminals, by their nature, are land intensive. This is to say that they require substantial dedicated land areas if they are to function efficiently. A 1981 conference of transportation specialists put this succinctly in noting that (2, p. 48) "land availability is an important prerequisite for the larger intermodal terminal complexes. Since land assembly can be difficult in large urban areas, it constitutes a major challenge in land use planning."

Here, also, another vital aspect of intermodal freight terminals was brought into focus, which is that these facilities are nearly always associated with an urban area. This association can further complicate intermodal freight terminal requirements. All urban-goods movements have long been the subject of intensive study and analysis simply due to the added costs and congestion inherent in moving freight within areas of high traffic densities.

Earlier on, urban freight movement research had concentrated on such micro land use problems as loading zones and off-street parking. Model solutions for these micro problems seem to now be well in hand (3). In the process, the overall roles of the cities have likewise been examined and delineated, and both their strengths and weaknesses have been noted (4).

Regarding single-mode freight terminal requirements, basically only those applicable to trucking have been addressed as they relate to locational needs within urban areas. However, the high level of trucking flexibility provides considerable latitude in siting facilities (5). Initial investigations have been attempted, which relate trucking industry requirements to those of other transport modes in terms of intermodal terminals (2, pp. 46-47; 6), but to date such efforts have lacked specific input from the other freight modes.

LOCATIONAL NEEDS AND PROBLEMS

Empirically, intermodal freight terminals may be characterized as (a) requiring relatively large tracts of land, and (b) being almost always located within an urban area. Operating from these basic assumptions, the 1981 Engineering Foundation Conference on Goods Transportation in Urban Areas (GTUA) raised five questions that the conferees considered germane to the problems of intermodal terminal location (7, pp. 43-44):

1. Does the quantity and quality of freight movement availability influence land use in urban areas? If so, can transportation planners help desired land use patterns? Are certain modes of goods movement preferred for special types of land use or site development? Does lack of specific quality of goods transportation inhibit urban land use or economic development?
2. Can efficient freight operations, especially terminal operations, be carried on without significant adverse economic, environmental, or land use impacts? Where such impacts exist, do they vary significantly between different modes of transportation?

3. What can be done with land now considered unproductive because of obsolete or underutilized freight transportation facilities?
4. Are there certain transportation activities which are potentially so harmful to the urban environment or to society (e.g., hazardous material wastes, coal terminals) that they require protected areas?
5. How can goods movement requirements be incorporated into an overall urban land use plan in both the long and the short range?

These concerns vis a vis freight terminals and land use are by no means a new issue nor one unique only to the 1981 GTUA conference. Eight years earlier, in 1973, a similar conference produced a probe group report on the social, environmental, economic, land use, and technical problems in this area (8). Specific motor carrier terminals had been the subject of a 1976 FHWA study concerned with ameliorating neighborhood impacts and that also considered buffers (against) noise (9). Nor were the more recent concerns merely a repetition of earlier findings. Participants in the 1981 GTUA conference received status reports dealing with such problems as the redevelopment of 4,000 acres of underused multimodal terminal sites in St. Louis. Further, they received detailed information concerning community disruptions being caused by new and expanded intermodal coal terminals. Some specifics here included severance of community services, emergency vehicle delay, and lowered community growth and vitality (10).

LAND USE CONSTRAINTS

Clearly, a case was being made (at the 1981 GTUA conference) for recognizing the special and unique nature of intermodal freight terminals insofar as land use is concerned. Just as clearly, there was a realization by the attendees that this unique nature exposes such facilities to one or more land use constraints. Such constraints can be categorized as locational, operational, and environmental.

Locational Constraints

Locational constraints may take the form of denied zoning or of restricted-use zoning that could limit intermodal facilities to specific areas or even to specific locations. Here, one would hope that enlightened planning and unbiased appraisal would permit the placement of intermodal terminals at locations viable for both users and developer-owners. However, in real-world terms, this may be more than can be reasonably expected. Intermodal freight terminals are land intensive, and there is competition for sizable land parcels in virtually all urban areas.

As examples, major modern airports seldom occupy less than 1,000 acres of land. Seaports can easily use an equal amount of landside area, with container terminals being particularly land intensive in this regard. Rail piggyback terminals can require up to several hundred acres for full operational control and on-site vehicle storage. Even the single-mode motor carrier terminal--if it is a major break-bulk facility--may occupy 80 or more acres of land. In virtually all instances, as noted earlier, these large land parcels are within or immediately adjacent to an urban area, where conventional wisdom indicates that land is at a premium.

To return to a point made in the opening section of this paper, overall locational constraints may be dictated by the mode or modes of transport being served. That is to say, a seaport cannot be separated from water nor can an airport be reasonably located on hilly terrain. Here the line between locational and operational constraints becomes, of necessity, blurred.

An example of locational constraints may be found at the Potomac intermodal rail terminal in Arlington, Virginia, which is immediately adjacent to Washington, D.C. This long-used site is literally locked in on all four sides by highways and recent commercial developments. Short of complete demolition and reconstruction, improvements are virtually impossible; in any event, expansion is impossible. The site is also viewed as a prime candidate for high-type commercial redevelopment by local real estate agents and government land use planners.

Operational Constraints

Operational constraints may be characterized as those constraints on intermodal terminal facility sites that are dictated by the day-to-day requirements for economic viability. Ease of access, economic siting, and proximity to markets are prime examples. A specific example could be the new intermodal freight facility at Long Beach, California (11). There, an integrated terminal at portside will permit rapid intermodal freight transfer, which previously required an inefficient bridging leg between Long Beach and Los Angeles.

Accessibility can be one of the most serious operational constraints at many intermodal terminals (6). It is essential that goods moving intermodally be able to flow freely both into and out of a modal transfer area. Thus, a piggyback terminal located in a congested urban area provides less-than-optimum accommodation for the trucks that deliver and pick up trailers. Similarly, airports with restricted commercial vehicle access (which is not uncommon) cannot offer a land and air interface with minimum delays.

In economic terms, siting an intermodal facility in an area of high land values, in a high tax location, or in an area subject to such adverse conditions as flooding or fog can impose operational constraints of a different type. Because intermodal terminals are land intensive, developers and operators want to minimize both acquisition and operating costs. Further, use of irregular terrain involves excessive site preparation costs or maintenance or both. It must also be recognized that limited accessibility (as discussed above) will have an adverse economic impact on the operation of an intermodal terminal in terms of time, fuel consumption, and the like.

Two current examples of operationally constrained intermodal facilities are the Delaware Avenue docks in Philadelphia and Dulles International Airport, which is some 20 miles outside of Washington, D.C., in Virginia. At the Philadelphia facility, trucks, railroads, and ships all vie for limited dockside space and even more limited access. Predictably, it has difficulty attracting business. At Washington's Dulles Airport, commercial vehicles are currently barred from all direct access routes and literally must use back roads. Again, predictably, most air freight movements are being diverted to the more accessible Baltimore-Washington International Airport some 60 miles to the east.

Market proximity in an urban area is sometimes looked on as being relative over time. For example, there is an observable continual shift in business and commercial patterns within urban areas. Industries move farther from city centers over time, while new satellite communities may develop in somewhat unpredictable locations. Redevelopment of older areas can sometimes arrest, or even reverse, these movements.

Again, conventional wisdom based on experience indicates that intermodal terminals be located so as to provide both proximity to current markets and a best estimate of future markets. In terms of highway links, proximity based on minimum transit times, rather than minimum mileage, has been found to result in the best overall facility siting. In this instance, advantage may be taken of major highway arteries.

This approach is not necessarily applicable to all intermodal facilities, however, due to the locational constraints noted earlier. Thus, a compromise may be required in which all factors are weighed, i.e., mode-specific needs, land availability, access, costs, and market proximity. Although such an approach can never yield an ideal solution, if properly done it can provide for a best available location.

Environmental Constraints

Environmental constraints on intermodal freight terminals could take a number of forms. Hours of operation might be specified, as may the maximum permitted noise levels. A major facility might be classified as a point source, which requires an environmental impact analysis of the air pollution that would be generated. Because the very term environmental impact carries such a wide range of connotations, it is most difficult to predict or evaluate all of the aspects of an intermodal freight terminal operation that might be affected.

However, it is apparent that any time-of-day or day-of-week constraints on the operations of such terminals would severely inhibit both efficiency and productivity. Today, many modal as well as intermodal freight terminal facilities operate literally around-the-clock. Time restraints would result in unacceptable back-ups or an uneconomically large facility in order to provide required capacity based on limited operating hours.

Already some major airports have limited their operating hours due to environmentally generated noise constraints (no night flights). These airports can exhibit such (expected) problems as underuse and artificial volume peaks. National Airport in Washington, D.C., is a prime example. This heavily used facility bans commercial flights from 10:30 p.m. to 7:00 a.m.--the most preferred times for air freight. Flight patterns and noise-abatement procedures are also enforced, as are maximum noise levels.

Environmental constraints based on noise or on visual intrusion from high-intensity yard lights could affect all types of intermodal freight terminals at one time or another. Trucks entering and exiting, aircraft, shift-side cranes, and rail cars being shunted are all phenomena that can and do occur in intermodal operations.

NEW TERMINALS VERSUS REJUVENATED FACILITIES

All of the above requirements and constraints can come into play when a decision must be made regarding continued use of an existing intermodal freight terminal versus construction of a new facility. Questions to be addressed are, Can the present terminal be expanded, modernized, or otherwise made more efficient? and Is there a better intermodal terminal location available?

Users have sometimes discovered that land developers, community redevelopment groups, and even the general citizenry are eagerly awaiting the time when an existing facility becomes outmoded. Their goal is to rezone the land such a facility occupies to what is sometimes referred to as a higher use, but which in reality may represent a device for removing what is considered to be a local eyesore.

At the same time, terminal developers and users may find that their alternatives are severely limited. Land parcels of sufficient size to support new, relocated, intermodal operations may be unacceptable from an operational standpoint, or the costs involved in purchasing and preparing the site may make the proposed location uneconomic. Zoning restrictions, access limitations, and all of the other factors that must be considered when siting a new facility may militate against the establishment of a new intermodal terminal. Even the expansion of existing facilities could be affected by all or some of these constraints.

SOLVING THE CONSTRAINT PROBLEMS

The problems described above are neither new to the intermodal terminal planner nor are they necessarily insoluble. Transportation requirements and land use planning need not be an adversary procedure as, for example, has been demonstrated in Maryland (12).

In addressing the overall problem of freight terminals within generally urban areas--and, as noted, such terminals are primarily urban-area oriented--the 1981 GTUA conference attempted to place the issue in perspective with a series of recommendations. The conference report recommended "use (or reuse when currently deteriorated) of parcels of transportation-oriented land within the inner urban areas, in such a way as to improve urban goods flows, reduce overall transportation requirements, and generally enhance the economic viability of the region" (7, p. 44).

The same conference went on to make other, more specific, recommendations. These included, "where necessary zoning ordinances should be modified to include freight terminals specifically as a preferred land use in the most appropriate locations" (7, pp. 45 and 49), and that there should be a "master guide to terminal location and zoning" (13). Other groups, too, are examining the interrelations between land use and transportation. A recent report from TRB (14) explored the implications and opportunities associated with joint development under the land use concepts.

CONCLUSIONS AND RECOMMENDATIONS

Developers and operators of intermodal freight terminals must be prepared to recognize that such facilities are not universally accepted as ideal land users. Communities and community groups may view these terminals as being undesirable neighbors, with possible reactions ranging from tolerance all the way to militant opposition.

As intermodal terminals are redeveloped, constructed, or expanded, it is probably inevitable that the developers and users will encounter constraints that may render their operations less-than-optimally efficient. Such constraints could, conceivably, literally result in evicting an intermodal terminal from its existing site. More probable would be environmental restrictions on operations that could at least partly incapacitate a terminal by limiting hours of use, access, on-site storage, and so on. Presence of hazardous cargoes at an intermodal terminal could only exacerbate possible constraint scenarios.

Following recommendations that emerged from the deliberations of the 1981 GTUA conference, intermodal freight terminal designers should be prepared to present convincing arguments in favor of special-use zoning that would recognize the requirements of such facilities, and the limited viable available alternatives.

Further, they must be prepared to justify such zoning through any available appeal processes, such as mobilizing, when necessary, business, industry, and civic leaders in order that the community as a whole may be made aware of the need for intermodal facilities. Emphasis should focus on reduced overall transport costs, energy conservation, reduced congestion, increased employment, and, most important, a more efficient and less publicly intrusive transport network.

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Rail and Water Terminal Interface

PHILLIP RADZIKOWSKI

A discussion of how the growth of bridge traffic and today's competitive industrial environment have forced changes in marine intermodal terminal design trends is presented. The objective of the changes is to improve productivity of both the terminal operation and the transportation system in which the terminal participates. Specific examples and case studies of productivity improvements in terminals and in transferring containers to and from the marine terminal and the railroad are presented.

The marine terminal is an increasingly important partner in a more complex, competitive, and integrated world transportation network. Competition among terminals for local traffic has spurred design changes to improve productivity and lower the costs of container moves. Also significant are design changes in response to the requirements for terminals to interact more efficiently with railroads; therefore, the overall productivity of intermodal transportation networks is raised. This requirement results from the growth of bridging, which is a relatively new segment of the transportation industry. Bridging involves the use of both rail and ship for transporting containers moving under a combined bill of lading.

There are different types of bridges. A land bridge involves moving containers from port to port by rail. For example, a shipment from Japan to France would be off-loaded at a U.S. West Coast port, shipped by train to the East Coast, and then loaded onto a vessel to complete the journey to Europe across the Atlantic Ocean. Also, combined bills of lading are used increasingly to ship containers from a port by rail to inland destinations--a microbridge. A minibridge is for when a container is unloaded at one port, shipped by rail over a high-volume route to another port, and then shipped from this second port by rail (or truck) to its final destination.

Since 1972, bridging has been one of the fastest-growing segments of the transportation industry. It was made possible by the maturing of the marine container freight transportation system that began about the same time. Figure 1 shows that the level of U.S. import minibridge traffic has grown from approximately 0.7 million long tons per year in 1976 to 1.1 million long tons per year in 1981. (Note: Traffic data in this paper are based on import minibridge movements because of data availability. Although indicative of trends, actual growth rates of total bridge traffic may vary.) This growth rate of approximately 10 percent/year is substantially higher than the annual growth rates of 5 percent or less for all waterborne and rail traffic during the same period.

The growth in bridge traffic is due to the relative economic advantage of using railroads to transport containers from the first landfall port to inland points rather than using all water routes. This is true even when the hinterland destination is another port on the other side of the North American continent. Bridging results in shorter overall distances and transit times and allows shippers to take advantage of generally lower rail transportation rates. It also increases the number of round-trip voyages that a container vessel can make.

Capturing an increasing share of bridge traffic offers an important growth opportunity for the water carrier, port, and railroad networks, which offer the lowest-cost bridging chain. The chain that flows from Europe through Gulf Coast ports to California has diverted traffic from East Coast ports and has increased the Gulf's share of California-bound shipments from Europe from 35 to 80 percent since 1976 (see Figure 2).

Figure 1. Import minibridge movements in the United States.

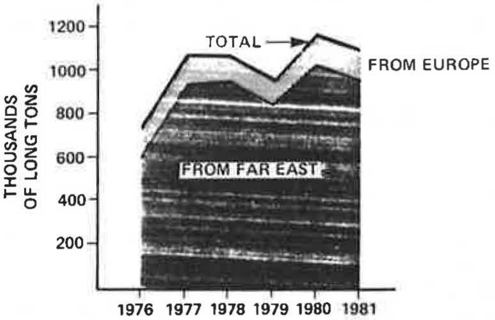
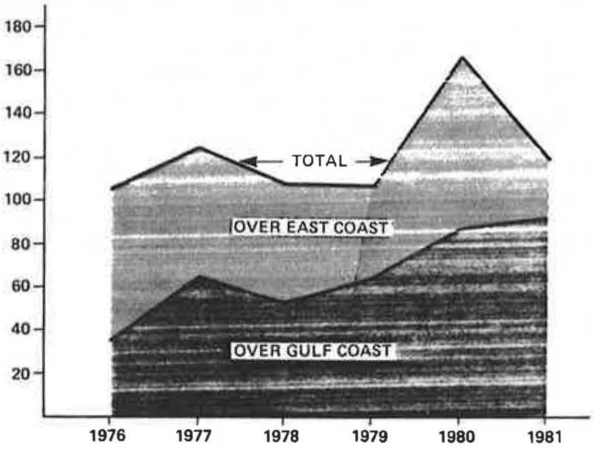


Figure 2. Minibridge movements from Europe to the West Coast.



Another example of a successful bridging chain is that of the Ports of Los Angeles and Long Beach. As shown in Figure 3, these two ports have increased their share of minibridge imports from the Far East from 55 percent in 1976 to 65 percent in 1981.

Container terminals are working to improve the productivity of their operations and to integrate those terminals that operate more efficiently with those of their transportation partners in order to capture a greater share of bridge traffic and improve their overall efficiency in these times of intense competition. Such improvements in container terminal operations aid both bridging and local container movements.

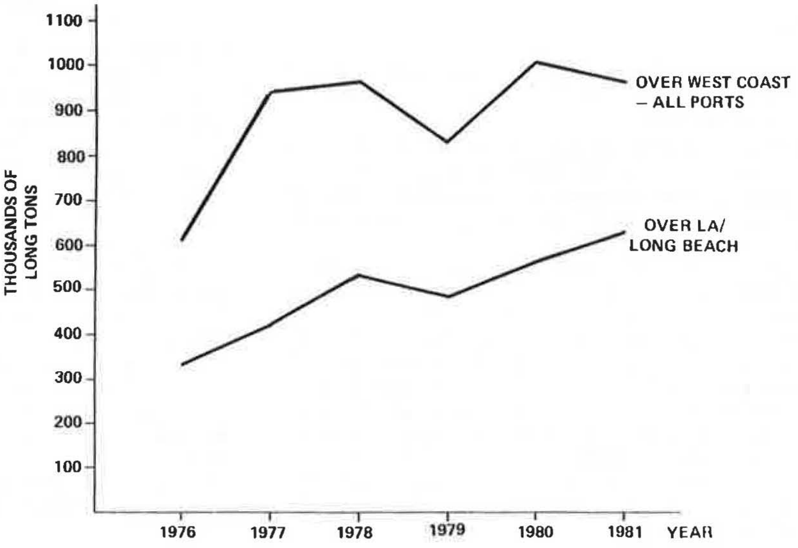
Although there are many opportunities to enhance overall efficiency, two of the most significant means of reducing terminal costs of moving containers are in the transfer of containers to rail sidings (rail interface) and the discharge and loading of vessels (water interface).

RAIL TERMINAL INTERACTION

In most ports, containers for bridge movements are transferred from the marine terminal to an inland terminal because, traditionally, rail terminals have not been located at sites adjacent to ports. For import containers, this requires discharging the containers from a ship and storing them on a chassis for a brief period of time. They are then moved (drayed) on chassis to the railroad siding and stored or loaded on a flatcar. Because of short storage time and rapid transfer rates, storing the container on a chassis in the marine yard is preferable to stacking. However, the process does require up to two sets of container moves, which cost approximately $30 each, and incurs a drayage cost of $100-$150/move. There are also other costs involved, e.g., the use of a chassis for transferring the container and rapid high-volume block container movements.

In these competitive times, it is no longer feasible to have a water carrier pay up to $200/container to link up to the railroad. This is especially true because the rail segment of the trip might cost only $900 (West Coast to Chicago) or $1200 (West Coast to East Coast). An entire move-

Figure 3. Far East import minibridge movements.



ment from the Far East might bring in only $2,000-$2,500 in revenue--and revenue levels are softening.

The long-term trend in high-volume bridging applications will be for the rail loading to occur at the marine terminal. Direct transfer of containers from the vessel to railcars is also possible. In high-volume applications, the terminal interacts directly with the railroad and not with an intermediary that adds cost, but no value, to the system. This integrated approach, however, is probably not feasible in low-volume bridging applications because of complexities in operating trains for a relatively small number of container moves and the cost of extending rail spurs to the port. To date, however, this integration concept is not widely accepted by the U.S. railroad industry.

Although no organization (as of yet) has made a commitment to completely integrate rail and marine terminal operations because of constraining technological and institutional factors, some companies are trying to integrate rail and water operations by reducing the distance between the respective terminals. These include the Ports of Los Angeles and Long Beach, New York City, and Sea Land.

Ports of Los Angeles and Long Beach

The Los Angeles and Long Beach port complex is serviced by three railroads: Southern Pacific; Atchinson, Topeka, and Santa Fe; and Union Pacific. These railroads have rail transfer facilities, located between 22 and 28 miles from the port complex, that serve both marine containers and domestic piggyback trailers. During periods of low traffic density, one-way road time between the ports and the rail yards averages about 90 min. During periods of peak traffic, the transfer takes much longer.

To reduce the cost of transporting bridge containers through the Ports of Los Angeles and Long Beach, the respective port authorities have agreed to jointly construct a new railroad yard for the railroads at a site approximately 2.5 miles from each port complex. This was determined to be more feasible than constructing two smaller rail yards at each port. The proposed facility is expected to be developed in four phases. At its projected completion in the year 2000, it will cost approximately $130 million. The facility is expected to increase the amount of bridge traffic carried through Los Angeles and Long Beach by reducing the cost to ship via these ports. So far, however, only Southern Pacific has expressed its willingness to use the new integrated facility.

New York City

New York City has captured only a small share of the container traffic that enters and leaves the Port of New York. This is partly because the city does not have as good a rail connection as do the facilities on the New Jersey side at Port Newark/Elizabeth. Only 2 percent of the waterborne container cargo is transferred to rail in New York City compared with 15 percent in Port Newark/Elizabeth. The city is attempting to improve railroad service to its ports by revitalizing its railroad car float industry. Reconstruction of a rail yard in Owls Head is under way to support railroad-based industries in Brooklyn. In another effort, the city is attempting to bring waterborne traffic back to the facilities located in New York City by developing a modern terminal in south Brooklyn. It has identified a rail link as an important ingredient to a successful terminal in south Brooklyn and is emphasizing the availability of the nearby Owls Head terminal in its planning efforts.

Sea Land at Tacoma

Sea Land Service recently announced its intention to relocate its port facility from the Port of Seattle to the Port of Tacoma. When the move occurs, the Port of Tacoma will increase its ranking from the fiftieth largest to the eighth largest container port in the country. There are many reasons for the move, one of them being the availability of a rail siding at the new terminal. Sea Land currently drays its containers in the Port of Seattle to and from its marine terminal--a distance of 30 miles. The company feels strongly enough about the importance of railroad access that it will not only bear the costs of moving to a new facility, but it will also incur additional ocean costs as its vessels will have to travel an additional half-day to reach the new terminal.

DISCHARGING AND LOADING VESSELS

An increase in crane productivity is currently one of the greatest leverage points in raising overall marine intermodal terminal productivity for vessel operators. Improved crane productivity reduces the port time of vessels calling at the terminal, and it lowers vessel costs by allowing operators to make more voyages per year. In addition, increased crane productivity allows the high overhead cost of cranes and berths to be spread over more container moves, thereby reducing costs.

Increasing the productivity at the berth aids in increasing overall transportation system efficiency and therefore promotes an increase in bridge traffic to those systems that pass through the terminal. In addition, increased productivity provides the unloading capacity needed to handle large blocks of container movements expeditiously.

The key to improving vessel discharge and loading is not increasing the speed of the crane motions or developing a new series of crane motions, but rather it is eliminating the constraints to higher production rates that are inherent in today's stevedoring operations. Meaningful results are being achieved by

1. Reducing the number of unproductive moves,
2. Reducing crane waiting time,
3. Decreasing crane cycle times,
4. Automating crane functions, and
5. Installing diagnostic computer systems.

Unproductive crane moves occur when containers are relocated within the vessel during port operations. Some unproductive (or redundant) moves are unavoidable; e.g., when containers are loaded with refrigerated or hazardous commodities, they must be placed above deck before reaching their destination. Some redundant moves can be eliminated by using computer-aided stowage techniques. These techniques expedite stevedoring planning by developing stowage plans that optimize vessel trimming (to reduce vessel operating costs) and by satisfying other loading criteria (e.g., port destination sequencing and hazardous commodity stowage).

Even the most productive terminal operation has idle cranes when there are containers to move. This can often account for as much as 15 percent of the working time of the cranes and results when the coupling of the stevedoring tractors, the crane, and the ship is out of synchronization. To prevent yard operations from slowing down crane operations, crane buffers are being employed, notably in the Matson system and by ECT in Rotterdam. The buffer device (Figure 4) provides a place for depositing offloaded containers and supplying containers to be onloaded.

Figure 4. Schematic diagram of crane buffer.

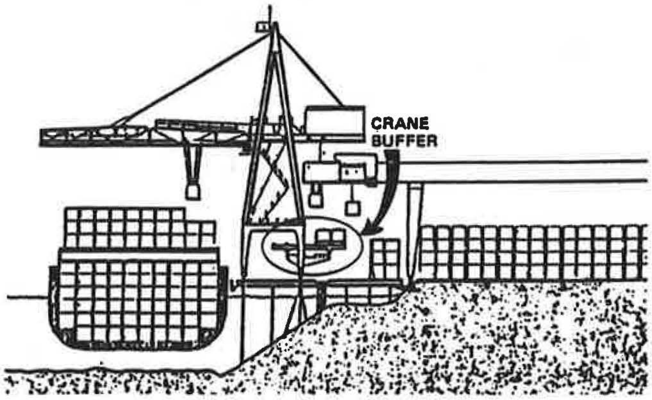
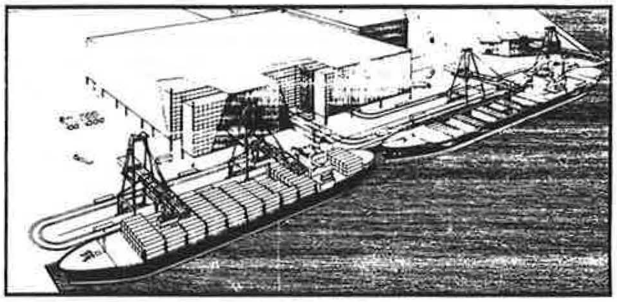


Figure 5. Possible future intermodal terminal.



Productivity is also improved by reducing the time used to locate spreader bars over containers and containers over chassis in order to decrease crane cycle times. "Dancing" motions can take 10 sec or more in a single crane cycle of 90-175 sec and are caused by the pendulum effect of the dangling spreader bar. Landside container guides and antisway cables reduce these unproductive hunting motions.

Container guides have been pioneered by ECT in Rotterdam and consist of movable guides at the roadway level underneath the crane. These guides eliminate the dancing by providing lateral support at the lower end of the pendulum. Another approach (available through Paceco, Kocks, and others as an option on their cranes) is employing antisway systems that reduce pendulum swings underneath the crane both on the landside segment of the cycle and on the shipside segment.

Semiautomatic crane functions also improve the discharge and loading of vessels by making production uniform. In a system developed for the Port of Los Angeles, the crane operator programs a microprocessor by going through one cycle of crane motions manually. The hoisting, lowering, and trolley travel of subsequent cycles are then directed by the computer for the remainder of the lifts at the hatch being worked.

In another approach, the Port of Seattle has provided computer diagnostic capabilities on its cranes. The computer monitors critical parameters such as temperature, current draws, and voltage drops to identify components that might fail. This warning system allows the component to be replaced before a breakdown during operation occurs, thus improving productivity by reducing equipment unavailability during critical periods.

These and other approaches that enhance crane production result in cranes achieving a production level of 40 moves/hr or greater.

LONG-TERM VIEW

Over the next 15 to 20 years, terminal systems will evolve in response to industry demands for increased terminal productivity and more effective integration with street and rail vehicles. The terminal systems of the future (such as the Paceco Speed-tainer system shown in Figure 5) will depart radically from those we see today. Technology will be used to the fullest extent possible as a vehicle for generating a large number of these changes. The terminal of the future will be more complex and more capital intensive, but it will also achieve higher levels of production and lower throughput costs.

In many respects, the modern container terminal may evolve in the same way as the modern bulk terminal of today--a sophisticated, high-volume, low-throughput-cost marine process plant that is fully integrated with its supporting railroad system.

Furthermore, the superior economies (but high required throughput levels) of these next-generation systems will combine with the possible emergence of 2,000 forty-foot equivalent unit (FEU) class vessels and a more rational regulatory environment to create a network of high throughput ports. Because the total volume of U.S. import and export traffic over the next decade probably will not grow substantially, the emergence of these ports will have to develop from a centralizing process. The innovative 6 to 12 ports that have access to the required rail networks and make the investment in technology will emerge as the future container load centers of the United States.

Analysis and Comparison of Rail and Road Intermodal Freight Terminals that Employ Different Handling Techniques

ERWIN HÉJJ

The purpose of this paper is to determine the possible advantages for rail and road intermodal freight terminals of eight different handling techniques by comparing them with transfer by gantry crane. Design concepts were drawn up for each technique for three typical terminal sizes that were designed for the forecast volume of intermodal freight in West Germany in 1990. Functional capability and cost were the bases for comparison. The terminals were also viewed within the context of the West German transport system as a whole. Although all of the techniques studied were found to cope with the peak-hour work load, there are major differences in terms of capital outlay and functional properties. The costs of terminals with handling techniques that involve little or no vertical movement are significantly higher than the others. None of the new techniques offers any advantages over the gantry crane. The unit handling costs of large terminals are not lower than those of medium-sized terminals. The handling costs in terminals are inferior to the total cost of inland intermodal freight transport. Based on capacity assumptions made for the typical terminals considered in this study, the optimum number of terminals for West Germany is 50 in terms of the total cost of the intermodal freight transport system.

Intermodal freight transport varies markedly from one country to the next. This is due, among other things, to differing statutory regulations, distances that have to be covered, and admissible dimensions and weights. These differences are particularly pronounced between the United States and Europe. Thus, only limited transfer of experience and know-how is possible.

A welcome exception is the international standardization of shipping container sizes, which has led to the establishment of uniform container handling techniques throughout the world. For inland freight traffic, however, transport units are still being used for which there are, at most, only national standards. [It suffices here to mention the swap bodies widely used in West Germany and the trailers-on-flatcars (TOFCs) used in the United States.] Terminals in the United States have to perform different tasks than do terminals in West Germany and are accordingly designed and equipped differently.

Despite the differences from country to country, the publication of major findings in one country can be useful to other countries. This is the case for the study of intermodal transport in West Germany carried out over the past few years by the Krupp Research Institute for the Federal Minister for Transport (1). The original aim of this study was to establish whether handling techniques that deviate from the conventional use of gantry cranes offered any advantages. The study was not restricted to freight terminals but covered the entire West German intermodal transport system, including rail transport and road haulage to and from the terminals. This was necessary because an isolated study of handling techniques or terminals could have produced misleading results.

Studies of various handling and transportation techniques for inland intermodal freight have also been undertaken in other countries, e.g., the United States (2,3) and the United Kingdom (4). It was not possible to include their results in this paper because both their objectives and terms of reference were different. The procedure employed in and the results gained from this study are, however, worthy of note because they are in part unique and in part generally applicable. They could thus provide food for thought in other countries.

HANDLING TECHNIQUES STUDIED

In all, nine handling techniques were included in the study. Eight of them were either selected from previous studies as being promising or were put forward at the beginning of the study (in 1978). The ninth technique, which furnished the basis for comparison, was transfer by rail-mounted gantry cranes such as that applied by Deutsche Bundesbahn in its freight terminals.

The handling techniques studied can be divided into three main groups. Classified into the first group are those techniques in which handling involves pronounced vertical movement of the load units. One example is transfer by gantry crane. This group is therefore designated vertical handling. The four members of this group are as follows:

1. System DB: In this system, gantry cranes straddle the tracks, road-vehicle lanes, and storage areas (see Figure 1). Transfer is by spreader for containers or grappler arms for swap bodies or semitrailers. (Note that system DB is used as the basis for comparison with the other systems.)
2. System DA: This is a rail-mounted gantry crane (see Figure 2). It differs from system DB in that it features an L-shaped lifting attachment that is capable of operating under overhead wires. However, this imposes restrictions on the layout of the terminal.
3. System AC: This system is for loading and unloading rail vehicles by using a special-purpose gantry crane that can operate underneath overhead wires (see Figure 3). It can handle intermediate storage of load units, and there is an additional rail-mounted gantry crane for subsequent loading onto road vehicles and also into storage.
4. System SF: This system is similar to system AC; the difference being that the gantry crane can serve a very large storage area so that the load units do not need to be stacked (see Figure 4).

The second group comprises the three following handling techniques, which entail little or no vertical movement and in which horizontal movement is predominant. This group is therefore called horizontal handling. One example of this technique--although it was not included in this study because of its impracticability in Europe (insufficient loading gage)--is the transport of TOFCs with road vehicles driving onto and off of rail vehicles. The horizontal handling systems are described below:

1. System R: Vehicles and ramps are fitted with powered roller conveyors (Figure 5) for the simultaneous transfer of all load units to the neighboring lane. In addition, the gantry crane serves the

Figure 1. System DB handling technique.

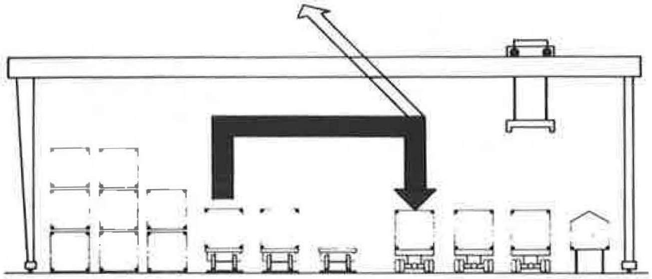


Figure 2. System DA handling technique.

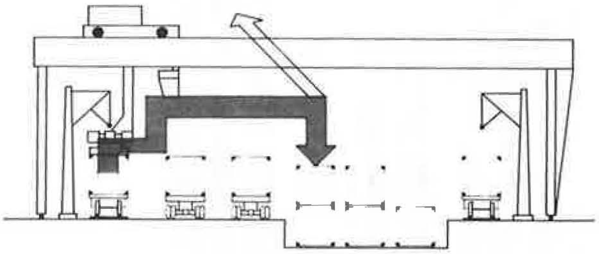


Figure 3. System AC handling technique.

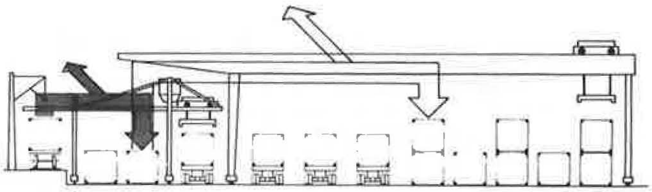


Figure 4. System SF handling technique.

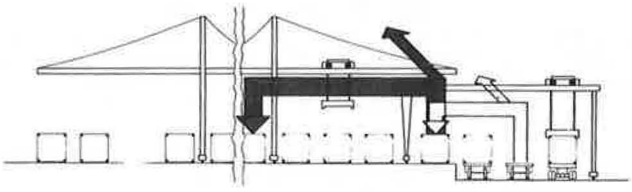
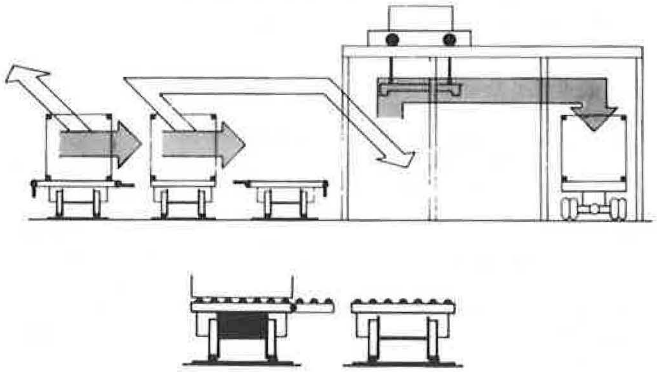


Figure 5. System R handling technique.



storage yard and is used for transfers to road vehicles.

2. System H: This system includes rail-mounted transfer equipment that picks up the load units from the neighboring track by lifting from below and subsequently loads onto road vehicles in the neighboring lane or vice versa (see Figure 6). To facilitate pickups, load units are in a raised position.

3. System W: The load units are swap bodies, which are unloaded from the road vehicle and positioned above the track so that the rail vehicle can move underneath and take the load (see Figure 7).

The third group is made up of two techniques that cannot be classified as clearly belonging to either of the other two groups:

1. System SH: This is a combination of handling equipment and high bay racks for the load units (see Figure 8).

2. System LS: This system is similar to system H, with the difference being that the transfer equipment grabs the load units at the top and can also put them down at ground level (see Figure 9).

TERMINAL ASSUMPTIONS

A comparison can only be objective if underlying conditions are uniform. Toward this end, the tasks and capacities of typical terminals were exactly defined in this study. The terminals were designed to accommodate the various techniques, and it was assumed that all the terminals would have to be built from scratch. The comparison was then made on the basis of a functional and a cost analysis.

In line with conditions prevailing in West Germany, three capacity classes for terminals were entered. These were defined as the number of load units that arrive at the terminal monthly by rail vehicles. On the basis of the forecast (5) that by 1990 a total of 23 million tonnes of goods will be transported by combined modes, 500, 3,000, and 10,000 load units per month were set as the capacities of the small, medium, and large terminals, respectively (sizes A, B, and C). Daily density,

Figure 6. System H handling technique.

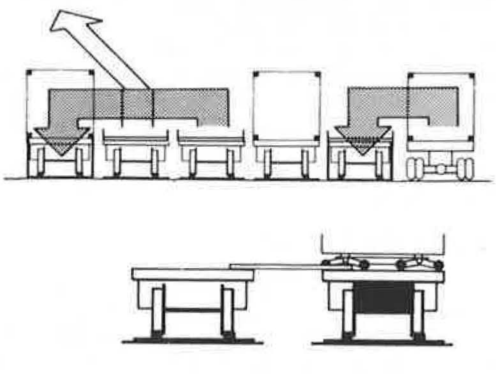


Figure 7. System W handling technique.

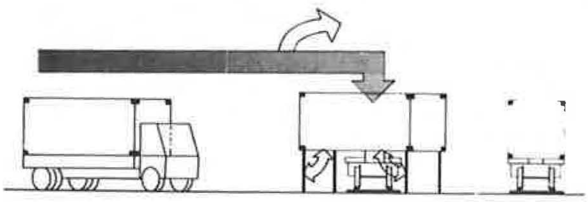


Figure 8. System SH handling technique.

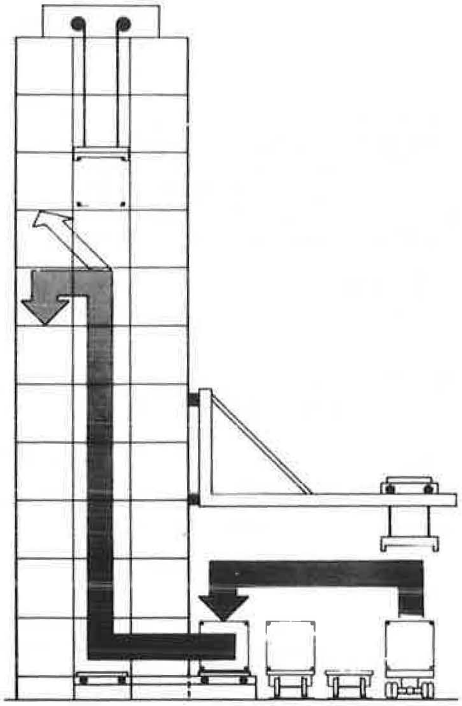
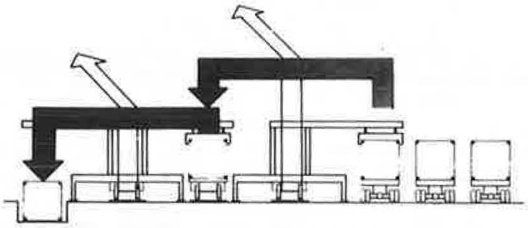


Figure 9. System LS handling technique.



peak-hour and peak-day work load, and the respective volumes of freight carried by container or swap body and semitrailers were projected for 1990 on the basis of data from current terminals.

Freight terminals, particularly those of high capacity, require a lot of space and involve considerable expense. As Figure 10 shows for the large system DB terminal, seven gantry cranes are required over two groups of track. Efficient use of equipment will keep costs, and possibly the amount of equipment needed, low.

SIMULATION USED FOR COMPARISONS

To examine efficiency and to determine the space and equipment requirements, the peak hour is usually considered. By determining equipment capacity use during the peak hour, a good reference value is obtained. Although this enables major errors in dimensioning to be recognized, the realistic examination of terminal concepts is only possible by computational simulation. A complex simulation program was therefore developed to look into all operations within the terminal, and this has proved an effective tool for analysis. Its structure and some of the results achieved are mentioned here because of their general importance.

A total of 12 origin-to-destination connections are possible in transfer operations between rail and road as well as storage and intermediate storage means in a freight terminal. Some of the events in these connections run parallel, but load units, times, routes, handling equipment, and priorities may differ considerably.

Figure 10. Layout of intermodal freight terminal size C, system DB.

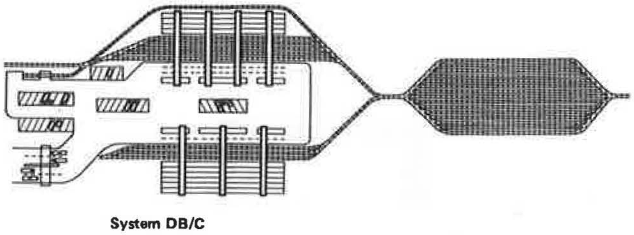
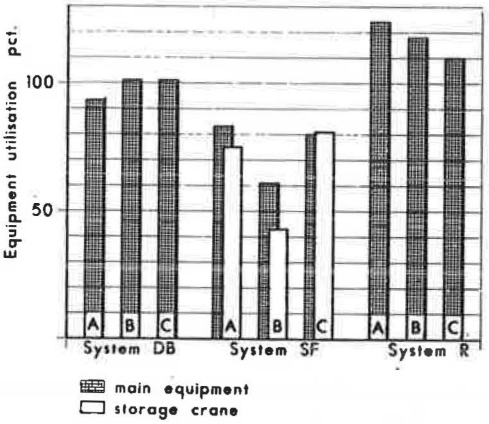


Figure 11. Peak time capacity use.



The various functions of the terminal are simulated in several quasi-parallel processes via event control. These functions include the physically active items (such as handling equipment, trains, and road vehicles) as well as administrative tasks (such as management of vehicles in the parking area or of containers in the intermediate storage yard awaiting transfer to the main storage yard) that have to be carried out independently of physical events. The necessary linking of the individual modular processes is effected by a central control unit.

The results furnished by the simulation program include the following items:

1. Specific time values (such as load unit transit times, road vehicle turnaround times, train stopping times, and handling equipment cycle times),
2. Load capacity utilization (e.g., handling equipment, and duty factor of in-terminal vehicles and various terminal areas), and
3. Sensitivity of the complex to changes in priorities, allocations, sequences, loading, and equipment breakdowns.

RESULTS OF SIMULATIONS

Functional analysis on the basis of equipment use in the peak hour and by simulation showed that all 27 concepts (9 handling techniques for each of the 3 terminal sizes) are able to perform the tasks set. Because of the characteristics of the individual techniques, there are major differences in the capacity use of the equipment in the peak hour. For example, Figure 11 shows that the gantry cranes in system DB are used to a large extent in all three terminal sizes. Although the equipment in system SF is in some cases badly underused, the equipment in system R is overloaded. The amount of equipment needed to cope with the work load differed considerably. As will be demonstrated, this has a major bearing on costs and capital spending. Unfortunately, only a few examples from the wide range of realistic results of the simulation calculations can be cited here.

Figures 12 and 13 represent the daily density diagrams of the handling jobs that employ systems DB and AC measured at half-hourly intervals in a size B terminal. Comparisons of the target and actual density curves show that both terminals satisfy the requirements. The fact that the target and actual lines are at times out of synchronization stems from bringing forward scheduled handling jobs. The higher volume of work in Figure 13 reflects the extra yard movements caused by the separation of the container storage yard from the intermediate storage yard and by the use of different equipment to serve these yards.

Figure 12. Daily density diagram of handling jobs for system DB, terminal size B.

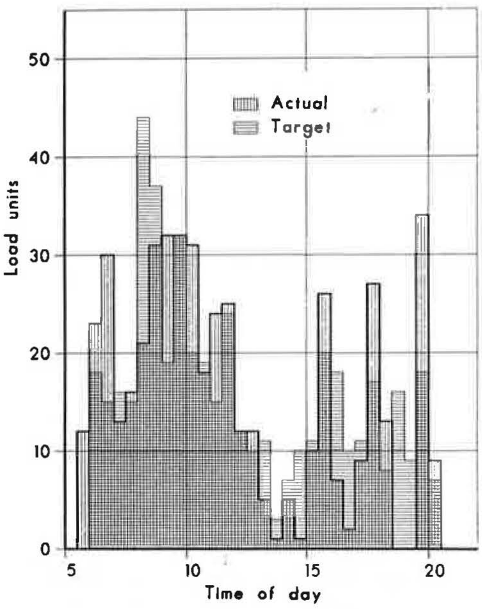
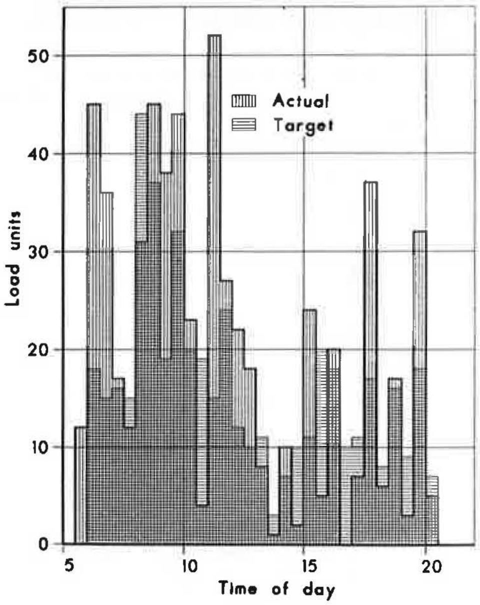


Figure 13. Daily density diagram of handling jobs for system AC, terminal size B.



Better insight into the performance and potential of the terminals is afforded by comparing terminal transit times. In the case of trucks, the transit time is identical with the turnaround time, i.e., the time spent in the terminal. Figure 14 shows a few examples for the mean turnaround times of the road vehicles and the transit time of the direct-transfer load units (rail and road and road and rail). Note here that terminal size B, which employs the LS technique, and terminal size C, which employs the AC technique, compare favorably with the others.

The selection of the correct operating strategy has a major influence on terminal productivity. Figure 15 shows the simulation results for the truck turnaround times in the size B terminal for three different working sequences in accordance with three priorities: P1, P2, and P3. Although system AC remains virtually unaffected by the changes in working sequence, the turnaround times in system DB show a steady drop as the working sequence changes from P1 to P2 to P3. In system LS, however, strategy P2 brings a substantial deterioration on P1 and strategy P3 brings a slight improvement.

Figure 14. Turnaround times of road vehicles and direct-transfer load units.

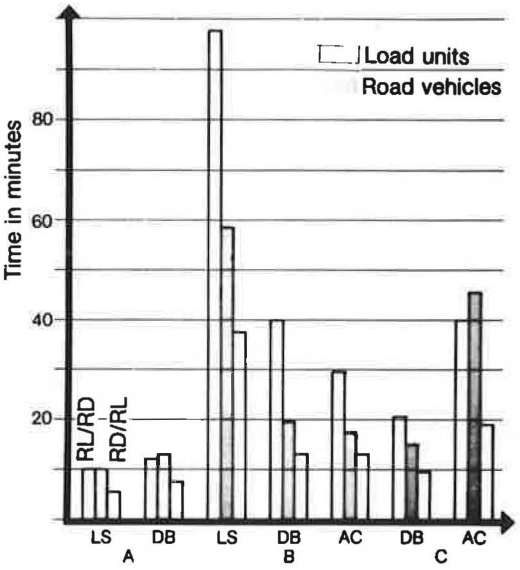
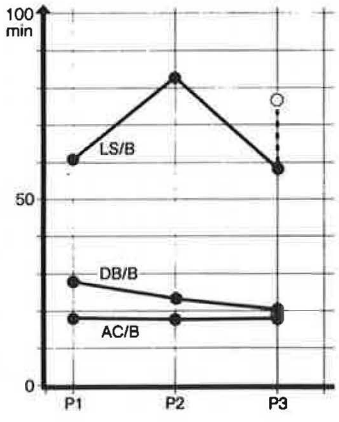


Figure 15. Changes in truck turnaround times that reflect changes in operating strategies.



The costs of simulation depend greatly on the specific circumstances of the terminal to be simulated. However, they are much less than, for example, the cost of a gantry crane that could be saved by optimizing terminal operations with the aid of simulation.

TERMINAL COSTS

Given adequate functional capability, profitability plays a decisive role in the comparative assessment of alternative terminal concepts. Everything else being equal, this is determined by the costs incurred. These in turn largely depend on investment expenditure. For all 27 terminal concepts, capital expenditure was therefore determined on the basis that all would have to be set up from scratch, including land, building, plant, and equipment. The total cost was then calculated by adding depreciation, interest payments, operating costs (utilities, repairs, maintenance, and so on), personnel costs (management, loading and unloading, supervision, operation of equipment), and miscellaneous costs (e.g., shunting). (Note that the figures given in the following graphs reflect prices and interest rates for 1978.)

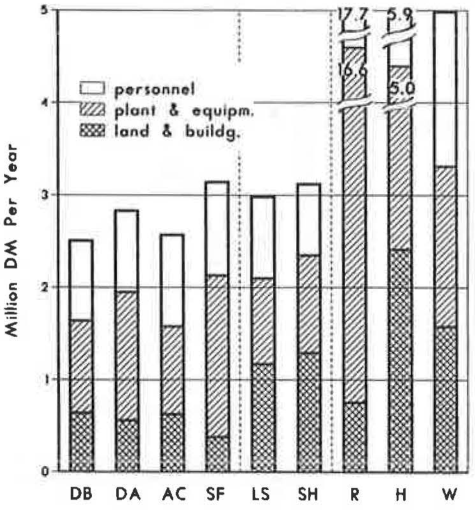
Figure 16 compares the annual costs of the individual techniques for the medium-sized terminal. Costs for plant and equipment in terminals of the horizontal handling group are pushed up by the fact that the vehicles, load units, or both require extra features (e.g., roller conveyors, supporting blocks) that are proportionally allocated to the investment cost for the terminal.

It is also noticeable that, for some techniques, equipment costs are far higher than land and building costs, whereas for other techniques the latter predominate.

Terminal sizes A and C exhibit the same ratio. It can be seen that the horizontal handling group involves, in part, substantially higher costs than the two other groups, which are roughly of the same order of magnitude.

It can prove very interesting to determine specific terminal costs, i.e., the annual costs that refer to the load units arriving at the terminal by rail. Figure 17 shows the specific terminal costs for the three groups as a function of monthly arrivals by rail. The poor position of the horizontal handling group is noticeable, but much more important is the finding that, from about 3,000 arrivals/month and more, specific terminal costs (unit costs) stop decreasing. This means that bigger terminals can no longer by advocated on grounds of cost. This finding is to be welcomed, at least in West Germany with its high population density, because proposals for the construction of large terminals are encountering ever-increasing difficulties.

Figure 16. Annual cost of size B terminal.



COST-BENEFIT ANALYSIS

As a final assessment of the alternative terminal concepts, a cost-benefit analysis was undertaken. To determine the benefit, a number of criteria relating to efficiency, reliability, and flexibility were defined and weighted according to their relative significance. The alternative concepts were given points according to how well they fulfilled these criteria. These were set against the cost ratio. Figure 18 shows that, for the size B terminal, a strange situation applies whereby system DB (the basis of comparison) provides the highest benefits and also involves the lowest costs. This finding also applies for the two other terminal sizes.

NETWORK EXAMINATION

Viewing the terminal in isolation (i.e., separate

Figure 17. Specific terminal costs.

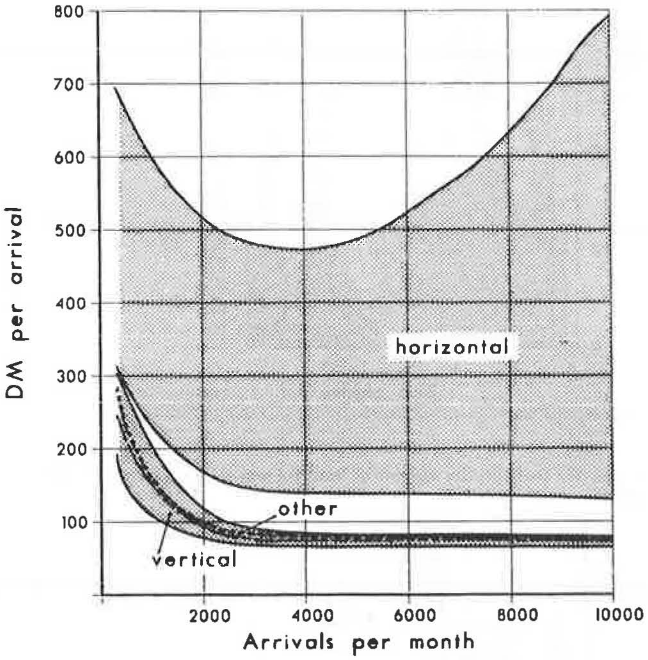


Figure 18. Cost-benefit comparison for size B terminals.

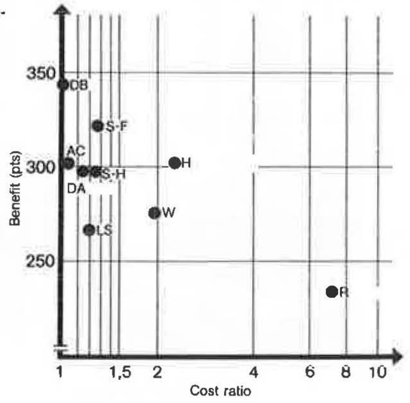


Figure 19. Total cost comparison.

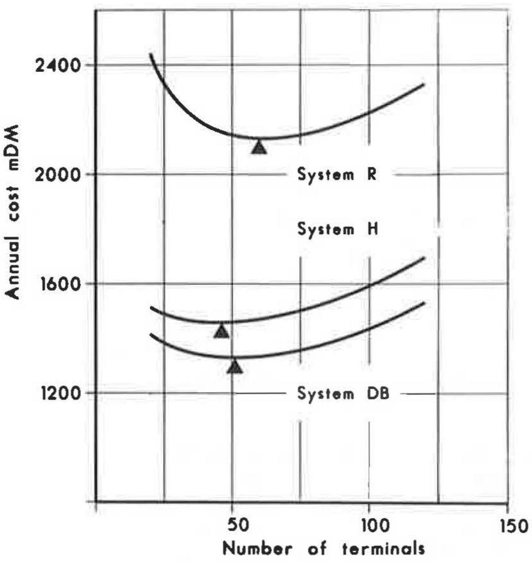
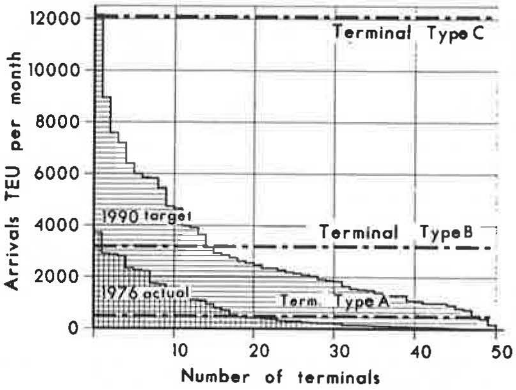


Figure 20. Terminal work loads.



from the transport system as a whole) can lead to wrong conclusions. Such errors are liable to occur when, for example, the basis of comparison--the three terminal sizes as defined--are out of line with future circumstances. To avoid such an error, the terminal study was followed by an examination of the transport system as a whole. The rail network that connects the terminals, optimizes rail transport, and connects the road links for forwarders and consignees with the terminals was studied. The total costs for several alternatives, which differ in the number of terminals, were determined. The details of this study cannot be dealt with here, but some of the significant and interesting findings are highlighted.

The annual cost of running the entire intermodal freight transport system is made up of the costs for rail transport (including operational service), for the terminal itself, and for road haulage. The cost for the terminal demands only 10 to 15 percent of the total costs against the cost of rail transport, which takes up by far the higher share. For a small number of terminals, the same is true of road haulage. Although the level of costs for rail transport increases with the number of terminals, road haulage costs rise inversely to the number of terminals. There is thus an optimum number of terminals at which the annual cost of West Germany's intermodal freight transport system, based on the assumptions made for this study, is at its lowest.

CONCLUSIONS

As revealed by the cost-benefit analysis (Figure 18), none of the alternative handling techniques examined offers advantages over the base technique practiced by Deutsche Bundesbahn, and some are much less favorable.

The optimum number of terminals at which the annual costs of the transport system studied is at its lowest was determined to be approximately 50.

Although the terminal costs are inferior to the total costs of transport, the overall optimum was determined for comparing handling technique DB with techniques H and R (both horizontal). As can be seen from Figure 19, the technique employed has no significant bearing on the optimal number of terminals. By contrast, the total costs for systems H and R rise substantially as a result of the higher terminal costs.

The final check was to determine whether the terminal sizes used in the comparison reflect real circumstances. For the optimum rail network with 50 terminals, the work load of the individual terminals was calculated. Figure 20 shows the results, including the situation as it was in 1976 (46 terminals). It is clear that the capacities selected for the typical terminals match very well the work loads expected for 1990. The graph also shows that capacity of the current terminals will have to be substantially increased to cope with future volumes of goods.

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Large or Small Terminals in Intermodal Transport: What Is the Optimum Size?

S.G. HOWARD

Intermodal terminals are frequently large and serve wide catchment areas. Whereas many believe these terminals must be large in order to be cost effective, in this paper the advantages of small terminals and a denser network of terminals than most systems currently enjoy are discussed. In many countries the largest flows of traffic are over relatively short distances (400 miles and often less), where road collection and delivery account for between a third and a half of the overall costs of an intermodal movement. Research in Britain and West Germany suggests that a much denser network of container or trailer-on-flatcar terminals could substantially reduce these road costs without an equal increase in rail movement costs. Such a network would require small terminals with a suitable pattern of rail services, perhaps linked through one or more container or trailer sorting centers. Freightliner's experience during almost 20 years of service is that small and medium-sized terminals are less costly per unit to operate and provide the shipper with a higher quality of service than do large terminals. Also, they are unlikely to be more costly to build per unit of capacity provided. Intermodal operations, which now face growing competition from road carriers and the effects of world recession, require innovation in order to remain viable and to expand. Successful features of existing systems, such as Freightliners' high-speed fixed-formation trains, need to be welded together with new and radical ideas.

Intermodal terminals for container-on-flatcar (COFC) and trailer-on-flatcar (TOFC) are frequently large, and it appears that their average size is growing. Many people believe that, like breweries or supermarkets, they need to be big in order to be economical. However, the experience of Freightliners, the large British intermodal operator, is that the larger the terminal, the higher the unit costs and the lower the quality of service to the shipper.

Freightliner has been in operation for almost 18 years and now handles around 1 million containers [measured in twenty-foot equivalent units (TEUs)] annually at the 25 terminals it owns and an additional 10 that it serves (mostly container ports). The Freightliner company (Freightliners Limited) is a fully-owned subsidiary of the British Railways Board but enjoys much autonomy in management. Freightliner does not undertake the movement of trailers (TOFC) by rail, nor does any other operator in the United Kingdom, because of restricted clearances and the arched design of railway tunnels and bridges, which are mostly less than 12 ft above rail level as compared with mainland Europe.

The various attributes of intermodal terminals of various sizes are examined in this paper by drawing on Freightliner's experience. These include economies of scale in terminal operation and construction and service quality. Terminal coverage is also considered. This is the density of terminals in urban and rural situations in relation to market requirements, train size and rail operational strategies, the rail network, and land availability. In a transit of up to 500 miles in Europe, road-collection and delivery costs are frequently the major cost element in an intermodal movement and are greatly influenced by terminal coverage.

ORIGINS OF FREIGHTLINER

Rail terminals or freight stations developed in Europe in the 19th century at intervals of around 5 miles, which was considered a suitable distance for goods to be collected and delivered by horse and cart. Although some freight railheads in Britain closed in the 1930s as a direct result of the development of the motor lorry (truck), big changes in the pattern of rail terminals did not occur until the 1950s and 1960s. Initially at least, the lorry was seen as complimentary to rail as it was able to collect and deliver goods over longer distances than the horse and cart. The number of rail terminals contracted and some lines closed altogether in this later period as freight rationalization, as it was euphemistically called, was carried out.

Gradually, times changed and the truck became as much a competitor as a conveyor to and from rail terminals. When Freightliner emerged in the mid-1960s, it was designed to combat competition from the trucker for the throughput (origin-to-destination) movement of freight. British Rail planned a Freightliner grid that would saturate the country with container terminals--more than 100 in all--yet most of these terminals were never built.

There is no single answer to why Freightliner developed as it did and not as it was planned. First, the weight and size of lorries were increased dramatically, beyond what was anticipated at the time of planning; and second, the national motorway (expressway) network began to develop. Both of these developments increased road competition with rail, which was further intensified with the abolition of road carrier licensing and full deregulation in 1969. At the same time, motorways and larger lorries allowed collection and delivery of containers over greater distances.

Freightliner terminals exist in the main conurbations (metropolitan areas) and principal cities only, with many relatively large centers being served from terminals 20 or more miles distant. The network is shown in Figure 1. Examples of this are Stoke, which has a population of 257,000 and is 43 miles from Manchester, and Plymouth, which has a population of 256,000 and is 120 miles from Bristol. Certain less-heavily populated parts of the country, north Scotland, north and central Wales, and the Southwest do not have terminals at all. Yet, the original plans assumed terminals would be built in all of these areas.

The decision to use fixed-formation (unit) trains has been a major factor in determining the share of the market that Freightliner has obtained, and this in turn has influenced the shape of the terminal network. These high-quality trains have helped Freightliner carry the large, relatively long-distance flows efficiently. But they have prescribed the market to the extent that the network does not provide adequately for smaller or more fragmented flows. Thus, there is no requirement for a diffuse network of terminals. Modifications to the fixed-train concept have progressively developed, with trains usually comprising 20 wagons (cars), each 60 ft in length, that are now capable of being split into 5 wagon sections so as to serve a wider spread of terminals.

Clearly, had road competition been less strong, Freightliner might have captured higher market shares and thus been able to operate more direct services than it does currently, including those over shorter distances. The reverse has been true, and as road competition has increased, the domestic container business has declined in 10 years from 406,000 to 315,000 containers/year. This decline,

Figure 1. Freightliner network.

though, has been more than matched by the most impressive growth in deep-sea maritime traffic, which has risen from 104,000 to 364,000 containers/year over the same period.

TERMINAL OPERATING COSTS

Freightliner has many types and sizes of terminals, all of which, except those at ports, are designed for the transfer of containers between road transport and rail wagon. Three particular types of inland container terminals, which are readily described as large, medium-sized, and small, have been selected for examination. All have rail-mounted, electrically driven portal cranes. Large terminals have wide-span cranes, with six lanes between the crane rails and two or three more lanes on either side served by cantilevers. These are described as having a 2.6.2 or 2.6.3 configuration (see Figure 2). The cranes at the medium-sized and small terminals that do not have cantilevers and serve only four lanes are described as 0.4.0. The 2.6.2, 2.6.3, and 0.4.0 cranes at medium-sized terminals are rated as class III, with a theoretical capacity of 3,000 operating hr/year. The small 0.4.0 cranes are rated class II and have a capacity of 2,000 operating hr/year. In practice, all types of cranes operate for longer periods, often up to 22 hr daily.

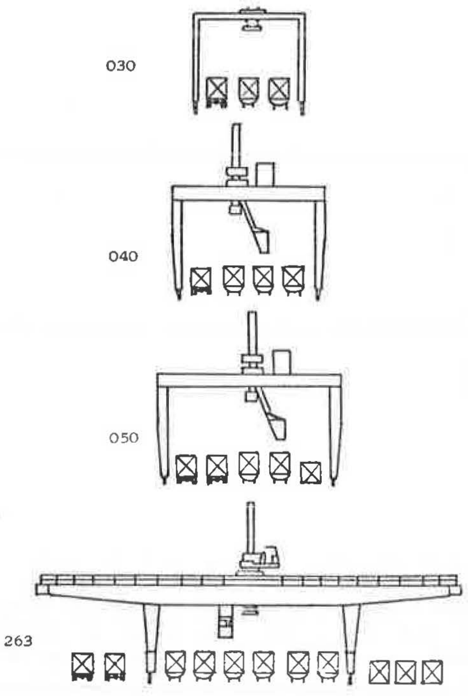
As far back as 1976, the Transport and Road Research Laboratory (TRRL) published a report (1) that concluded that unit costs were not lower at large terminals; indeed, they were higher. Comparison of unit costs between terminals operating at different levels of capacity is liable to create distortions, so the report also compared the three types of cranes already mentioned operating at maximum theoretical capacity. This gave the lowest unit cost for the class III 0.4.0 crane; followed by the class II 0.4.0 crane, which was 4 percent higher; and then the large 2.6.2 and 2.6.3 cranes, which were as much as 24 percent higher [see Table 1 (1)].

The earliest terminals on the Freightliner system, which were built almost 20 years ago, used Drott travelifts, which had rubber tires running on fixed heavy-duty concrete runways. As many as four were used in one terminal, although seldom did more than two operate at any one time. Throughputs in these terminals reached 250 containers/day, but the Drotts were fully stretched in meeting operational requirements, and it was decided to standardize on electric rail-mounted cranes. The basic design of the terminal has proved durable, with a crane transfer area (similar in length to the usual size of trains handled), one-way road circuit, and separate vehicle parking.

Apart from Kings Cross in London and Dundee where small class II portal cranes were used (so as to fit existing yard layouts), Freightliner's initial choice was class III 0.4.0 cranes, with 30 being supplied for use throughout the country from Edinburg in Scotland to Swansea in west Wales. For the conurbations, the much larger 2.6.2 or 2.6.3 cranes were used, with 13 going to inland terminals.

Freightliner was not alone in buying these very large portal cranes; a number of other European railways also ordered cranes of broadly similar configurations. These "goliaths," as they are called, are truly massive machines, weighing around 250 tons. On the face of it they have certain clear advantages over the 0.4.0 designs. Accommodation for trains can be increased with up to six being under the cranes at once, which is desirable given the train pattern in the United Kingdom of overnight movement between terminals, with trains standing in the daytime. Also, there is more container storage, and experience has showed that this had been greatly underestimated in the original planning. The cantilever provided the ideal means of servicing trucks without requiring them to cross one of the crane rails, as with 0.4.0 or similar cranes. These cranes also were designed with an ability to turn containers when lifted, not quite in a complete circle, but through 340°, which is a feature that the cantilever design made possible. Containers could thus be turned so as to ensure that end doors were positioned appropriately for both rail and road movement.

Figure 2. Examples of crane types and configuration used on Freightliner system.



The large cranes have generally proved more costly to operate and maintain and have proved less reliable, with overall maintenance costs being 20 to 100 percent higher than for the class III 0.4.0's. At many terminals the high dynamic loadings caused rail and beam failures and the costs of redesign and reconstruction have been high. Increased sophistication (partly untried) in electronic control equipment led to poor initial reliability, but advances in technology have allowed subsequent replacement of components at reasonable costs.

Throughputs and costs at selected Freightliner terminals are given in Table 2, together with a brief description of the transfer equipment used. To reduce the table to a manageable size, not all terminals have been included. The highest unit costs arise at the two largest terminals, although costs at Liverpool are appreciably lower than those at Manchester. Particularly interesting is the similarity in unit costs for medium-sized terminals, with throughputs ranging from 54,000 containers in 1981 at Leeds to as little as 23,500 at Nottingham. At Aberdeen, unit costs, which are well within the range of the other terminals, are achieved with a throughput as low as 9,800 containers/year. Kings Cross, surprisingly, achieved the lowest unit costs of all--10.2/container--and yet handled 31,100 boxes in 1981 with very basic equipment: class II 0.3.0 cranes. Freightliner unit costs are compiled on a comparable basis for all terminals. Comparison of costs with terminals in other countries is likely to be far less meaningful because different cost elements may have been included. There are two main elements in Freightliner terminal costs: basic handling costs and joint costs. These are as follows:

1. Handling costs--wages and other costs of handling staff, internal motor drivers, and maintenance staff associated with handling equipment; also included are repairs carried out by outside contractors, fuel and power, depreciation (of handling

Table 1. Freightliner portal cranes: theoretical costs per lift.

Equipment: Portal Cranes[a]	Capital Cost (£000s)		Life (years)	Annual Cost (£000s)		Working Hours per Year		Working Rates		Other Operating Cost[c] (£000s/yr)	Total Cost[d] (£/hr)	Cost per Lift[e] (£)
	Equipment	Installation[b]		Depreciation	Maintenance	Rated	Actual	Lifts per Hour	Maximum (lifts per day)			
Class III 0.4.0 30T rigid mast	140	112	15	17	4	3,000	5,000	20	380	94	25.7	1.35 = 100
Class III 2.6.3 30T rigid mast and turntable	350	280	15	42	10	3,000	5,000	25	475	115	40.1	1.68 = 124
Class II 0.4.0 30T rope hoist	70	56	8	16	2	2,000	5,000	15	285	74	19.8	1.39 = 103

Note: All costs are at October 1974 prices.

[a] For an explanation of configurations 0.4.0 and 2.6.3, see Figure 2.

[b] Installation costs for portal cranes are assumed to be 80 percent of capital costs of equipment.

[c] Other operating costs = (Freightliner terminal handling costs – depreciation and maintenance costs at throughputs equal to maximum working rate)/1.5 lifts per container.

[d] Total cost per hour = [total operating costs + interest at 10 percent (on average) annual investment]/number of hours working.

[e] Cost per lift = total cost per year/(maximum number of lifts per day x 250).

Table 2. Selected Freightliner terminals: traffic volumes and unit costs in 1981.

Terminal	Through-put (000s)	Unit Cost per Container (£)	Handling Staff Shifts (daily)		Main Transfer Equipment[a]	Ancillary Lifting Equipment[b]	Loading Area Serviced by Cranes[c]
			Main Cranes	Ancillary Equipment			
Large							
Liverpool	77.9	14.7	6	3	2 x class III 2.6.3; rail mounted, electrically driven	2 front-loaders (1L and 1E)	5400 (6x900)
Manchester (Trafford Park)	73.0	18.4	5	4	2 x class II 2.6.3; rail mounted, electrically driven	1 straddle carrier (L) and 1 front-loader (E)	5400 (6x900)
Medium-sized							
Leeds	54.4	10.9	6	1	2 x class III 0.4.0; rail mounted, electrically driven	1 front-loader (E)	2700 (3x900)
Nottingham	23.5	12.8	2	-	2 x class III 0.4.0; rail mounted, electrically driven	None	2700 (3x900)
Small							
London (Kings Cross)	31.1	10.2	4	-	2 x class II 0.3.0; rail mounted, electrically driven	None	1200 (2x600)
Aberdeen	9.8	12.1	1.5	-	2 x class II 0.4.0; rubber-tired, diesel powered	None	1200 (2x600)

[a] Crane configuration 2.6.3 and 0.4.0 are shown in Figure 2. The 0.3.0 crane spans 3 lanes as compared with the 0.4.0, which spans 4.
[b] Ancillary lifting equipment is provided for storing either loaded containers (L) or empty containers (E).
[c] Loading area is length of rail sidings (in feet).

equipment), and the hiring of any additional equipment; and

2. Terminal joint costs (of which only a proportion is attributable to terminal handling)--administration, management, and staff salaries; establishment costs (rents, rates, gas, water, and so on); maintenance of the terminal infrastructure; and terminal depreciation.

A major reason why economies of scale do not arise in terminal operations is that large terminals with large wide-span cranes are much more expensive to construct and operate than smaller terminals but do not give an increase in throughput of the same magnitude. Wide-span portal cranes do not have double the working capacity of class III 0.4.0 cranes; indeed, cycle times may sometimes be longer with the greater multiplicity of tasks to perform and wider span. The effect of this is that, at large terminals, the cranes are frequently unable to meet all the various requirements for lifting at periods of peak demand. This problem is usually overcome either by accepting delays in servicing trains and turning around (loading and unloading) road vehicles or providing additional container storage with separate lifting equipment away from the main transfer area. In Freightliner, most container storage at large terminals is now carried out away from main transfer areas, despite the fact that spare space to stack containers under the main cranes is available. This is costly and is more responsible than anything else for pushing up costs at large terminals to much higher levels than were anticipated.

It is significant that TRRL calculations give theoretical costs per lift for the wide-span portal cranes that are 20 percent higher than those of smaller cranes, and that more recent Freightliner studies show that large terminals that use these cranes incur unit costs (per container handled) and storage that are some 17 percent above those at smaller terminals. This suggests that the large terminal with large cranes is inherently more costly per unit of output than the small terminal. It does not, of course, exclude the possibility that cost-effective large terminals exist or can be designed. At the same time, it is of some importance to have demonstrated that small terminals are likely to be more cost effective than many large terminals, rather than the reverse, which is commonly supposed.

The figures on Freightliner unit costs (Table 2) demonstrate a further important characteristic of small and medium-sized terminals: broadly similar unit costs at a wide range of throughputs (9,000 to 54,000 containers/year) in respect to the terminals in the table. This is achieved by closely matching labor costs, which account for between 50 and 75 percent of total costs, to work load. The progressive increases in shifts worked and time periods over which cranes are scheduled to operate are given in Table 2 for the various terminals. The slight step effect on costs of introducing or withdrawing handling-staff shifts is usually offset by variations that may occur at other levels of throughput, such as in the numbers of other staff, i.e., administrative, sales, maintenance, and supervisory.

TERMINAL CONSTRUCTION AND EQUIPMENT COSTS

Of the earliest Freightliner terminals, only Aberdeen remains virtually unchanged. At other terminals, Drott travelifts have been replaced by electric cranes, and large areas for containers and lorry parking have been added over the years. The majority of electric cranes were installed in the period between 1967 and 1971, when the major expansion of Freightliner took place, and are still in operation. During the past 10 years, inflation has greatly increased construction and labor costs, which are a large element in construction and have risen substantially in real terms. This and technology have changed relations between the different elements in construction costs as compared to when the terminals were built.

There are many reasons why exactly similar terminals would not be built today. Yet most of the research carried out in other container transfer systems has not produced any new method that is obviously more economical than overhead cranes. The Research and Development Division of British Rail, after examining most commercially built mobile handling equipment, along with various novel forms of horizontal and end transfer, concluded that only a rail-mounted transfer car (Linercrane) would produce significantly lower unit operating costs than overhead cranes. Advances in technology over the past 10 years have brought improvements in the cranes that would be applied in the construction of new terminals, particularly in the electronic field. Control gear would be less costly and more reliable, and the microchip makes automation readily attain-

Table 3. Hypothetical terminal construction and capacity costs.

Terminal	Container Capacity[a] (per year)	Construction Cost (£000 000s) Main Cranes	Other[b]	Total	Lift Capacity per Year[c] (000s)	Unit Cost per 1 Container per Year Capacity (£)	Main Transfer Equipment
Large	90,000	1.9	2.28	4.18	247	46.4	2 x class IV 2.6.3
Medium-sized	60,000	1.1	1.32	2.42	168	40.3	2 x class III 0.5.0
Small	30,000	0.4	0.48	0.88	108	25.1	2 x class II 0.4.0

[a] Capacity assumed is based on experience and assumes some double lifting of containers by the main cranes, as well as unavoidable idle time.

[b] Other costs have been based on multiplying main crane costs by a factor of 1.2, but they are similar to notional costs, which are calculated to cover infrastructure (crane beams, roads, rail lines, and offices), power supply, and ancillary lifting equipment for the various sizes of terminals.

[c] Lifting capacity per year is based on 225 working days/year and the following performance factors: class IV cranes = 25 lifts/hr x 22 hr/day; class III cranes = 20 lifts/hr x 18 hr/day; and class II cranes = 15 lifts/hr x 16 hr/day.

able. Computers can also be used to control operations hour by hour.

It is difficult to estimate accurately the cost of building an intermodal terminal today without designing it first and then pricing the materials and the work involved. That can be a long process and is itself costly. In using notional costs to compare the costs of building terminals, it is necessary to accept appreciable margins of error, but tentative conclusions can be valuable pointers for decision making and the need for further research.

It is commonly supposed that large terminals, although more expensive overall to construct, are significantly less costly in unit terms (cost per unit of capacity). This is not supported by the comparisons given in Table 3 between hypothetical terminals of various sizes, based on Freightliner practice. The levels of capacity that have been selected are in all cases less than 40 percent of the theoretical lift capacity available. Lift capacity has been calculated by multiplying the number of hours worked daily by the number of lifts possible per hour (assumed cycle times), both of which are also given in Table 3, and then multiplying this figure by 225, the likely number of days in a year that a terminal might operate. This margin of some 60 percent covers the double handling of containers--at most Freightliner terminals, containers are lifted between 1.5 and 2 times by the primary transfer equipment--and idle time, which is often unavoidable, particularly at night.

The prices shown for the various cranes are estimates of what they might cost if purchased today. Other costs include virtually everything else at a terminal apart from main cranes. The main items are rail lines, roadways, supporting crane beams, trailer parking, container storage (with ancillary equipment at the large terminal), power supply, lighting, offices, workshop, and so on. The figures used are somewhat arbitrary and are obtained by multiplying the costs of the main cranes by 1.2, but accord closely with estimates produced by Freightliner engineers of what existing Freightliner terminals might cost to build today at current prices.

Firm conclusions on economies of scale in terminal construction cannot be drawn without further and much more detailed research, but this preliminary work does suggest that small and medium-sized terminals can be built at no greater cost per unit of capacity provided than large terminals and most probably much more cheaply. A small terminal may also be able to make use of existing rail infrastructure, roadways, and rail sidings so as to reduce further expenditures. This had not been assumed in Table 3. At Kings Cross in London and Aberdeen, existing rail sidings, roadways, and offices were used, whereas at no large or medium-sized terminal has this been possible.

SERVICE QUALITY

Rail services that compete directly with road transport must match service quality as well as price to be competitive. The consequences of not doing so may be serious and result in a much lower rate (charge) level, up to 15 percent perhaps, than might otherwise have been obtained or a substantially reduced market share. Intermodal rail services operate in markets that are particularly vulnerable to road competition.

In recent years, as the road network in most countries has dramatically improved, so has vehicle technology. This, coupled with the simplicity of road haulage as compared with intermodal operations and the highly personalized service road operators are able to give, frequently gives road the competitive edge. Road businesses tend to be relatively small and sensitive to customer needs, whereas rail and intermodal operations are normally large and are all too often institutionalized and less responsive to the market.

An intermodal service is like a chain with many links: all must hold together for the service to perform efficiently. A recent study by the Research and Development Division of British Rail into service quality on Freightliner reached the following conclusions:

1. Road collection and delivery are the areas of activity where most failures occur,
2. Failures are most frequent where activities are operating close to capacity, and
3. Service failures are heavily concentrated in the largest terminals.

A road-collection and delivery service has many attributes, with some independent of terminal operations, but others--such as the ability to perform timed collections and deliveries efficiently--are closely linked to terminal performance. In Freightliner, as many as 50 percent of the shippers in the domestic business require timed (scheduled) collections and deliveries, which can only be achieved if vehicles are not unduly delayed at terminals.

Sixty percent of the complaints examined in the research study of service quality arose at only three terminals, all of which were large. As more traffic is handled (in aggregate) at large rather than small terminals, this is not surprising; but the position revealed was that complaints were between two and five times more likely at large than small terminals per unit of business actually handled.

An external consultant brought in to assist in establishing meaningful criteria for the assessment of system and terminal performance came to conclusions that were not too different from earlier work by the Research and Development Division. It was found that shipper appreciation of the service was influenced particularly by the following attributes: ease of booking, on-time collection of containers, on-time delivery of containers, container delivery in good condition, container contents complete and undamaged, quick turnaround of road vehicles at the terminal, trouble-free documentation, and prompt information in the event of problems.

The consultant then proposed various means of assessing performance in these critical areas of activity. Performance indicators were constructed that would measure the turnaround of private vehicles in the terminal, containers forwarded on the days scheduled, train punctuality, and security of the container and its contents. These were all considered important in relation to the service given shippers, because their perception of an intermodal service is influenced by performance in these areas.

The system has only been operating a few months, so it is too early to draw firm conclusions. To ensure an acceptable overall performance, terminals will need the ability to handle current traffic, even in the busiest periods, with sufficient reserves of capacity to cushion shippers from all but major disruptions--and at a realistic cost.

The turnaround of private vehicles achieved at the various terminals in November 1982 is given in the table below:

Terminal	Trucks Detained More Than 45 Min (%)
Large	17
Medium-sized	13
Small	3
Network avg	16

That small terminals appear to produce the best results, with medium-sized terminals next and large terminals last, should come as no surprise, but it must be emphasized that these are from the early days in the performance measurement. Overall, there is an improvement as compared with a study undertaken in 1975 by TRRL, which concluded that the average dwell time for road vehicles (including Freightliner's own) was between 50 and 60 min. Figure 3 shows that now only 16 percent of the private vehicles entering terminals are detained more than 45 min. The figures are not, strictly speaking, comparable because the current results exclude Freightliner vehicles, but an improving trend is nevertheless apparent.

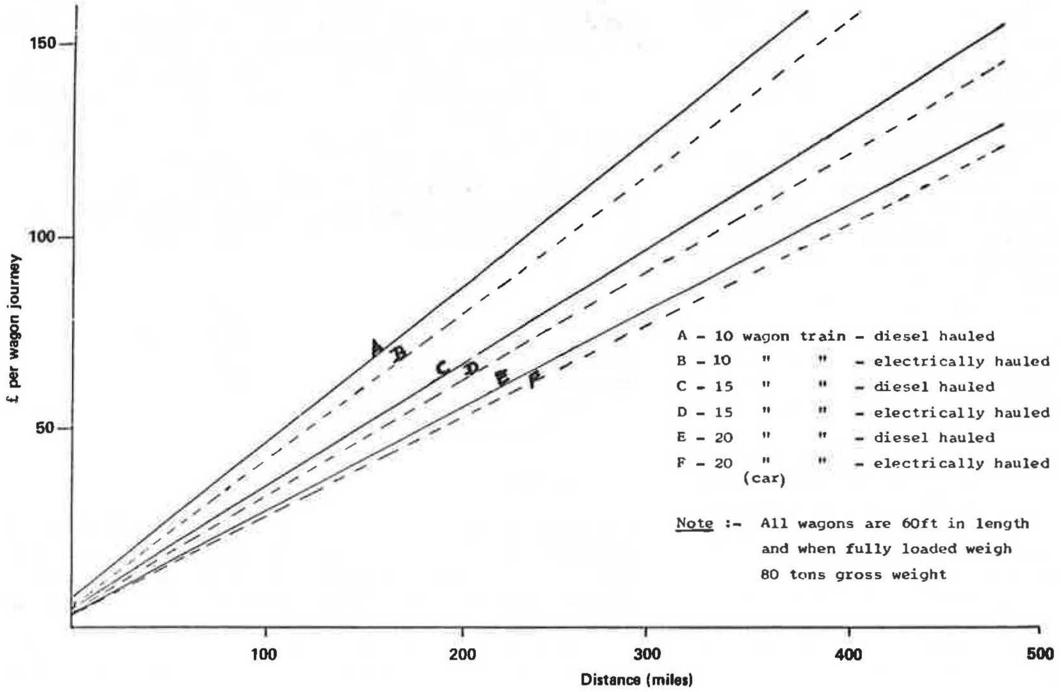
TERMINAL COVERAGE

The reasons why the Freightliner terminal network comprises large and widely spaced terminals, given the industrial nature of much of Britain, have already been discussed. The direct, permanently coupled trains have achieved a high quality of service and wagon use, but the large terminals have proved inherently expensive to operate in terms of unit cost. Widely spaced terminals also involve road collection and delivery of containers over long distances, which is more expensive (obviously) than delivering from closely spaced terminals.

The competitive situation in the United Kingdom has not favored rail in recent years. Whereas deep-sea (world-wide) and European (short-sea) container traffic have been reasonably buoyant, the effect of increased competition from road transport on inland traffic has been great. In short, carryings have fallen and margins have become depressed. This is not a recent phenomenon; the development of a national motorway network and increases in road vehicle efficiency and carrying capacity have been progressive over the past 10 years, but now these factors, which are exacerbated by recession, have depressed margins as never before. Road transport rates have not risen appreciably, and in some areas they have actually fallen over the past 12 months. In May of this year, the gross permitted weight for road vehicles was further increased from 32.5 to 38 tons.

Freightliner has pruned its costs with vigor, but unfortunately this has not improved margins by the

Figure 3. Comparative line-haul costs by size of block train for diesel and electric traction.



Note :- All wagons are 60ft in length and when fully loaded weigh 80 tons gross weight required amounts. Road collection and delivery costs that absorb around half the revenue--and this may be true of other intermodal networks--are a prime target for reduction. Road vehicles are now more expensive (in real terms) to purchase, operate, and maintain than 5 years ago; and whereas the motorways have increased the productivity of vehicles operating over long distances, urban traffic congestion has worsened the productivity of vehicles operating from Freightliner terminals.

Road-collection and delivery costs have to be reduced if intermodal operators are to remain in business on the short-haul routes of up to 400 miles. In Freightliner, great efforts are being made to improve the efficiency of the vehicle fleets based at the various terminals. This is important, but by itself it is unlikely to transform the economics of the inland services. An expansion of terminal coverage through a denser network of smaller terminals could reduce road-collection and delivery costs by as much as 30 percent, according to the Research and Development Division. A national study showed that the current 25 inland terminals would be replaced by around 100. In greater London--one of the largest urban areas in the world--the current 3 terminals would be replaced by 12. The small terminals, as we have seen, need be no more costly to build or operate than large terminals.

Rail movement costs in the United Kingdom are around one-sixth of the road movement costs, so if rail movement is increased and road costs reduced, overall costs of intermodal transit should be reduced. In theory, increasing terminal density or coverage should have that effect, but in practice it is not quite so simple. There are implications for rail line-haul costs of fragmenting traffic between a greater number of terminals. Line-haul costs for different sizes of trains that use electric and diesel haulage over various distances are shown in Figure 3. The aim must be to provide wider terminal coverage with reduced costs of road collection and delivery, without appreciably increasing line-haul costs, through using less-economic sizes of trains or increased shunting (sorting) of wagons.

On the European continent, there generally exists a denser network of container terminals than in the United Kingdom, although there has been a trend in recent years toward closing smaller terminals and concentrating traffic in the larger terminals. The European railways achieve this denser terminal network by continuing to send individual container wagons by conventional freight services and sorting them at intermediate marshaling yards.

Research in the United Kingdom and in West Germany has supported this wider terminal coverage but has rejected the individual movement of wagons and the use of marshaling yards for sorting. Schwanhäuser (2) of Aachen Technical University argued that container transfer stations were necessary in West Germany because the movement of wagons through marshaling yards was slow and expensive and uncompetitive with road transport. He went on to describe a container transfer station where a mobile transfer machine mounted on rail tracks (containerumschaggerat) would exchange containers between trains.

In the United Kingdom, research has been undertaken in container network design, with the principal aims being to reduce the break-even distances at which Freightliner is competitive with road, to increase the density of terminal coverage, and to permit the movement of containers between any pair of terminals. The most obvious way of achieving this denser terminal coverage and wider choice of destination is through sorting containers, preferably at terminals built especially for that purpose.

There are a number of forms that these terminals or sorting centers might take, where Schwanhäuser's ideas differ in detail, if not entirely in concept, from those researched in the United Kingdom. The basic ingredients in a sorting center are low cost and rapid transfer of containers between trains. Trains would remain coupled during the sorting or exchange of containers and no wagons would be shunted. In a small country there might be one central sorting center, whereas in a large country there might be a number that cover defined regions. All terminals would forward all containers, except those in sufficient quantities to justify direct rail services, to a sorting center. In the United Kingdom it is unlikely that containers would need to pass through more than one sorting center; in a large country, though, it is possible that they might need to be sorted more than once.

A sorting center might have one or more (probably two) container transfer areas where wide-span portal cranes would serve six trains standing alongside each other, among which containers would be exchanged. No containers would be transferred from rail wagon to road or vice versa. In the United Kingdom, research has shown that a typical sorting center might need to be capable of handling 820 container wagons and 1,500 containers in 24 hr. The table below compares the cost and efficiency of a container sorting center with modern marshaling (classification) yards in Switzerland (note that marshaling yard figures are based on Muttenz II, Basle, and Limmental in Switzerland):

Item	Container Sorting Center	Marshaling Yard
Capital cost (£000,000s)	6.5	25
Unit cost (£)	5.8	16.4
Area (acres)	20	300

A sorting center requires only 10 percent of the land of a marshaling yard, and construction and operating costs are calculated to be 25 and 33 percent, respectively, of marshaling yard costs. Also, there would not be the damage to wagons and merchandise that frequently arises from the impact of wagons striking each other during shunting.

Sorting centers should reduce overall transit costs, thus reducing break-even distances for container services by shortening the distances over which containers are collected and delivered by road and by improved use of rolling stock. It is calculated that overall costs would fall by 12 percent on a movement of 250 miles, and collection and delivery costs, which are currently 50 percent of overall Freightliner costs, would fall by 40 to 34 percent of the total, as given in the table below (note that operating costs are for a typical transit of 250 miles):

Item	Operating Costs (%)
Rail haulage	20
Wagon and container provision	16
Terminal handling	14
Road collection and delivery	50

CONCLUSIONS

The fear of reproducing the complex network of rail terminals that existed before intermodal transport and the perceived economies of large and small terminals have led to a wide spacing of terminals in some countries. This simplifies the rail operation and increases road-collection and delivery distances, which is perhaps what some operators had intended to achieve. Yet rail movement costs are substantially lower than road movement costs, and road collection and delivery of containers or trailers are particularly expensive because of the low level of use of the motor units usually obtained. On the other hand, a denser terminal network could substantially reduce that cost without necessarily increasing rail costs by an equal amount.

After describing why the development of Freightliner took the form that it has today, the extent to which economies of scale have been achieved in terminal operation (by contrasting costs and performance at terminals of various sizes) was examined. The results of work undertaken by TRRL in 1976 and by the Research and Development Division of British Rail and Freightliner more recently show that unit costs for small or medium-sized terminals that are between 15 and 25 percent lower than those at large terminals. Interestingly, both theoretical studies, which cover per-lift costs for different sizes of cranes and average costs per container of throughput for various sizes of terminals, show broadly the same magnitude of difference between the large terminal, which uses the large crane, and small or medium-sized terminals. Average costs per container are a relevant measure of cost-effectiveness, provided that terminals are not operating well below rated capacity. Such costs reflect field conditions, where the pattern of terminal activity is influenced by the characteristics of rail and road traffic movement.

Small terminals with small cranes appear to be inherently less costly, the equipment and infrastructure required being much less elaborate and less expensive both to provide and maintain. At small terminals, labor costs are a higher proportion of total costs, but providing these can be varied to match throughputs; relatively uniform levels of unit costs can be achieved at almost any level of throughput. Initial performance measurements carried out at Freightliner terminals also appear to point to higher-quality service to the shipper at small rather than large terminals.

It needs to be said that perhaps these conclusions apply only to large terminals as Freightliner has designed them. It is likely that there are parallels elsewhere, but this has to be demonstrated. It is also likely that large terminals could be designed so as to avoid many of the defects discussed. However, that is a subject in itself. Freightliner experience does suggest that large terminals, if they are to be built at all, should not have just a few sophisticated and expensive cranes, but a greater number of smaller transfer devices.

The significant point about the comparisons is that it is the small terminal that both exhibits the lowest unit costs and offers the best opportunity for reducing road-collection and delivery costs through increased terminal coverage or density.

Increased terminal coverage need not result in dramatically increased rail haulage costs or in sacrificed service quality. The central sorting of containers or trailers at specially designed interchange centers facilitates a network of small terminals and private sidings that are served by intensively used low-cost block trains that operate to and from the centers.

As the recession continues and competition grows, intermodal operators must pursue not only technical innovation, but must also thoroughly explore new concepts and ideas in terminal and system design.

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Intermodal Freight Terminal—An Open System: The Infrastructural Perspective

JEROLD B. MUSKIN

Attention is focused on those people who are involved with the planning, design, and operation of intermodal freight terminals and their essential support systems, i.e., their infrastructures. The interface role of intermodal terminals is significantly constrained by the quality of the related infrastructure, how it is operated, how access to it is controlled or regulated, and what pricing practices are applied. The intermodal freight terminal is a characteristically complex system operating, as it does, between two dissimilar modes of transportation. This means that terminal performance is affected by at least two separate operating policies. The terminal's administration must accommodate to the scheduling and performance standards of the management of the two modes and at the same time achieve acceptable levels of throughput—at a profit. Confounding these and other related matters is the infrastructure issue. Where two modes are involved, there are, necessarily, two dissimilar rights-of-way. Each may have different capacities and restrictions, neither of which is under the control of the intermodal terminal operator. For example, an ocean container terminal may be faced with uncertain channel depths, custom delays, tugboat and pilot shortages, and limited crane capacities on the waterside and, on the landside, traffic congestion, length and weight limits, clearance restrictions, and oppressive traffic regulations. Other infrastructural elements of concern include communications; labor quality and availability; services such as refrigeration, chandlery, fire, and police; medical services; and line-haul and distribution networks for the modes in question. The infrastructure concept is presented descriptively along with systems planning and analysis. Examples of intermodal freight terminals in the context of their infrastructure are offered to illustrate the need to take infrastructure into account in planning, designing, and operating intermodal freight terminals.

Intermodalism is the fusion of the services of distinct carrier types designed to improve the physical distribution performance of freight movements, thereby achieving less costly and wider access to product markets and supply sources. Intermodal applications apply to freight movements that may require or benefit from transfers of freight between the modes. A principal factor that distinguishes intermodalism from the simple cooperation of transportation modes is the method by which the freight transfer is accomplished. Current intermodal technology employs the highway trailer or the modes-adaptable container to achieve the transfer. Cooperation is achieved by the transfer of individual packages or unitized groups of packages from one modal container to another (1).

The freight-bearing equipment, the transporting units, and the mechanical interfacing apparatus by which the intermodal transfers are accomplished are, necessarily, viewed and dealt with as a system; that is, system in the interacting elements sense. The design, capacity, and operating characteristics of each of the elements are constrained by the design, capacity, and operating characteristics of the companion elements. As the design or operation of one element is altered, some other elements are affected; therefore the system is altered, and the outcomes produced through the system are changed.

Intermodal freight terminals (IFTs) provide the location, mechanical devices, space, and operating conditions under which the transfer functions take place. Site selection, facility design, transfer technology, and administrative and operating practices are intended to achieve efficient container transfer. Space and structure considerations should reflect storage requirements, freight congestion avoidance for vehicle operations, and growth expectations. All of these elements fit together to represent the IFT subsystem of what is the wider total system. Usually, the IFT subsystem is seen as a costly constraint on the wider intermodal system and is responsible for backups and delays. To make such a judgment suggests that there is some standard by which IFT performance can be measured. If measurement is possible, can reliable design criteria for the handling of intermodal units at IFTs be established? There are several reasons why this will not be likely. The one considered here is that IFTs cannot be designed, operated, or evaluated according to valid performance standards until the total system in which IFTs function is identified and brought under scrutiny.

TOTAL SYSTEM

The panorama of intermodal freight system elements can best be viewed from the vantage point of the marine container terminal. We can observe the diversity of modes, factors, and considerations that influence the elements and their interactions. That is, we can identify and thus evaluate the entire commercial intermodal system, taking into account the widest range of modal alternatives. Further, the intermodal system can be placed into the context of the physical distribution system. [Note: Reference is made to the commercial system to recognize that additional interactions exist. These include environmental, political, recreational, and community considerations, both as inputs and products of IFTs. Awareness of these elements establishes the IFT as an open system (not self-contained or closed) and points to another area that requires analysis.]

System Goals and Standards

As expressed at the outset, intermodalism is employed to improve the physical distribution performance of freight movements in situations in which the attributes of two or more transportation modes are necessary to accomplish the move or are desirable for efficiency reasons. The physical distribution performance considerations normally include time in transit, security and reliability of delivery, handling and administrative costs incurred by the users of the transportation services, and transportation charges assessed by the carriers.

The two measures that can most clearly be applied to the performance of the intermodal system as it relates to its physical distribution efficiency goal are described as

1. Throughput, which expresses the number of freight-bearing equipment units that pass through the system in a specified time frame [for rail and ship or truck and ship operations, the term used is the twenty-foot equivalent unit (TEU), which reflects the increments in which intermodal units occur; one wonders, however, if the 20-ft standard will survive the 1983 U.S. law that permits 28-ft double trailers on major highways; the change also raises questions regarding the systems effect of such a growth in the container and trailer standard], and
2. Transportation-related charges assessed system users (i.e., the total of inland transportation, handling, accessorial, and ocean transportation charges that apply to an intermodal movement).

Users understand their physical distribution costs to be time (and reliability) sensitive (the consistently quicker the delivery, the lower the interest charges, the lower the inventory requirements, and the higher the user's sales success). Transportation charges reflect, to some degree, the costs of providing intermodal services. Costs, in turn, depend on freight volume handled, shipment sizes, shipment frequency, level of service quality provided, technology employed, and compatibility and cooperativeness of the companion elements of the system. They are, therefore, variables that must be measured and managed in order to achieve the goals of intermodalism. From the transportation providers' side, it means an optimal balance of throughput and cost. System users, on the other hand, see the intermodal goal as an optimal balance of service quality and transportation charges, i.e., minimized physical distribution costs.

Infrastructure: The Economic Catalyst

Infrastructure is the group of facilities and services that underpin economic and social activity. Infrastructures catalyze and facilitate productive activity. Some examples of the infrastructure of any urban community are health services, communications, transportation, and electric power. For desirable quality of life, economic prosperity and growth, and cultural enhancement, infrastructure of a quality, magnitude, and scope to support them must be in place.

Infrastructural facilities may be provided by the private or public sector or by joint funding arrangements. Access to components of the infrastructure may be provided at zero monetary price to the user, at market price, or may be subsidized to permit access at a less-than-market price (2). Examples of each of these funding and pricing situations are given, and the effects of the diverse functions are assessed as the specifics of the infrastructural component of the intermodal freight system are discussed in more detail.

Intermodal Infrastructure

The infrastructure associated with the intermodal system of which the marine container terminal is a part is, in turn, composed of a set of supportive facilities and services. The aggregate of the intermodal subsystems is a part of the physical distribution infrastructure that functions responsively to a core of demand, which is the group of product storage, transportation, and delivery conditions placed on the product's supplier by its customers.

The infrastructural components are given in Table 1. Each major component is identified, and its supportive facilities and services are outlined. An example is subsequently employed to illustrate the concept and to suggest the system effects.

Table 1 is intended to be an exhaustive listing of the elements of the intermodal freight system and the infrastructural components that underpin each of the elements, but other observers, particularly those intimately involved with the system elements, will be able to add to the list. Those who design new systems or their elements, or evaluate those that now exist, will want an exhaustive list so that a comprehensive planning and design job can be done. The missing variables in the table are the quality, magnitude, capacity, and interactions of the items indicated. These dimensions are the ones that investors, planners, and designers attempt to define through their respective arts. My purpose is to suggest the character of the investment planning and design problem by emphasizing the system, public, and infrastructural dimensions of the problem. The remainder of this paper is meant to underscore some of the planning issues that should be taken into account in designing or redesigning IFTs.

QUALITY AND CAPACITY OF INTERMODAL FREIGHT SYSTEM COMPONENTS

Ideally, the total intermodal freight system will be designed as a unit. Those involved in planning and decision making can specify the design and operational character of subsystems over which they have direct control. The ability of outsiders to influence subsystems not under their control depends on their negotiating power. Nonetheless, the system will succeed best if the components are effectively integrated.

To illustrate, consider the hypothetical example of a steamship company that proposes to provide triweekly, large container ship service, one from each of three northern European ports to a major eastern United States port. The proposal hinges on a 40-ft channel depth being maintained and a 24-hr turnaround with a minimum 80 percent load factor in both directions. The steamship company notified port officials that the line will not pay more in port service charges than are current at any time at the port's two principal competitors, both of which are less-well situated than the port receiving the proposal.

This offer by the steamship company has potentially wide-ranging implications. Not only must there be the commitment to maintain the required channel depths, but there must be a marine container terminal with available berthing capacity and sufficient storage, equipment, and operating capacities to provide the throughput required to turn the container ship around in 24 hr. (Note: Terminals of the future, which would handle "pods" of containers by "six packs," should be considered. This would not only change throughput, but would affect the entire system.) The marine container terminal's storage capacity should be augmented by the sequenced arrival and departure of barges, railcars, and highway vehicles delivering and picking up containers in coordination with the container ship's arrival. Further, port-related costs assessed to the ocean carrier had to be pegged to that of competitive ports.

Customs services must be in place, as must facilities for handling and storing cargoes that must be "stuffed" in containers at the marine terminal. Documentation, communications, financial, and insurance services, as well as tugboat and pilotage services, must also be on hand to accommodate the time and quality needs of these high-cost, time-sensitive ships.

A large group of agencies and firms must respond to the conditions set--the U.S. Army Corps of Engineers for channel maintenance; other federal units, states, municipalities, and regional authorities where these government units affect locational, environmental, funding, administrative, and pricing decisions; and private firms that provide direct and support facilities and services. It is certainly in the steamship company's decision domain to initiate

Table 1. Infrastructure of intermodal freight system.

Intermodal System Components	Supporting Facilities and Services
Inland transportation system of modal alternatives in which highway trailers or containers are employed	
Motor carriers	Highways, bridges and tunnels, interchanges and access roads, vehicular control systems, freight and vehicle handling facilities, communications, and control systems
Railroads	Rights-of-way, bridges and tunnels, train and car processing yards, freight handling facilities, communications, and control systems
Barges	Inland waterways, docking facilities, locks and dams, control systems, communications, and navigational systems
Ocean transportation capability to transport highway trailers and containers: steamships and ocean-going barges	Tugboats, navigational aids, and communications
Ports	Pilotage, channels, navigational aids, safety, tugboats, cargo handling facilities, recreational facilities, customer-related agencies and firms, financial institutions, chandlery and repair capability, communications, turning basins, breakwaters, control system, insurance adjustment capability, health care delivery, storage and bonded warehouses, anchorage, air and surface passenger transportation, brokers and forwarders, firefighting, and bridge locations and clearances
Intermodal freight terminals	Access to principal modal rights-of-way, container and trailer loading and unloading facilities, storage areas, control systems, communications, maintenance and repair facilities, processing capability, security, piers and other berthing structures, container lifting gear, trained personnel, heavy lift gear, freight handling structures and equipment, vehicle and equipment maintenance, closed and open storage for cargo, location with respect to cooperating modes, and accessibility to major inland routes and sea lanes
Companion terminals' intermodal freight system[a]	Similar supporting facilities and services as listed under intermodal freight terminals

[a] Companion ports represent constraints on the system, thus influencing the design, capacity, and performance of the remaining system elements. For example, the lack of lift capability or adequate depths at berths in certain ports may dictate the use of Ro-Ro or LASH ships at the origin and destination ports. This imposes the need for Ro-Ro ramps at the unconstrained intermodal terminal or, if depths are at issue, the need for LASH handling capability. In either case, investment, capacity, and performance for the system are affected (3). For a view of port characteristics and hinterland issues (such as road capacities that might limit container sizes and weights), a helpful compendium of ports and their characteristics is available (4).

and sustain the proposed service, but only if it is supported in its decision by its companion elements in the total intermodal freight system. And yet, what types of negotiating power can it bring to bear to gain the required support?

The answer comes principally in terms of incentives offered to those who provide the services and facilities or influence those who do. If sufficient employment and investment benefits to the region (state and so on) are anticipated, decisions with a political component can be influenced. If the expectation of acceptable profitability can be tied to the required facilities and services provided by the private sector, those facilities and services will be forthcoming. [Note: Suggestive of a port's interest response to infrastructural barriers to profitable business is the action of the Philadelphia Port Corporation, a quasi-public organization charged with developing, constructing, managing, and marketing the Port of Philadelphia. The Port Corporation is funding track and tunnel clearance improvements for the Consolidated Rail Corporation (Conrail) and the Chessie System. Historically, oversized loads have been excluded from the port. With the improvement, it is expected that the port's potential will be greatly enhanced. Because of the spill-out benefits, the Philadelphia Port Corporation has chosen to underwrite the risk (5).]

Loadcenter Concept

Sufficient cargo must be available to the port to justify the volume requirements of large container ships. To comprehend the significance of this volume requirement, certain aspects of the technology and economics of container ships and their operations must be understood. Specifically, because of the significant costs per day of owning and operating large container vessels, and their great potential for generating revenues as each trip segment is accomplished, such vessels are most efficiently employed by operating from a single origin port to a single destination port. There are significant economies associated with container ship size. These scale economies spill over onto the requirements for correspondingly large-scale marine container terminals (6).

The result is the development of the loadcenter concept, in which containerized cargoes originating from (and destined to) very wide regions are focused on a single origin port (and destination port) so that frequent, direct sailings can be achieved. This assumes that the efficiencies gained for single port container ship operations are not overwhelmed by the higher inland transportation costs, the possibly higher shipment delay costs (taking into account costs at both ends of the movement), and the higher costs imposed on other parts of the infrastructure. Physical distribution performance, in other words, should be improved rather than impaired. Other planning questions that should therefore be asked, and answered, are as follows:

1. What are the scale economies (or diseconomies) of the companion elements to the large container ship?
2. Are there joint positive or negative effects on any of the intermodal freight system's infrastructural components from the presence of other types of demands on those infrastructural components (e.g., does bulk cargo shipping or use of rails and rail yards for domestic container and other traffic improve the quality of rail service, or does it cause congestion)?
3. If bottlenecks or other infrastructural inadequacies in the system exist, how should they be dealt with? If added investment is called for, who decides and who pays?
4. If physical distribution performance affects port choices made by shippers, which variables influence that performance? Also, what factors influence carrier choices of ports on which to concentrate services? How should the affecting variables be weighted?
5. What are the determining factors in shippers' and carriers' port choices (i.e., tradition, regulations, or convenience)?

Responses to these questions will emphasize the implications of the design and operation of complex systems that are further complicated by the condition in which the system components are under the control of separate decision makers. Further, the circumstances occur in the changing contexts of technology, markets, economics, politics, and geopolitics. Any large-scale investment problem is difficult, particularly if it is risky. The ensuing discussion suggests a way to characterize and approach the difficulties.

The term scale economies has two dimensions. First, the term defines the threshold of demand that must be projected in order for a facility or service to be offered in a market. Second, it describes the influence that changing levels of activity have on the unit costs of operating the facility or providing the service. To justify the construction and continued operation of a ramp-style rail piggyback terminal, for example, railroad decision makers, according to Beier (7), must be able to predict a minimum of 10,000 lifts/year. Minimum costs are estimated at 20,000 lifts/year, with costs rising quickly beyond that volume. Mechanized terminals are reported as having threshold volumes of 20,000-30,000 units/year, with minimum cost levels for small mechanized terminals at 40,000 units.

With such data in hand for waterborne container operations (8), the impact of three large container ship arrivals and departures per week (which amounts in our hypothetical example to 7,500 TEUs arriving and an equivalent number departing the port) can be projected. Can the current system tolerate the additional volume? Can new or improved facilities now be justified? What effects would the new volume have on unit handling costs at terminals and other facilities? Will costs increase or decrease? Will congestion occur at certain facilities? What are the time and dollar costs of such effects?

Determinants of Port Choice

Shippers or consignees have the right to specify port, carriers, and methods of transport. However, inland carriers can influence these choices by advice, price, and service quality provided between inland points and the various ports. Ocean carriers may influence choice by restricting their service to specific ports or by providing through rates between origins and destinations. This is a central issue in evaluating and dealing effectively with the loadcenter concept.

What variables affect user choice of carriers and ports? Because of the influence that carriers have over user choice, the more important question is: What variables affect inland and ocean carrier port choice? If a carrier chooses to offer preferred service and price levels at one port, this may limit or even foreclose the options available to users. For example, twice-weekly sailings and favorable rail rates involving port X with respect to much of port Y's hinterland forecloses port Y as a choice to those shippers, particularly if, at the higher rate, port Y has only weekly sailings. This allows port X to encroach on port Y's natural market area.

The length of the time intervals consumed by intermodal freight system components, and by the system as a whole, is determined by the following characteristics of the components:

1. Quality--location (in terms of accessibility to and distance from other interacting facilities), technology, state of repair, and design;
2. Capacity--potential for accepting, processing, holding, releasing, or transmitting the volume levels or unit types involved;
3. Control--efficiency and responsiveness with which the system component, given its quality and capacity, is operated;
4. Coordination--ease and speed with which system elements achieve their required interactions or transfers of functions from one element to another; and
5. Integration--formal or tacit organization plan (including communication links) through which system elements interact to facilitate coordination.

The extent to which inland carriers, marine terminals, and other private-sector elements of the intermodal freight system possess various levels of these characteristics depends on factors such as capital availability, investment alternatives, managerial proficiency, communication situation, facilities already in place due to historical traffic flows and transportation practices, and freight volume projections.

The characteristics of public-sector components of the system may be influenced by the same factors listed for the private sector, but other factors probably predominate. These include "pork barrel" investments, investments due to special-interest lobbying efforts, public interest concerns, and national security considerations. In fact, certain private-sector components of the system may directly or indirectly be affected by government for those reasons.

The system components' characteristics for both the private- and public-sector components are influenced--and perhaps determined--by the use of the facilities and services for diverse purposes. Volume thresholds for the financial institutions that provide services required by international trade would be different if it were not for the other uses to which their services are put. The same is true of highways, rail rights-of-way, port services, channel depths, and most other elements of the system.

The net effect of these influences and considerations is a group of system components with capabilities and constraints that represent efficiency-affecting, time-absorbing, and cost-creating functions in the intermodal freight transportation process. Does the resulting system function or can it be made to function within cost, capacity, reliability, and time standards that users require in selecting routes, carriers, and ports? If the system components can be created, modified, or organized to function acceptably in these terms (particularly those most influential in affecting the choice), the likelihood of loadcenter volumes being generated is greatly enhanced. And this is the "name of the game."

Correspondingly, the physical distribution infrastructure tends to rise where its historical and projected demands are greatest. Thus, the quality of the system that enables the East Coast port to make the volume and turnaround rate minimums will be, in part, the product of its past activity levels and the perceived long-term future demand levels on its services.

Cost Component

All of this appears to overlook the capital investment issues as they affect the investors in and operators of the components and, ultimately, the users of the system, as costs become reflected in transportation charges and, more broadly, in distribution costs. The quality and capacity of the components; terrain and spatial considerations; the durability of the facilities; the performance of the personnel who construct, operate, and manage the facilities; and, finally, the volume of activity calculated for and the actual activity of the system will be important cost determinants.

The problem of circularity is obvious here. The prices associated with the use of a system are an important determinant in attracting volume to the system. Conversely, the use level that exists on the system is a principal determinant of cost and therefore price. Circularity is resolved by volume forecasting; by marketing efforts to attract freight volumes (and qualities) to routes, carriers, and ports; and by risk bearing, in which investors commit capital to facilities and services in advance of actual dollar or nondollar returns.

Private investment in infrastructure is influenced greatly by public investment in cooperating facilities that are (a) installed for extra-economically (i.e., socially or politically) motivated purposes and (b) priced at levels that do not reflect the economic costs or demand conditions of the component. Where cooperating facilities of higher quality, higher capacity, and lower price than the market would provide are available, the tendency is for private investors to direct larger investments toward these projects than would be justified if the cooperating facilities were provided on purely economic grounds. Where this condition exists, user prices, tolls, freight rates, and so on will be lower than market-determined prices for the government-benefited components. Thus, additional demand can be expected to be attracted to the system.

The effects of these conditions are noteworthy. Theoretically, the extra-economic investment and pricing practices push the economy away from its economic efficiency position. In practice, favored routes, facilities, carriers, and ports are overused and benefit at the expense of those that fail to be favored. These outcomes are not a basis for criticizing the application of extra-economic criteria to investment and operational decision making. Consider, for example, the effects of the conscious federal effort to relieve the isolation and poverty in Appalachia through the Interstate highway program. The purpose of this discussion is to suggest the nature of the decision processes, influences, and relations that lead to the development and use of the intermodal freight system. Governments are often best equipped to promote the long-term, high-risk, high-cost investments for its jurisdictions (2).

An additional point, one that deals with the interaction of components, is that of subsidized investments and operations. The effects as well as the reasons for the subsidies are similar to those of other government investment and pricing practices. Subsidies, however, can be used to offset the effects of inadequate facilities, high-cost operations, disadvantageous location, distortions caused by regulation, and other reasons for underuse. Our hypothetical East Coast port could meet the container line's demands by subsidizing certain port use costs, and would be advised to do so if it were less costly than new investments or if it were laboring under disadvantages in some port selection criteria. Assume, of course, that the new sailings are sufficiently beneficial to justify the subsidy costs.

SUMMARY AND CONCLUSIONS

Returning to our hypothetical example, note that the array of considerations and options relating to the port in question in responding to the steamship company's proposal illustrates the nature of the system in which the IFT exists.

The central point is that the IFT is a component of a wider intermodal freight system (part of the physical distribution infrastructure, which is an even wider system). Because of the interdependence of the various components, the characteristics (quality, capacity, performance, pricing practices) of the IFT cannot be judged separately but must be evaluated in the context of the whole system.

The port's ability to respond affirmatively to the proposal of thrice-weekly container ship service requires a wide-ranging inquiry of system cost and service performance, projections of user volume, and response to price, performance, and promotional options engaged in by the port. It is also affected by the prospects of various levels of government affecting the system's costs and service performance by altering applicable rules, by investing in or underwriting a facility's improvement efforts, by subsidizing capital or operating costs of certain system components, or by subsidizing the users themselves.

Planning and evaluation where IFTs are involved are particularly troublesome areas. The investor, planner, and analyst are faced with the problem of hitting a moving target with a shaky weapon firing an unbalanced bullet. Uncertain demand, coordination requirements, shifting technology, and government involvement in the system are but some of the elements that make decision making in the intermodal area so difficult. In spite of this, the complexities must be taken into account in making decisions involving IFTs, and planning must be done.

The theoretical ideal solution to the problem is to merge all of the parties to the intermodal system into a single entity so that a single decision maker can balance all of the interests and arrive at an optimal solution. In a system of interacting elements, to optimize the system some of the elements are apt to have reduced rewards as a consequence of an improved system outcome. Therefore, only a single firm can engross the net effect. Given the system of federalism, modified capitalism, and constitutional guarantees in the United States, this is not about to happen. We have to settle for an inferior solution. In recognition of this, planning at the highest level of professionalism is essential. Broad-based membership and participation by regional, interregional, and international authorities, which focus on information sharing and planning, appear to be the best substitutes to the single firm solution. Let competition among the carriers, ports, and so on continue, but bring them under the banner of complementary subsystems for the sake of efficiency and progress.

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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.

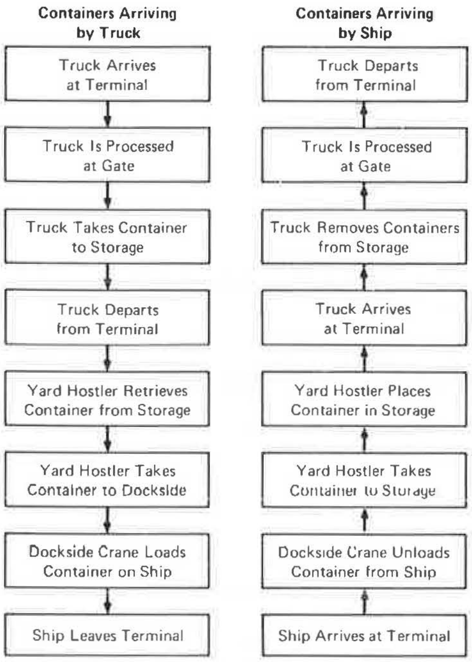
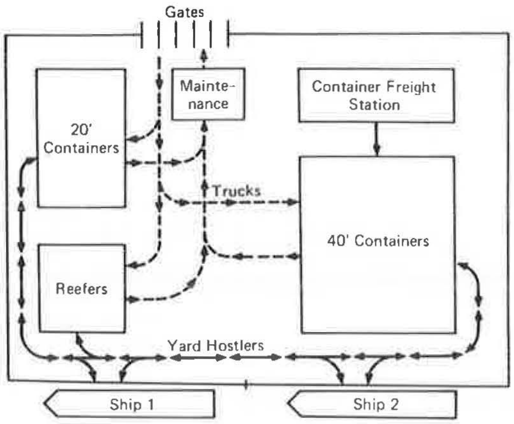


Figure 2. Sample layout of marine terminal.



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).

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.

Route	Container Travel Distance (ft) 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.

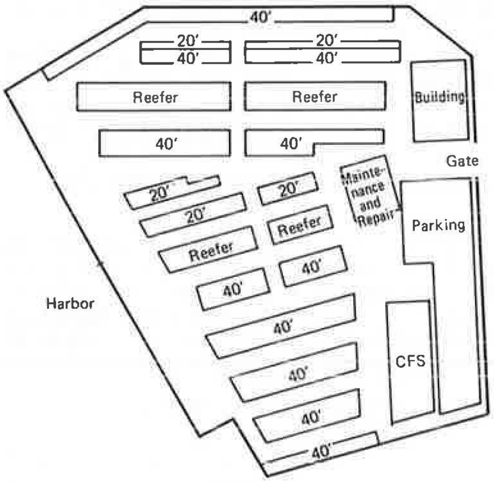
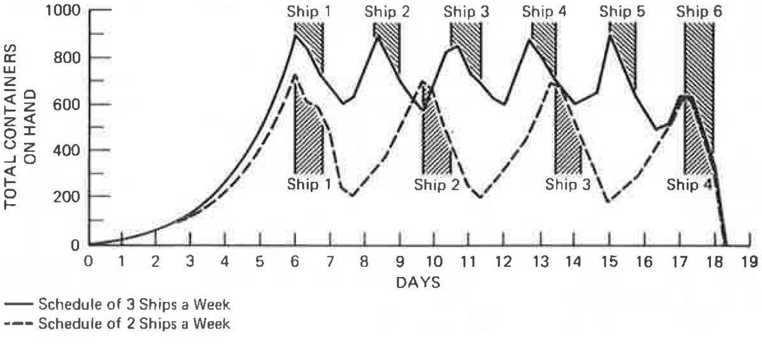


Table 3. Results of case study analysis.

Item	Ships per Week 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.

REFERENCES

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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

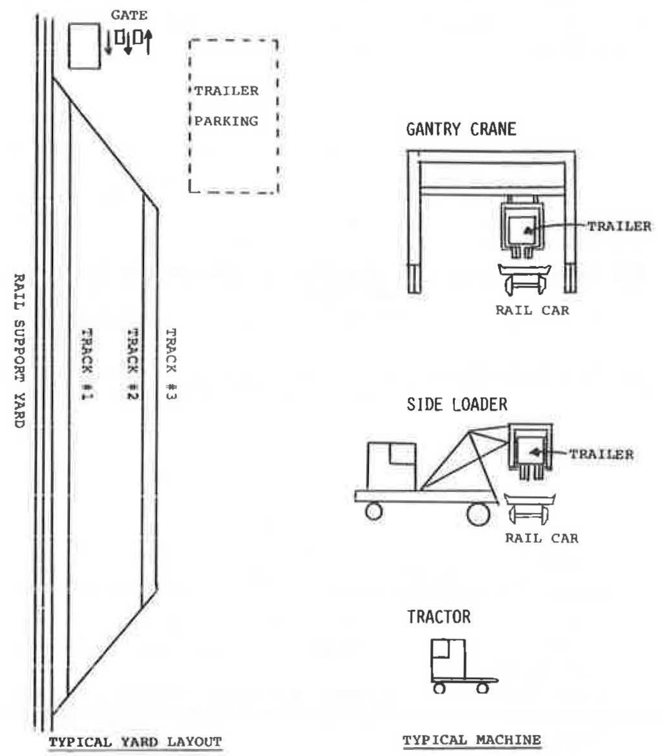
Simulations of operations have always been a powerful tool in designing intermodal terminals. They allow a systematic evaluation of various designs under different traffic levels and operating conditions. Two major difficulties have held back the full use of simulations: (a) the high level of detail 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.

Figure 1. Physical elements of typical intermodal terminal.



The elements of a typical terminal (shown in Figure 1) are:

1. The gate, where trailers enter or exit the terminal by the road;
2. Rail tracks, where trailers are loaded or unloaded on or off the railcars;
3. Trailer parking, where trailers are stored until railcars are ready to be loaded or (for unloaded traffic) until a tractor picks them up for delivery;
4. Lifting equipment, which lifts trailers on or off railcars from or to the trackside; and
5. Tractors, which pull trailers between parking and trackside.

The events simulated modify the status of the rail tracks, gate, and trailer parking. Status is expressed as the number of trailers at the above locations over time.

Events may be externally generated according to a train schedule or gate arrival distribution for train arrivals on the tracks (loaded with trailers) or trailer arrivals at the gate (individually by road), or they may be internally driven, i.e., unloading of trailers from the car (after train arrival) or loading of trailers onto the car (after gate arrival).

The sequence of events simulated for arriving trains is as follows:

1. Arriving train selects the best track: It must be free of cars, accept the largest number of cars from the train, and waste the least space on the track. If the whole train or part of the train cannot be placed on the tracks, the remaining cars are considered to be on storage tracks until a track is free.
2. Cranes unload trailers off railcars: As soon as the train arrives, unloading may start, provided that a lifting machine is available for unloading on that track. If more than one machine are free, the nearest one will be dispatched. Unloading will tend to be performed sequentially along the track, where the machine moves to the closest (and adjacent) trailer on the track.
3. Yard tractors bring trailers to parking area: Trailers may stay at trackside until an outside tractor picks them up for delivery or until the trackside must be freed for loading trailers; unloaded trailers are then brought by yard tractors to a parking area in the yard. Trailers depart from the yard according to a given probability distribution.

The sequence of events simulated for departing trains is as follows:

1. Trailer arrives by road at the gate: It is processed there according to a given service time. It then proceeds to a section of a track reserved for one of the final destinations of the train it will be loaded on. If the track is not yet ready to accept trailers, the arriving trailer proceeds to the parking area.
2. Yard tractors bring trailers to trackside: When the track is made ready to receive trailers, tractors will start to bring trailers in the parking area for that train to sections of track allocated for each destination.
3. Cranes load trailers on railcars: When empty railcars have been placed on the track, a crane will load trailers at trackside onto the adjacent railcar. The crane will move to the closest trailer to load on that track or any other track. This may result in substantial (and unavoidable) traveling if the track is blocked into a number of destinations and trailers arrive randomly at the gate for each destination.
4. Trains depart according to schedule: When the train must leave, trailers that have not yet been loaded on it remain on the ground. They will be brought to the parking area by yard tractors and remain there until the next train for that destination is placed on the tracks.

EVENTS NOT SIMULATED

Two types of events, railcar availability and trailer and railcar sizes, were not included in the simulation. They were considered too complex to simulate because they required too much detailed input and affected terminal operations in unpredictable or insignificant ways.

1. Railcar availability: In the simulation, it is assumed that empty railcars are always available in sufficient number to load all of the expected trailers. This is not necessarily the case in real life; there may be a lack of railcars, and some trailers would then remain on the ground. Simulating railcar availability requires that the whole fleet of cars across the country be simulated, which is outside the scope of this model.
2. Trailer and railcar sizes: Trailers come in different lengths (26, 40, and 45 ft long), as do railcars (holding a 40-ft and a 45-ft trailer, or two 26-ft trailers, and so on). The simulation does not match trailers to railcars by sizes. It matches them only by destination. Taking sizes into account would require that they all be input individually and that the transportation yard itself be modeled. Instead, an average trailer and car length are used to determine the number of trailers that can be loaded on a given track.

INPUTS REQUIRED

A brief description of the input may give an appreciation of the level of detail that is incorporated in the model. An example of such input is shown in Figures 2-5. The input detail is as follows:

1. Simulation parameters--day and time simulation starts and ends, percentage change in volume over stated traffic, average time to find a trailer in the storage area, average time between removing cars on the track and placing other cars, average car (and trailer) length, average distance between tracks, trailer-to-gate processing time, number of gates, and time between last trailer arrival and train departure;
2. Track--track number and length, distance from track position no. 1 to trailer parking, and other track numbers that share the same roadway;
3. Tractor--travel speed (in miles per hour), coupling and uncoupling time to trailer (in seconds), detailed schedule of working hours or downtime, and particular assignments to specific track or train;
4. Lifting equipment--type (gantry straddling track or side-loader), travel speed (in miles per hour), loading and unloading time cycles (in seconds), time to change tracks (for gantry cranes), detailed schedule of working hours or downtime, and particular assignments to specific track or train (if any);
5. Trains--train name, arrival or departure time, number of trailers on train, specific track (if any) it should be assigned to, time at which arriving trailers should be left at trackside, time before departure at which trailers may be brought

Figure 2. Input example--run parameters and track.

```
DAY AND TIME SIMULATION STARTS :  MON  0  0

SIMULATED TIME :  1.00 DAYS


% CHANGE IN VOLUME OVER STATED TRAFFIC :  0.  (EG. 5 FOR 5%)
        CHANGE CAN BE NEGATIVE (I.E. DECREASE IN VOLUME)
        EG.  -5.5  FOR A DECREASE OF 5.5%


TRACTOR TIME IN STORAGE :  1.0 MINUTES
        TRACTOR TIME INCLUDES THE TIME REQUIRED TO FIND THE
        DESIRED TRAILER OR TO FIND AN EMPTY SPOT TO PARK THE
        TRAILER, ANY INTERFERENCE BETWEEN TRACTORS IN STORAGE,
        THE PARKING AND PLACING TIMES EXCLUDING THE
        COUPLING/UNCOUPLING.

AVERAGE TIME FOR SWITCHING :  30. MINUTES

AVERAGE CAR LENGTH :  50.0 FEET

PAD WITH :  100.0 FEET

GATE PROCESSING TIME :  2.0 MINUTES

NUMBER OF GATES :  1

TIME BETWEEN CUT OFF AND PULL :  15.0 MINUTES

                        TRACK INFORMATION


  FIELD DEFINITION :
       TRACK   :   INTEGER REPRESENTING THE TRACK NUMBER
   PAD LENGTH  :   INTEGER REPRESENTING PAD LENGTH (FEET)
      ACCESS   :     DESCRIBES TRACK ACCESS AS FOLLOWS
                     1 - ONE END ONLY
                     2 - TWO ENDS
    DISTANCE   :     DISTANCE IN FEET BETWEEN BEGINNING OF TRACK
                     AND STORAGE AREA.
  CONNNECTION  :     OTHER TRACK CONNECTED TO BY SHARED ROADWAY
                     (ENTER 0 IF NOT CONNECTED)


TRACK      PAD LENGTH      ACCESS      DISTANCE      CONNECTION

  1           3000            2          500.0            1

END OF TRACK INFORMATION
```

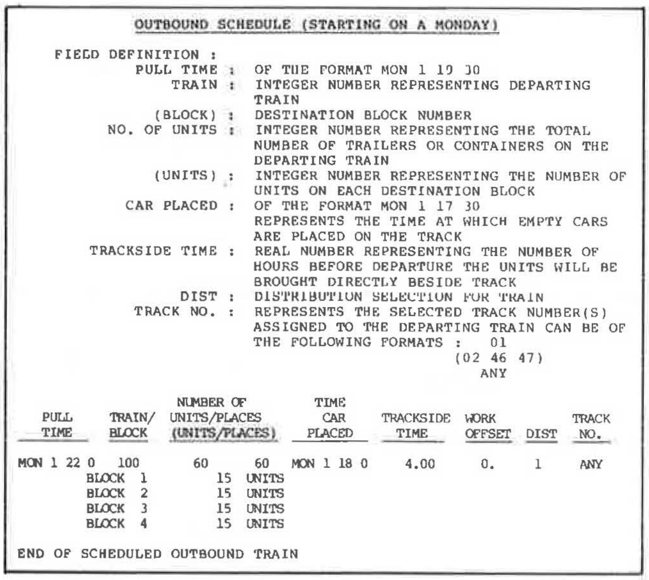
Figure 3. Input example--machine definition.

```
                       TRACTOR DEFINITION

   FIELD DEFINITION :
             TRACTOR I.D. :  UP TO 8 CHARACTER UNIQUE TRACTOR
                             IDENTIFICATION
             TRAVEL SPEED :  REAL NUMBER REPRESENTING TRAVELLING
                             SPEED IN MPH OF TRACTOR IN YARD
 COUPLING/UNCOUPLING TIME :  REAL NUMBER REPRESENTING EITHER
                             COUPLING/UNCOUPLING TIME OF A
                             TRACTOR TO A TRAILER IN SECONDS.


                  TRAVEL SPEED      COUPLING/UNCOUPLING TIME
 TRACTOR I.D.        (MPH)                 (SECONDS)

  TRACTOR 1          15.0                    60

 END OF TRACTOR DEFINITION

                     HEAVY EQUIPMENT DEFINITION

   FIELD DEFINITION :
       EQUIPMENT I.D.    :  UP TO 8 CHARACTER UNIQUE EQUIPMENT
                            IDENTIFICATION
         TRAVEL SPEED    :  REAL NUMBER REPRESENTING TRAVELLING
                            SPEED OF EQUIPMENT IN YARD
            LOAD TIME    :  INTEGER REPRESENTING ONE FULL CYCLE
                            TIME FOR LOADING OPERATIONS
          UNLOAD TIME    :  INTEGER REPRESENTING ONE FULL CYCLE
                            TIME FOR UNLOADING OPERATIONS
   CHANGE TRACKS TIME    :  TIME REQUIRED BY MACHINE TO CHANGE PADS
                            (MINUTES)
                 TYPE    :  MACHINE CAN BE OF ONE OF TWO TYPES,
                            CRANES OR FRONT LOADERS
                            (USE CRANE OR LOADER KEYWORDS)

                                                     CHANGE
              TRAVEL SPEED  LOAD TIME  UNLOAD TIME  TRACK TIME
EQUIP. I.D.      (MPH)      (SECONDS)   (SECONDS)   (MINUTES)   TYPE

 CRANE-1         6.0           136         115          1      CRANE

END OF HEAVY EQUIPMENT DEFINITION


MACHINE I.D.      TIME FROM       TIME TO

 CRANE-1          MON 1 18 0    MON 1 22 00
 TRACTOR1         MON 1 18 0    MON 1 22 00

                                       SELECTED AREA
MACHINE I.D.        TIME         TRACKS      TRAINS      POSITIONS

 CRANE-1          MON 1 18 0      ANY          ANY          ANY

END OF MACHINE ASSIGNMENTS
```

Figure 4. Input example--distributions and inbound train.

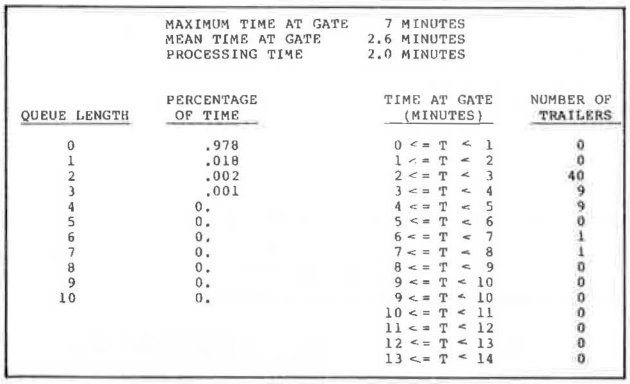
```
                       TRAILER DISTRIBUTIONS

GENERAL DISTRIBUTION OF TYPE 1 (ALWAYS NEEDED)

     FIELD DEFINITION :
         HOURS FROM TRAIN TIME :  NUMBER OF HOURS BEFORE TRAIN
                                  DEPARTURE TIME
             FRACTION TRAILERS :  FRACTION OF TRAILERS ARRIVING OR
                                  LEAVING DURING GIVEN HOUR.
                                  APPLIED TO NUMBER OF TRAILERS IN
                                  BLOCK.

DISTRIBUTION NUMBER :  1

HOURS FROM TRAIN TIME         FRACTION TRAILERS

          1                          .10
          2                          .10
          3                          .20
          4                          .30
          5                          .30

END OF GENERAL DISTRIBUTION


            INBOUND SCHEDULE (STARTING ON A MONDAY)

     FIELD DEFINITIONS :
         ARRIVAL TIME :  OF THE FORMAT MON 1 08 25
                TRAIN :  INTEGER NUMBER REPRESENTING ARRIVING TRAINS
         NO. OF UNITS :  INTEGER NUMBER REPRESENTING THE NUMBER OF
                         TRAILERS OR CONTAINERS ON THE ARRIVING
                         TRAIN
       TRACKSIDE TIME :  A REAL NUMBER REPRESENTING THE TIME, IN
                         HOURS THE TRAILERS WILL BE LEFT ALONG THE
                         SIDE OF THE TRACK TO BE PICKED UP DIRECTLY
                         BY THE CUSTOMERS.
          WORK OFFSET :  TIME (MINUTES) TO WAIT BEFORE STARTING WORK
                         ON TRAIN
                 DIST :  DISTRIBUTION SELECTION FOR TRAIN
            TRACK NO. :  REPRESENTS THE SELECTED TRACK NUMBERS
                         ASSIGNED TO THE ARRIVING TRAIN CAN BE OF
                         THE FOLLOWING FORMATS :  01
                                              (02 46 47)
                                                 ANY

                          NO.    TRACKSIDE   WORK
ARRIVAL TIME   TRAIN   TRAILERS    TIME     OFFSET  DIST  TRACK NO.

MON 2 10 30     201       37       5.00       0.     2       ANY
END OF SCHEDULED INBOUND TRAINS
```

Figure 5. Input example—outbound train schedule.



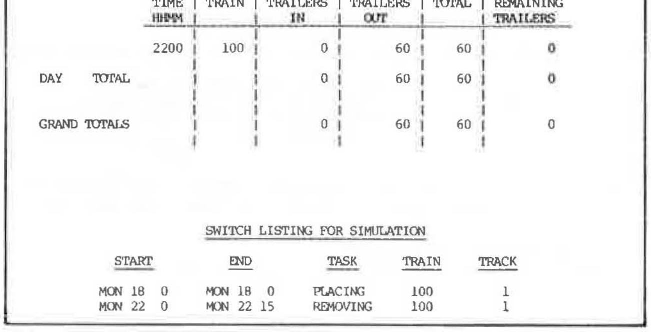
```
                OUTBOUND SCHEDULE (STARTING ON A MONDAY)

     FIEСD DEFINITION :
               PULL TIME :  OF THE FORMAT MON 1 19 30
                   TRAIN :  INTEGER NUMBER REPRESENTING DEPARTING
                            TRAIN
                 (BLOCK) :  DESTINATION BLOCK NUMBER
            NO. OF UNITS :  INTEGER NUMBER REPRESENTING THE TOTAL
                            NUMBER OF TRAILERS OR CONTAINERS ON THE
                            DEPARTING TRAIN
                 (UNITS) :  INTEGER NUMBER REPRESENTING THE NUMBER OF
                            UNITS ON EACH DESTINATION BLOCK
              CAR PLACED :  OF THE FORMAT MON 1 17 30
                            REPRESENTS THE TIME AT WHICH EMPTY CARS
                            ARE PLACED ON THE TRACK
          TRACKSIDE TIME :  REAL NUMBER REPRESENTING THE NUMBER OF
                            HOURS BEFORE DEPARTURE THE UNITS WILL BE
                            BROUGHT DIRECTLY BESIDE TRACK
                    DIST :  DISTRIBUTION SELECTION FOR TRAIN
               TRACK NO. :  REPRESENTS THE SELECTED TRACK NUMBER(S)
                            ASSIGNED TO THE DEPARTING TRAIN CAN BE OF
                            THE FOLLOWING FORMATS :    01
                                                    (02 46 47)
                                                       ANY

                      NUMBER OF         TIME
  PULL       TRAIN/  UNITS/PLACES       CAR     TRACKSIDE  WORK          TRACK
  TIME       BLOCK  (UNITS/PLACES)     PLACED     TIME     OFFSET  DIST   NO.

MON 1 22 0    100      60       60  MON 1 18 0    4.00      0.      1     ANY
          BLOCK  1          15  UNITS
          BLOCK  2          15  UNITS
          BLOCK  3          15  UNITS
          BLOCK  4          15  UNITS

END OF SCHEDULED OUTBOUND TRAIN
```

Figure 6. Output example—gate report.



```
                MAXIMUM TIME AT GATE    7 MINUTES
                MEAN TIME AT GATE     2.6 MINUTES
                PROCESSING TIME       2.0 MINUTES

                PERCENTAGE               TIME AT GATE   NUMBER OF
 QUEUE LENGTH    OF TIME                  (MINUTES)     TRAILERS

      0            .978                  0 <= T <  1       0
      1            .018                  1 <= T <  2       0
      2            .002                  2 <= T <  3      40
      3            .001                  3 <= T <  4       9
      4           0.                     4 <= T <  5       9
      5           0.                     5 <= T <  6       0
      6           0.                     6 <= T <  7       1
      7           0.                     7 <= T <  8       1
      8           0.                     8 <= T <  9       0
      9           0.                     9 <= T < 10       0
     10           0.                     9 <= T < 10       0
                                        10 <= T < 11       0
                                        11 <= T < 12       0
                                        12 <= T < 13       0
                                        13 <= T < 14       0
```

Figure 7. Output example—other reports.



```
                    INTERMODAL TERMINAL - CRANE SIMULATION

CRANE      DAY                MINUTES                           PERCENT
               LOAD  UNLOAD  IDLE  TRAVEL  TOTAL     LOAD  UNLOAD  IDLE  TRAVEL

CRANE-1     0   135       0    47      58    240      56.      0.   20.     24.
ALL         0   135       0    47      58    240      56.      0.   20.     24.
               ----  ------  ----  ------  -----     ----  ------  ----  ------



                    TRAILERS ARRIVAL AND DEPARTURE BY RAIL

  DAY :  MON

               TIME | TRAIN | TRAILERS | TRAILERS | TOTAL | REMAINING
               HHMM |       |    IN    |   OUT    |       | TRAILERS
              ------------------------------------------------------
                    |       |          |          |       |
               2200 |  100  |        0 |       60 |    60 |        0
                    |       |          |          |       |
  DAY    TOTAL      |       |        0 |       60 |    60 |        0
                    |       |          |          |       |
                    |       |          |          |       |
  GRAND TOTALS      |       |        0 |       60 |    60 |        0
                    |       |          |          |       |



                     SWITCH LISTING FOR SIMULATION

          START        END          TASK      TRAIN     TRACK

        MON 18  0    MON 18  0    PLACING      100         1
        MON 22  0    MON 22 15    REMOVING     100         1
```

directly to trackside by customer, time at which empty cars are placed, time at which loading or unloading may be started on that train, and number of destination blocks and number of trailers for each block; and

6. Trailers--trailer-arrival-to-gate probability distribution (expressed as a percentage of total trailers or exact number of trailers arriving randomly within an hour at any given hour of day or hour before train departure), trailer-departure-from-gate probability distribution (expressed in the same manner as arrivals), and any other number of probability distributions (they are referred to by number).

OUTPUTS GENERATED

Outputs summarize the various key statistics that help to evaluate different plant and operating methods (see Figures 6 and 7). Some outputs are also available that, on demand, give a detailed log of each event in the simulation. A description of the main outputs is given below:

1. Echo of input data;
2. Distribution of actual gate arrivals and departures by hour of day;
3. Trailer queues at the gate;
4. Trailer arrivals and departures by rail;
5. Hourly distribution of cars on each track;
6. Number of trailers in storage by hour of day;
7. Crane and tractor use by hour of day;
8. Machine time spent in loading, unloading, traveling, and idling;
9. Time-distance chart of machine position on track with operation performed; and
10. Track status at given hour that shows empty track, empty cars, loaded cars, and trailers by trackside by position.

TECHNICAL CONSIDERATIONS

The simulation is written in Simscript II.5, a computer language designed specifically for discrete-event simulations. It requires from 400 to 600 K of core and 1 to 5 sec/simulated day to execute, depending on the number of trains simulated. The cost per average run ranges from $10 to $20.

The reports process a log file created by the simulation. They require various compilers, e.g., COBOL, FORTRAN, and Data Analyzer.

APPLICATIONS

Two types of applications are discussed in this section--one on existing terminals and the other on proposed terminals that use results of a parametric analysis of key physical elements in a terminal.

Railway intermodal terminals are supported by a rail yard, where trains arrive and depart and where cars are sorted by destination. This simulation does not model any of these car classification operations. The actual configuration of the rail support yard may restrict the design of the intermodal terminal where trailers are loaded on railcars.

Modifications of Existing Terminals

This simulation has been applied to determine what modifications would be required if Canadian National Railway's (CN Rail) Toronto intermodal terminal were to handle 8 additional trains per day of 40 trailers each. This represents an increase of 80,000 trailers/year in and out of that terminal, or 100 percent.

The number of trailer lifts would double as compared with the current number. This does not mean that the terminal would have to expand to twice its current size to handle the extra traffic. It now has slack capacity, with two train arrivals in the morning and one in the evening and three train departures in the evening. The additional traffic is expected to be evenly distributed during the day, filling up the morning and early afternoon slack, but putting a strain on the fairly busy evening operations.

The question to resolve, then, is how many more tracks or machines would be required to handle this additional traffic. The length of additional tracks is fixed at about 2,500 ft because of existing trackage length. The type of machine is also practically fixed to ensure compatibility with gantry cranes currently used.

The terminal now operates two gantry cranes on three tracks. Most of the time only one crane is necessary. The second crane is used mainly as a backup.

Current plant and machines can easily handle the additional traffic during night and morning shifts. However, the table below shows that, during the evening shift, three cranes are required; two cranes cannot load all the traffic (note that the statistic for trailers remaining shows that the cranes did not have enough time to load those trailers before departure):

	Plant	
Item	Three Tracks and Two Cranes	Three Tracks and Three Cranes
Time spent (%)		
Loading	55	35
Unloading	20	15
Idling	9	45
Traveling	16	5
Trailers remaining	15	0

As can be seen, travel time decreases, when using three cranes, from 16 to 5 percent. Each crane may be assigned to just one track; no traveling from track to track need occur.

Three cranes on three tracks are thus considered the minimum operating plant to handle the extra traffic. One more track and crane may be recommended in the final design to provide slack capacity for railcar switching and crane breakdowns.

Design of Proposed Terminals

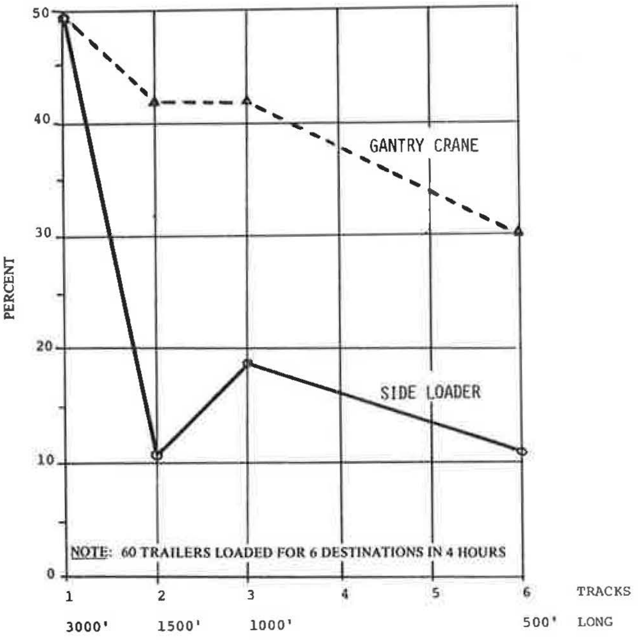
Proposed terminals do not have as many space or equipment constraints as does the extension to existing terminals. Track length and number, and machine type or number, may be allowed to vary more freely. The basic input to this model can be changed easily to test many different situations.

As an example, the simulation was used to test machine travel time as a percentage of loading time, given different track number, length, destination per track, and level of traffic.

Figure 8 shows the results of simulating the loading of 60 trailers for 6 destinations in 4 hr by using 1, 2, 3, or 6 tracks of, respectively, 3,000, 1,500, 1,000, or 500 ft each. Total track length in all cases is 3,000 ft. Each destination has 10 trailers that use up to 500 ft of track.

Two types of lifting equipment are being tested: the gantry crane that straddles a track and the side-lift that moves freely on one side of the track. The main difference between the two machines is that the gantry crane must travel to either end of the track it is straddling to change track, whereas the side-lift may move directly to an adjacent track without having to run to the end of the track. Therefore, use of the side-lift results in less traveling time.

Figure 8. Travel time for different track lengths.



Trailers arrive randomly at the tracks as 10, 20, 20, 20, and 30 percent of total trailers (60) at 1 to 5 hr before train departure for each destination. Thus, 3 hr before departure, 12 trailers will arrive, with 2 (on average) for each destination. The lifting equipment must load them as they arrive in their proper block.

Traveling between destination blocks is inevitable. The machine cannot wait for all trailers for one destination to arrive, because such an event will happen for all destinations separately shortly before train departure. As trailers arrive, the machine loads all adjacent trailers (for one destination), travels past empty rail cars, and loads the next series of adjacent trailers (which have already arrived for another specific destination).

Given those conditions, Figure 8 shows how both types of machines travel less needlessly as the number of tracks increases. Improvements are relatively slow for the gantry crane (50 to 30 percent for 1 to 6 tracks). They are more dramatic for the side-loader at two tracks (50 to 10 percent for 1 to 2 tracks) but do not improve further for a large number of tracks. They even worsen for 3 tracks (18 percent), which is understandable, as track 1 and 2, but not track 3, share the same roadway. An even number of tracks thus reduces traveling time as compared to an odd number.

Figure 9 shows how traveling time is sensitive to the number of destinations per track; e.g., loading 60 trailers in 4 hr on only 1 track for 6, 4, 3, 2, and 1 destinations. Traveling time as a percentage of loading time goes from 50 to 5 percent for runs of 6 to 1 destinations on 1 track. Ideally, at one destination per track, traveling time should be zero. This is not the case because some trailers (30 percent) arrive 1 hr before loading starts. They are stored in the parking area and brought to trackside when the lifting equipment is ready. Space is reserved at the beginning of the track for those trailers that arrived early. The lifting equipment must travel between trailers brought to

Figure 9. Travel time for different destination blocks.

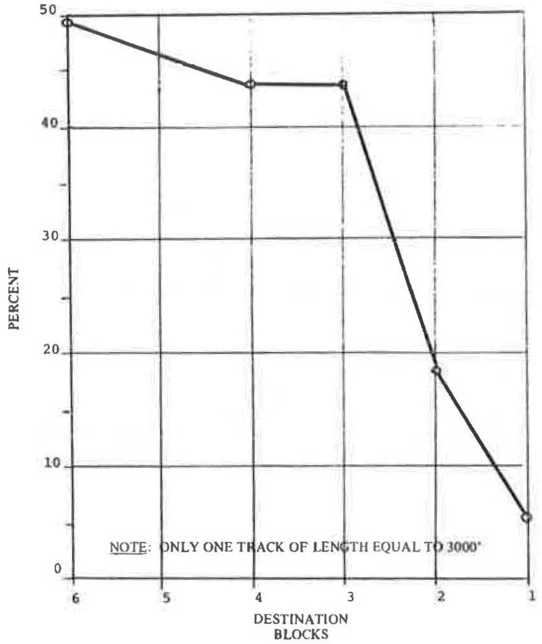
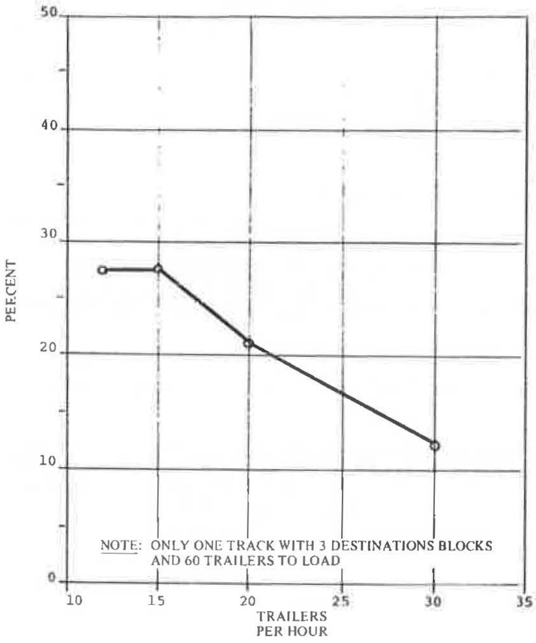


Figure 10. Travel time for different traffic levels.



trackside by the tractors and those arriving directly from the gate.

Because it is assumed that gantry cranes and side-loaders lift and travel at the same speed, there is no difference between those two types of equipment when loading on one track.

It is concluded from this example that it is best to have the least number of destinations for the traffic. That, however, is not a factor that can normally be changed at the terminal level because it is a traffic characteristic.

Figure 10 shows that lifting equipment travel time goes down as the number of trailers per hour goes up. This is to be expected, because the number of adjacent trailers is likely to be higher for any destination if the frequency of arrivals is greater.

This test was done with 60 trailers going to 3 different destinations to be loaded on 1 single track. Trailer arrivals were equal in each hour within each run and varied from 12 to 30 trailers/hr for different runs.

Not all trailers were loaded for frequencies of 20 and 30 trailers/hr. There was not enough time to load all of them before train departure. This implies that, for a given traffic pattern, there is a time to start loading before train departure that will minimize traveling time and at the same time be long enough to load all trailers. Lifting equipment utilization would then be maximized.

CONCLUSIONS

This parametric analysis shows how this model can be used to optimize track length and number and machine utilization. In any concrete applications for a proposed terminal, current and forecasted trains would have to be simulated under different scenarios. Particular traffic patterns would affect the results of this parametric analysis.

The model is limited to the analysis of plant and operating conditions of an intermodal terminal. It may be used to evaluate changes in operations quantitatively. It shows how well-used tracks and machines perform under different situations. But it does not perform an economic analysis on the size of the plant or the number or types of machines. That step comes after the operating analysis.

Incorporation of Operational Decision Making in Intermodal Terminal Simulation Models

DOUGLAS P. SMITH

The model structure outlined in this paper provides a framework for the analysis and improvement of certain terminal operating procedures. The foundation of the model is a procedure for forecasting and updating the volumes of trailers to be handled. The short-term uncertainty relating to outbound trailer volumes can be one of the major causes of terminal inefficiency, particularly with respect to hitch use. This uncertainty is incorporated into the model structure and is used in the assignment of railcars to hitches. A combination of automatic and interactive methods are used by the simulator to allocate terminal resources. These resources include loading equipment, tracks, railcars, and switching facilities. This allocation process simulates the management component of the terminal. The physical component is represented by a series of queues, buffers, and processors, each with specified capabilities and availability. Unloading activities, the gate, and storage are not included. Results that indicate the accuracy and potential applicability of the model are not yet available. Testing is being done by using Canadian National Railways' Brampton Terminal, which is located on the northwest corner of Toronto.

Simulation models have been touted as a tool that can aid in the development and planning of intermodal terminals and systems. The complexity of most intermodal operations makes it difficult to evaluate alternatives by using simple analytic methods, but it is reasonable to assume that a well-developed set of simulation models will allow the intermodal operator to test a variety of system configurations quickly and at low cost. Simulations are appropriate because of the time-varying nature of terminal activities and the intensity of peaks. The characteristics of a model currently being developed to perform detailed analyses of the loading operations in intermodal terminals are discussed in this paper.

TERMINAL OPERATIONS

In order to identify characteristics of typical terminal operations, many intermodal terminals were visited during summer 1982. These covered a wide range of sizes, layouts, and operation policies. Attributes of some of these terminals are given in Table 1. Although their physical characteristics may vary widely, analysis of the operations at these terminals reveals a number of consistencies in both the work-load pattern and the methods used to handle the work load.

Most terminals have two distinctive types of peak, one recurring on a daily basis and the other recurring weekly. The daily peaks follow from a terminal being in the load mode in the evening and the unload mode in the morning. Most trailers are loaded by customers during the day and delivered to the railway in the late afternoon and early evening; outbound train schedules reflect this pattern. Similarly, customers want to have their trailers available to unload during the day; thus, the early morning period is characterized by train arrivals and unloadings.

Although these patterns are generally true, other

Table 1. Characteristics of representative intermodal terminals.

Terminal	Railroad	Apron Tracks	Car Spots[a]	Loading Method	Parking Spaces	General Comments[b]
South Kearney	Consolidated Rail Corporation (Conrail)	5	153	5 side-lifts, 1 crane	1,800	TOFC and COFC[c]; high volume
47th Street	Conrail	3	91	1 side-lift, 1 crane	700	TOFC; high volume
West Springfield	Conrail	2	52	2 side-lifts	310	TOFC; medium volume
Beacon Park	Conrail	4	82	3 side-lifts	550	TOFC and COFC[c]; medium volume
Detroit	Norfolk and Western (N&W)	10	50	Circus	200	TOFC; low volume
		1	5	1 side-lift	200 TEU	COFC; low volume
Calumet	N&W	2	79	3 side-lifts	1,200	TOFC and COFC; medium volume
Luther	N&W	3	82	2 side-lifts	850	TOFC and COFC; medium volume
Ogden	Burlington Northern	2	52	3 cranes	600	TOFC; high volume
		1	25	2 side-lifts		COFC
Chicago	Missouri Pacific (MP) and Louisville and Nashville	10	166	3 cranes	1,000	TOFC and COFC[c]; high volume
St. Louis	MP	9	51	Circus	400	TOFC; low volume
		1	5	Rail-mounted crane		COFC; low volume
Chicago	Illinois Central Gulf	4	140	3 cranes	1,000	TOFC and COFC[c]; high volume
Corwith	Santa Fe	5	200	6 cranes	4,200	TOFC; very high volume
		1	12	1 side-lift		COFC
Detroit	Grand Trunk Western	2	48	2 cranes	500	TOFC; low volume
Detroit	Detroit, Toledo, and Ironton	7	38	Circus	500	TOFC; low volume
Chicago	Soo Line	3	35	2 side-lifts	120 200 TEU	TOFC and COFC; low volume
Alexandria	Southern	2	38	2 cranes (rail mounted)	300	TOFC; medium volume
Montreal	Canadian Pacific (CP)	4	57	7 side-lifts	3,000 TEU	COFC; medium volume
Toronto	Canadian National (CN Rail)	3	90	2 cranes	2,000	TOFC; medium volume
Montreal	CN Rail	10	40	Circus	260	TOFC; medium volume
		2	40	1 crane, 9 side-lifts	3,600 TEU	COFC; medium volume

Note: TEU = twenty-foot equivalent units.

[a] Figures for car spots are based on 89-ft cars.

[b] TOFC = trailer-on-flatcar and COFC = container-on-flatcar. Volumes are divided as follows: low = 0-200/day (load and unload), medium = 200-500, high = 500-1,000, and very high = 1,000 or more. These volumes are based on typical heavy days and are based, for the most part, on estimates rather than actual operating records.

[c] Indicates no ground storage for containers.

factors (such as multiple daily departures) will result in some variation about the daily norm. The weekly pattern is characterized by high levels of storage early in the week and high loadings toward the end of the week. This reflects a shipper tendency to move higher volumes toward the end of the week, which results in higher loading volumes on Thursdays and Fridays. Trailers that arrive at a terminal over a weekend are not likely to be picked up until the following Monday, which results in higher storage requirements during the early part of the week. These regular cycles simplify the analysis of individual terminals because they allow one to focus on particular periods during the day or week.

The reported decision-making process at the terminal level was also consistent over the terminals visited. When asked how they made operational decisions, most of the operators interviewed indicated that they would "play it by ear." They elaborated on this by saying they had a general idea what the demand pattern for a day (or week) would be, but that there was too much uncertainty to make a fixed set of resource allocations at a very early stage. Over-the-road arrivals of intermodal trailers are not controlled by the terminal nor is complete information on future trailer arrivals available, so all decisions are based on estimates of the daily volumes. An initial set of decisions is made and updated as the day progresses. Consistent with the scheduled timing of different services, these updates will be used for decisions with an ever-changing set of possible alternatives. An example of this change could be the feasibility of switching at different points in a loading schedule.

These characteristics of intermodal terminal decisions demonstrate the critical importance of human factors and local management in terminal operations. The uncertain environment of short-term decision-making activities requires carefully designed decision support systems together with appropriate operations policies, particularly with respect to the loading component of terminal operations. It is the loading component of the terminal that is affected strongly by complexity, and for this reason the current analysis focuses on loading. This emphasis is justified by the relative importance of the loading function to both terminal and overall system performance.

Examination of a terminal in the context of the overall rail network indicates that the level of effectiveness of that terminal in delivering service depends on the ability of the loading component to block trains appropriately and to assemble them quickly. The unloading component is important with respect to making trailers available to customers, but it is a relatively simple procedure with no blocking or hitch use issues as well as marginally faster cycle times, and therefore it is less likely to affect system performance. Other areas such as the gate, hostling, and storage are important for the support they give to loading. The lack of sufficient support could easily be the limiting factor for a specific terminal.

LOADING DECISIONS

The loading process for outbound trailers involves four general groups of decisions: (a) the assignment of apron tracks to specific trains, (b) the assignment of railcars to blocks for loading, (c) the determination of switching requirements, and (d) the determination of loading and unloading sequences. These are outlined below.

Track assignment refers to the selection of a specific track or tracks for assignment to each train. Track assignment is based on train length, expected track availability, and, in mechanized terminals, crane movement restrictions. Local conditions, such as the proximity to storage areas, the location of internal road crossings, and the physical characteristics of the apron, may also favor specific track assignments.

Cars are assigned to outbound blocks through the selection of appropriate strings of empty cars and their allocation to specific destinations. Anticipated volumes are the major decision factor. The assignment is normally done iteratively and can be reassessed as trailers arrive throughout the loading period. Blocks are located relative to one another in a way that facilitates train makeup.

Switching is required on outbound trains when there is a need to add railcars to the original allocation or to switch those for which there is nothing to load. Additional switching will be required if it is not possible to properly block the train during loading.

Loading sequence refers to the assignment of trailers to specific hitches on railcars. Sequence assignments are normally made so as to optimize some measure of hitch use; these assignments are made either in the gate office during check-in or by the crew during loading.

These decision groups are either preset as standard practice or are made by terminal staff on an informal basis. In many terminals, track or block allocations will not vary from day to day. This standard allocation stems from an earlier decision on operation procedures and may be adjusted, given a significant change in circumstances. Switching will commonly be done on a scheduled basis, but extra switches may be requested as required. The scheduled switch is part of current practice, but the decision for an extra switch is normally based on an informal assessment of the current situation. Hitch-assignment decisions are made continuously as trailers arrive at the terminal; this decision making is done on an informal basis.

MODEL STRUCTURE

The translation of informal decision rules into a form that can be used by a computer simulation can be done in two ways. The first is to allow interaction between the computer and the operator. This type of simulation, known as "man in the loop," has been recommended for the simulation of intermodal terminals (1) and is used by CN Rail to test and develop designs for classification yards (2). The computer is used primarily for bookeeping purposes, and all decisions are made by the operator in the same manner that they would be made in the terminal. This method effectively removes the requirement of specifying decision rules in machine formats, but it is disadvantageous in terms of simulation time and cost. The second method is to develop a structured set of rules that closely approximate the observed decision-making process and can be coded into a computer algorithm. These rules will usually involve selecting the decision that is optimal according to some predetermined criterion.

Decision making in the computer model is achieved through a combination of interactive and automatic methods. Those decisions that are repetitive are made automatically consistent with a predetermined set of rules, and those that are seldom repeated are handled by an experienced operator. The decisions, their criteria, and the methods used for each are described below.

Track assignment is handled via the interactive interface. These decisions are made at the start-up of a simulation and at pauses in the simulation (also known as interrupts), which are generated whenever the status of a track changes. Examples of status changes include completion of unloading or loading. The operator assigns tracks on the basis of anticipated volumes, the relation between apron tracks and storage areas, and the physical characteristics of individual tracks.

Block assignment is handled via the interactive interface, with some updates made automatically and others interactively. A preliminary block assignment is made during track assignment, and the relative location of blocks is a function of train makeup considerations and expected volumes. Initially, only the starting point and the loading direction (or directions) for a block are set. The finishing point remains flexible, which reflects the uncertainty in volumes. Automatic decisions would include the release of sets of cars for loading in a block. Essentially, this means that the adjustment of block assignments will reflect changes in the expected volume due to variations in the trailer arrival pattern. If volumes are higher than expected, it may be necessary to reallocate railcars and possibly require a change to either the block or track assignment. This decision is made interactively, and the required simulation interrupt is generated when there is a conflict in the automatic updating of block assignments.

Switching decisions are handled interactively, while the switch itself is handled automatically. The factors leading to a switch include a requirement to spot cars for loading and for postloading train makeup. Any of the simulation interrupts used to make decisions on track or block allocation can be used for switching and, in addition, any indication of future railcar shortages will generate an interrupt. This reflects the advantage inherent in being able to schedule switches early rather than waiting until the last minute when it may be physically impossible to load the newly placed cars before cutoff.

Hitch allocation is done automatically in concordance with a specified set of rules. Three basic rules are used. The first is "first suitable hitch," in which a trailer will be assigned to the first space within which it will fit. A 40-ft trailer, for example, could be placed in either a 40- or a 45-ft position, but not a 27-ft position.

A second rule is "best hitch," in which a trailer is placed on the best hitch available. By using this rule, the 40-ft trailer would be placed on the first 40-ft position or, if none were available, on the first 45-ft position.

The final rule is "minimize excess train length." Hitch positions would be assigned according to expectations of volume and trailer mix. If a relatively high proportion of 40-ft trailers were expected, the optimum allocation could have some of them placed on 45-ft hitches. The determination of the expected increase in train length is based on the probability associated with specific trailer arrival events.

A simple example of the approach concerns a situation where nine railcars each have one 40-ft trailer loaded on the 40-ft hitch at 1 hr to cutoff. A tenth 40-ft trailer arrives and the current decision concerns whether to put it on the first 45-ft spot or load it on the tenth railcar in the 40-ft position. Based on past arrival patterns, the probability of more 45-ft trailers arriving in the last hour is as given in Table 2. (For simplicity, we assume that there will be no more 40-ft trailers.) The table shows that it is known with certainty that at least five 45-ft trailers are coming, so a minimum of five spots can be saved with no risk of penalty. The expected penalty associated with only five arrivals is calculated by determining the empty spaces that would remain and multiplying their total length by the probability of the event "five more trailers." A similar calculation is performed for each of the other arrival events with nonzero probability, and the sum of these products gives the expected excess train length associated with each decision. In this example, loading the 40-ft trailer in the 45-ft spot offers a clear advantage, even though an automatic 5-ft penalty is incurred.

These calculations are not suitable for a terminal clerk to perform each time a trailer arrives, but they are a reasonable representation of the type of intuitive reasoning an individual would make. Essentially, the individual would recognize that the likelihood of a large number of trailer arrivals is not high enough to warrant reserving many more positions. In the actual terminal simulations, the arrival events are much more complicated than the example, and frequently include compound events such as six 45-ft trailers, three 40-ft trailers, and three 27-ft trailers. Rather than summing over six possibilities, as is the case in the example, it may be necessary to consider hundreds of possibilities as is done in the simulation model.

The major requirements for the implementation of the minimum excess train length hitch-assignment rule are the probabilities associated with the various arrival events. These are determined by the analysis of historical information on trailer arrivals. Trailers will be grouped by destination, trailer length and weight, departure time, day of week, and plan (1, 2, 3, and so on); and the consistency and predictability of their arrival patterns will be determined. Ideally, these patterns would differ only in terms of timing and magnitude. This would greatly simplify the forecasting and data-collection tasks for a specific simulation. It is expected, however, that specific variations in pattern will be associated with different departure times and with plan 2 traffic.

Departure time or cutoff time may affect arrival patterns because of its relation to the times when shippers make trailers available. Most trailers will become available from mid-afternoon through the evening after being loaded by the shipper during the day. Clearly, shippers with multishift operations can delay or advance trailer releases with greater

Table 2. Sample hitch-assignment calculations.

Expected 45-ft Units	Probability	Excess Space	
		Load Car 10	Load 45-ft Spot
0-4	0		
5	0.2	5 * 45 = 225 ft * 0.2 = 45	3 * 45 = 135 ft * 0.2 = 27
6	0.3	4 * 45 = 180 ft * 0.3 = 54	2 * 45 = 90 ft * 0.3 = 27
7	0.2	3 * 45 = 135 ft * 0.2 = 27	45 ft * 0.2 = 9
8	0.1	2 * 45 = 90 ft * 0.1 = 9	0
9	0.1	45 ft * 0.1 = 9	40 ft * 0.1 = 4
10	0.1	0	2 * 40 = 80 ft * 0.1 = 8

Note: The total expected excess space for "Load Car 10" and "Load 45-ft Spot" is 144 and 75, respectively, The latter column incurs a 5-ft penalty, which brings the minimum up to 80.

freedom than can single-shift operations, but they form only part of the market. It is unlikely, therefore, that the arrival pattern for a 2200 cutoff can be represented by a 3-hr shift in the pattern for a 1900 cutoff. Similarly, it is not likely that plan 2 traffic, which is railway controlled, will have a pattern that matches non-rail-controlled traffic. The impact of finite pickup and delivery resources would be the primary reason for this variation.

Given that a consistent set of arrival patterns has been identified, it is possible to develop estimates that describe the probabilities of certain trailer arrival events and use these probabilities to identify optimal hitch assignments. Depending on the nature of the patterns, it may be possible to update the estimates as the day proceeds. The update of volumes for a specific train may depend on the volume of earlier arrivals for that train or possibly arrivals for a benchmark train. If, for example, a 1500 departure was expected to have 60 trailers and 80 turned up, it may be reasonable to increase the estimates for later trains by some factor. Similarly, plan 2 traffic may be a useful indicator of overall volumes because its magnitudes are known earlier in the day. The accuracy of the updates will depend on the consistency of arrival patterns and the relations between them. If these patterns turn out to be essentially random, then updating will not improve performance, but it should be recognized that the use of probabilities in hitch allocation would still result in long-run optimality.

There is a range of methods that can use additional information about a process to update the estimate of the final result. These range from simple look-up tables to complex techniques used in feedback control systems. Bayesian updating is used in this model; it essentially takes an initial estimate of trailer arrival probabilities, adds the information, and then produces an adjusted estimate of these probabilities. This adjustment is intended to approximate the intuitive updating done by terminal staff as the day progresses.

The decision-making algorithms described above will simulate the management portion of the terminal. The physical component will be handled in a manner similar to standard simulation models, which represent terminals by a series of queues, buffers, and processors (e.g., lines of trucks, parking lots, and cranes) with specified capabilities. Expected throughput is determined by calculating the expected availability of terminal resources that have known processing rates. Availability is a function of delays, which includes, for example, switching interference during respots or train makeup, nonproductive crane travel for the purpose of track changes, or waiting time during a changeover from loading to unloading. Where the forecast demand exceeds the short-term capability for processing, an interrupt will be generated so that more resources can be allocated if this is feasible.

The construction of a highly detailed terminal model is a large endeavor. To reduce the overall effort required, this model will focus on the train-loading and makeup activities, whereas the gate and parking will be considered as external factors. The trailer arrival pattern at the apron will be assumed to be the same as that at the gate. This assumption is reasonable in many situations, but it should be examined carefully, particularly where hostling requirements are severe or gate delays are highly variable. Similarly, the impact of off-loading requirements on loading can be ignored where a terminal follows a morning unload and afternoon and evening load cycle. If this is not the case, the analysis must become more complex.

The programming languages used for the model are BASIC and Assembler and all programming has been done by using an IBM personal computer with 512 K of memory. Actual memory requirements for the finished version will be less.

The model is being developed by using the CN Rail TOFC terminal in Brampton, which is located at the northwest edge of Toronto. This facility serves the southern Ontario market. The Brampton Intermodal Terminal (BIT) has a number of advantages that favor the development of this type of model. The terminal follows a simple morning-load and afternoon-unload pattern; there are no space restrictions in the facility; and each of the three apron tracks is of similar size and accessibility. Hostling requirements are minimal, and gate delays are not a factor in the loading operation. BIT uses two overhead cranes. Three of the four daily trains are blocked by destination and respots may be required during the loading period. The need to load 8 to 10 major blocks over three tracks creates conflicting demands on the cranes and requires appropriate blocking patterns.

CN Rail operates a much wider variety of railcar types and carries a more complex mix of trailer sizes than other North American railroads. Hitch use is extremely important to terminal operations, and the assignment rules will have many more alternatives than would be the case with 89-ft cars and either 40- or 45-ft trailers. Experience gained in this analysis may provide valuable insights into what may happen in the United States, given a mixture of 89-ft and multiplatform articulated cars together with 40-, 45-, 48-, and possibly 27-ft trailers in the system.

POTENTIAL APPLICATIONS

Three possible applications for a model of the type described are presented here: (a) the development of a simple decision support system for clerical staff in loading operations, (b) the identification of optimal blocking and switching strategies, and (c) the evaluation of alternative railcar fleets.

There is a simple relation between the minimize excess train length hitch-allocation method used in the model and the simple best-hitch or first-hitch rules. Depending on the expected trailer arrival patterns, the minimization of train length could cause switching between the two simpler rules. A diagram similar to Figure 1 could help the clerk in this switching process. The vertical axis represents the time remaining until cutoff and the hori-

Figure 1. Points of equivalent effectiveness of best-hitch and first-hitch rules.

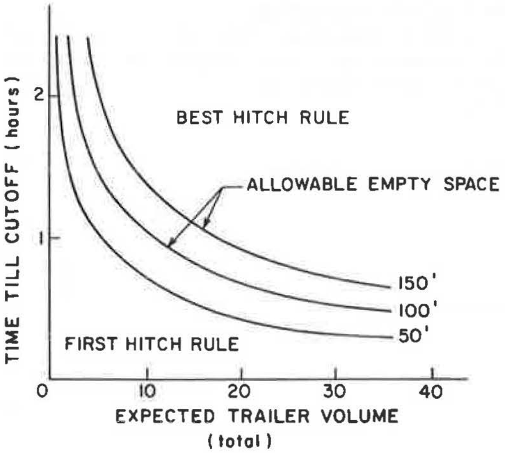
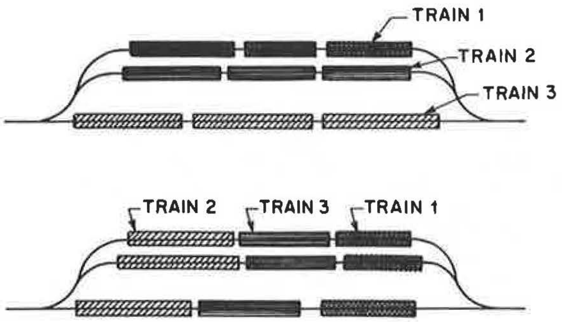


Figure 2. Alternative blocking arrangements for apron tracks.



zontal axis represents the total volume expected for that train or block. The curved lines on the graph represent the railcar length that can be skipped in order to load an arriving trailer on the best hitch available.

For example, if 20 trailers were expected, and 48 min remained until cutoff, it would be feasible to leave up to 110 ft of the train empty in anticipation of future trailer arrivals in order to use the best-hitch rule. If selection of the best hitch required leaving more than 110 ft, then the first-hitch rule would be used. The simulation model would be used to determine the nature of the trade-off for each terminal, as well as for each block and trailer type if this level of detail was necessary. In addition, the potential benefit of this decision aid could be evaluated. This would depend on the consistency of trailer arrival patterns and the complexity of the trailer and railcar fleet.

A second application of this model is related to the development and testing of alternative arrangements for the loading and assembly of trains. Figure 2 shows two possible methods for the loading of three trains, each of which has three blocks. Three tracks are available in the terminal. In the first method, each train is loaded on a single track, which can result in either empty cars or insufficient cars, both of which require switching. The other method assigns one block per track but requires that all tracks be shut down during switching. The relative advantage of a method depends on volume characteristics, schedule timings, and switching, and it could be determined by repeated simulation.

A final application of the model could be to determine the impact on hitch use of changes in the character of the trailer and railcar fleet. This would involve changing the characteristics of the operating environment of the model, which includes the trailer arrival distributions and the strings of cars that are available for loading. The loading activity could then be simulated to determine the impact of these changes and the results used in the evaluation of the effectiveness of various additions to the current railcar fleet.

These three examples indicate the potential of the model for providing decision support in situations that require repetitive short-term decisions, medium-term operating policy decisions, and long-term capital investment decisions. In each case, the evaluation is based on a detailed analysis of the situation that exists at a terminal during the loading phase.

SUMMARY

The model structure that has been outlined in this paper provides a framework for the analysis and improvement of certain terminal operating procedures. The foundation of the model is a procedure for forecasting and updating the volumes of trailers to be handled. The short-term uncertainty relating to outbound trailer volumes can be one of the major causes of terminal inefficiency, particularly with respect to hitch use. This uncertainty is incorporated into the model structure and is used in the assignment of railcars to hitches.

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TOFC Terminal Simulation Model

DOUGLAS S. GOLDEN AND CARLTON F. WOOD

A trailer-on-flatcar (TOFC) terminal simulation model (TSM) is currently under development, and it is being used in concert with the trucking subsidiary of a major class I U.S. railroad. TSM will provide a detailed simulation of the operation of an individual rail-highway intermodal terminal. Its purpose will be to support analyses of productivity and throughput of trains and trailers by the terminal facility. It will be able to address a variety of terminal configurations, terminal equipment types, and train service and traffic patterns. TSM will support both report and computer-graphic outputs. It will be a basic event-queue-processor simulation model, running against a 24-hr clock in daily increments. The model will be run from start-up through a designated number of daily increments; start-up and shutdown periods will then be discarded in order to analyze the terminal in a steady-state environment. As its primary output, TSM will generate a detailed audit file of all simulated activities; this file can then be used as input into a variety of postprocessor reporting and analytical programs. TSM will be written in FORTRAN in order to maximize its portability and installation options.

Given the recent increases in trailer-on-flatcar (TOFC) traffic moving on the railroads and the long-term opportunities for intermodal traffic growth driven by current and projected fuel costs, it is evident that virtually every major railroad is embarking on new programs. These programs are aimed at (a) diverting boxcar traffic to TOFC; (b) instituting dedicated intermodal train corridors; (c) eliminating low-volume TOFC terminals, especially nonmechanized ones; (d) upgrading or replacing existing intermodal terminals with new mechanized facilities; and (e) improving the overall profitability of intermodal traffic.

Transportation and Distribution Associates, Inc., has developed the terminal simulation model (TSM) to provide managers with an analytical tool that will allow them to answer the following questions:

1. What is the most efficient way to operate an existing terminal, in terms of use of tracks, loaders, jockeys, and so on, with existing train service? Conversely, how will changes in train schedules, facilities, or personnel affect the productivity of a terminal?
2. What is the best configuration for a new terminal to serve some planned intermodal service?
3. What changes in the operation of a terminal will optimize the servicing of priority traffic with the least degradation of service to other traffic?
4. How will major changes in traffic volumes through a terminal be accommodated?
5. What is the cost of operating a terminal under any of the options and configurations discussed above?

All of these questions are currently being or will be asked of railroad managers as the industry attempts to position itself in the transportation marketplace for the last two decades of the 20th century. Given the lead times for facility construction, and the capital costs and durability of such facilities, investment decisions for the intermodal sector must be made now, and correctly, in order to be in place when needed.

TERMINAL SIMULATION MODEL

TSM provides a detailed simulation of an individual intermodal terminal. It performs an analysis of the productivity and throughput of trains and trailers and containers at a terminal. It can support a variety of terminal configurations, train and traffic loadings, and report and graphic outputs. TSM permits evaluation of the productivity of a TOFC terminal (e.g., throughput rate and facility use) under a variety of configuration modes. TSM is a basic event-queue-processor simulation model. The simulation clock is a 24-hr one, advancing at fixed 1-min increments. The model is run from a start-up for some number of daily increments, such as for 21 days (3 weeks). The start-up and shutdown periods (first and last day) may then be discarded in order to analyze the terminal in a steady-state environment. All model input tables and parameters are stored in permanent files that can be modified to change the model's environment.

Work Units

Work units are the material that flows through the simulation. Work units are characterized by type and identity, as described below.

1. Flatcars are characterized as loaded (by stanchion count) or unloaded. They are placed in the main line, yard, or storage queues and are moved by switch engines. When cars are loaded, they are designated for a specific outbound train and for a specific destination block on that train. Cars are characterized by length (used for track capacity) and by a car-type descriptor. Each type or car can be loaded only with specific types or mixes of trailers and containers (i.e., containers only, a 45-ft trailer plus a 40-ft trailer, two 45-ft trailers, a single 48-ft trailer, and so on). The size limitations are maximums within a trailer type; thus, a car that can spot a 45-ft trailer could instead carry a 40-ft trailer in the same position.
2. Trains are identified by train symbol and date (in simulation); thus, TV-15 00950710 would be train TV-15 arriving on the 9th week, Thursday (day 5) at 7:10 a.m. Arriving loaded cars carry their train identification until unloaded. Departing loads receive a train designation when loaded. Train symbols can be given a priority to be applied to their traffic. Traffic characteristics are a function of each train and determine statistically the number and type of cars and trailers for each train. Trains that have the same symbol but run dissimilar schedules on different days are treated as separate trains by the model. Day of the week peaking of arriving or departing traffic (by destination) can be specified for each train.
3. Trailers are the basic work unit of TSM. They are characterized as inbound (from street to train) or outbound (from train to street), and by a block code that indicates a destination point for train-dispatched trailers. Trailers can be characterized as trailers, containers (not on chassis), or other unspecified equipment types. Each trailer can be given a statistically sampled length (up to five for each equipment type), such as 20-, 40-, 45-, 48-, and 50-ft trailers. Further, each trailer can be given a priority code, ranging from 0 to 10, to indicate priority handling of the traffic.

Events

Events are externally supplied and cause the insertion of work units (cars, trailers, trains) into one or another of the processor queues, as follows.

1. Train arrival is set for each train and is driven by a Monte Carlo sampling of earliest-likely, latest-likely, and most-likely arrival time, which is shaped into the so-called Beta (normal) distribution. Arrival time can be totally fixed, or it might be permitted to be nonoccurring on some probability basis.
2. Train departure is the scheduled departure time for originating trains. This serves as a target, with actual departure time resulting from the simulation outcome. Where the terminal is an intermediate point for a train, the departure time is a function of the simulated arrival plus processing time, so as to be ready for departure.
3. Trailer arrival is when the driver arrives at the gate with a trailer for loading. This event is driven by a Poisson distribution sampling mechanism, which is most appropriate for generating a random distribution of N events (trailer arrivals) over a fixed time period. The number and identity of arriving trailers are determined separately by a Monte Carlo sampling procedure.
4. Trailer departure is when the driver becomes available to remove a trailer from the terminal. Driver arrivals to pick up trailers that have come in on trains are normally distributed over a time interval that is offset from either the scheduled arrival or actual arrival time of each train.
5. Random events are subsequent refinements of TSM that are selectively introduced into the simulation. Such events encompass equipment failures, weather impacts (reduced processing rates), train nonarrivals, and so on. Also, trailers moving in and out of the terminal for storage and loading will be generated through this mechanism. This represents the additional load on the terminal imposed by the necessity to maintain an inventory of trailers for outbound loadings.

Queues

Queues hold work units that are awaiting some processor's attention. Queues are characterized by a capacity, which may be infinite. When a queue is full, work units must wait in a previous queue until space in the next queue is available. Queue categories are described below.

1. The main line, which is the holding area for inbound trains, is assumed to have infinite capacity but may be characterized as a first-come, first-served queue or one in which any train in the queue may be processed next, based on its priority. The former situation would be applied where trains must in fact line up for access to the terminal; the latter would be applied where adjacent siding or yard capacity would permit storage of trains and access when required.
2. Yard tracks are represented by the number and capacity (in cars and equivalent feet) that are available. Cars are placed on these tracks to be loaded or unloaded. The capacity used must include allowances for breaking cuts to keep crossings open. Additional support tracks for car and locomotive storage are not included in this queue category.
3. Storage tracks may be of infinite capacity and are external to the terminal simulation itself. Cars may be sent to storage tracks or fetched from storage without queue capacity or volume constraints. The problem of having sufficient flats available for required loading, or, conversely, of disposing of surplus cars, is beyond the current functionality of TSM. However, an inventory of surplus cars can be defined to act as a constraint on outbound loadings. If this inventory is defined as sufficiently large, then no constraint of flatcar availability would be imposed. However, TSM will contain a processor time for switch engines to move cars to or from such storage. The model will keep running if a flatcar shortage occurs, but it will record when and how many additional flatcars would be required by the terminal in order to keep the traffic moving. Also, if too many flatcars accumulate in the storage yard or yards because of inbound and outbound loading imbalances, surpluses of these cars will be dropped periodically from the storage yard to keep the model running. A message indicating that this has occurred will be issued.
4. The inbound gate (also called the street) holds trailers that arrive from the street that are awaiting clerical and inspection processing before entering the terminal. The capacity of this queue is infinite.
5. Outbound gate areas hold trailers that drivers have picked up while they are awaiting clerical and security checkout before leaving the terminal. Their capacities reflect the size of the interior gate areas.
6. Parking areas hold outbound trailers awaiting pickup by drivers for departure. They also hold inbound trailers awaiting loading onto flats. There may be several parking areas, and they are generally used in conjunction with the loading tracks closest to them.
7. Tarmac (or pad) areas provide trackside parking for trailers that have just been grounded by packers or cranes or that are awaiting loading. Generally, the capacity of the tarmac area is equal to the track capacity of the adjacent loading tracks. However, more than one yard track may be forced to use a single tarmac strip in a congested terminal.
8. Track queues are the trailer equivalent of the yard tracks for flatcars. Each yard track has a matching track queue, which represents the trailers loaded aboard the flatcars placed in the yard track queue. When cars from arriving trains are placed on their yard tracks, the trailers carried on the cars are placed in the matching track queue.

Processors

Processors move work units from one queue to another. Processors are characterized by the rate (in minutes) that they require to perform one such action and the numbers of each processor available. Although the TSM clock moves in 1-min intervals, processor work times may be specified in tenths of a minute. If a process is indicated to require an average of 8.3 min/cycle, then the model will use a process time of 8 min (7 out of 10 times) and 9 min (3 out of 10 times), which results in a average processing time of 8.3 min. A random-number generator is used to produce this fractional average. Processor times have a fixed time component (per operation) and a variable time component (per unit handled). In practice, this Ax + B process time is only used for switching, where a number of cars will be handled at the same time. Other processors handle single units only.

Processors are assigned crews, machines, day of the week availability, and starting and stopping times (including up to 10 breaks). Processors are essentially crew assignments (rather than machine assignments) that have defined shifts and breaks. If a processor is in the middle of a work process when a break occurs, it will complete the task and then extend the break period to make up the time worked. Similarly, if a crew is working, it can be relieved by another crew at break time or quitting time, and the relieving crew will finish any work task currently under way. Provision for crew overtime can be made if (a) work remains for the crew, and (b) there is no relieving crew available. There can be multiple processors of each type, which have different characteristics and processing rates.

Loading and unloading of trailers from flatcars can be performed by any combination of overhead cranes, sideloaders (packers), or circus ramps. The loading function moves trailers from the trackside tarmac queue to a flatcar. The processing rate includes actual loading time plus tie-down time. The unloading function removes trailers from a flatcar onto the trackside tarmac queue. The processing rate includes tie-down release, safety inspection, and actual grounding of the trailer. All loader and unloader processors must be explicitly moved from one trackside location to another. Where fixed overhead cranes are used, these cranes can only work designated tracks. Processor attributes are described below.

1. Packers load and unload trailers from trackside. Several packers can work a single track if necessary. Also, packers provide the maximum flexibility in their use through their greater mobility.
2. Cranes function similarly to packers in being able to load or unload at any spot on a track, but suffer from mobility problems when moved from one track to another.
3. Ramps, especially the loading and unloading rates for circus ramps, are a function of the number of cars standing at the ramp and the number of empty spots to be backed over to reach the farthest spot. Thus, the loading rate would speed up as the cut is filled, while the unloading rate would increase as the spots closer to the ramp were cleared. Ramps may be fixed in place or portable, and thus movable from one track to another.
4. Jockeys are used to move trailers between parking lots and trackside (tarmac). They are also used as part of the loading or unloading process by ramps or when handling containers (which require the jockey to position the container bogie).
5. Drivers are draymen or other drivers from outside the terminal who deliver or pick up trailers to or from the street. Drivers may fetch their trailers directly from the tarmac or from a parking lot. Drivers may take trailers directly to trackside for loading (if their train is being loaded next) or leave them in a parking area.
6. Gates handle the receipt of trailers from the street and the dispatch of trailers to the street. The gate crews perform clerical, inspection, and security processes on each arriving and departing trailer.
7. Train crews may be used to "yard" trains or pull them from yard tracks to the main line. Work rules or terminal layout may preclude their use at all or limit access by train crews to only some of the yard tracks. Generally, train crews will not be used if the train is not yarded within an hour of its arrival or if the train must be broken up to (or pulled from) more than one yard track. In lieu of using the train crew, a switch engine would have be be employed.
8. Switch engines are used to move cars from the main line to yard tracks (train breakup), from yard tracks to storage, from storage to yard tracks, and from yard tracks to the main line (train assembly). Each movement is characterized by a fixed time increment plus additional time per car handled in each movement. An additional switch engine process would be to "drill" a yard track, i.e., adding in more cars or digging one or more out.
9. Stanchion setup may be required before cars can be loaded. This processor uses a random-number generator to determine the probability of having to raise a stanchion (for a trailer) or lower it (for a container). A rate per stanchion is specified. Further, stanchion processing may be assigned to a packer crew or jockeys, or it can use a separate crew.

Figure 1. Sample report of utilization and productivity of packer crews.

```
                   PACKER UTILIZATION
                       LIFTS MADE

                                                         CREW:
       11111111+++                             11111111  PACKER 1
                 2222222222222222                        PACKER 2
       333++                              3333333333333  PACKER 3

                                                         MACHINE:
       11111111+++                             11111111  PACKER 1
                 1111111111111111                        PACKER 1
       222++                              2222222222222  PACKER 2
       -+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
        1 2 3 4 5 6 7 8 9101112131415161718192021222324  HOUR
       -+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
LIFTS |
   15 +
      |
   13 +
      |
   11 +                                   *************
      |                                   .
    9 +                                   .
      |                                   .
    7 +**********                         .
      |         .                         .
    5 +          ***********              .
      |                    .              .
    3 +                    .              .
      |                     ***           .
    1 +                       .           .
    0 |                        ***********
       -+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
        1 2 3 4 5 6 7 8 9101112131415161718192021222324  HOUR
                       <TIME OF DAY>

       AVERAGE LIFTS/DAY = 274.3
       MAXIMUM LIFTS/DAY = 344.3  (+ 2 STANDARD DEVIATIONS)
       MINUMUM LIFTS/DAY = 207.3  (- 2 STANDARD DEVIATIONS)

     AVERAGE OVERTIME HOURS =   8 % OF TOTAL HOURS
     AVERAGE MACHINE UTILIZATION RATE =  57 % OF AVAILABLE HOURS
```

MODEL OUTPUTS

The basic output of the simulation model program is the generation of three files that contain (a) a record of the terminal queue status whenever work units enter or leave a queue, (b) a processor activity file that records the completion of each activity undertaken by a processor, and (c) a work unit history file that shows the activities performed on each work unit. All files carry a standard time stamp (WWWDHRMN) and can be sorted to analyze the history of each work unit or processor or to display the concurrent activities of the terminal.

These files provide input to a series of program report generators. The report generators permit flexibility in both reporting format and content. A highly graphic output format is desired, although output analyses of mean and standard deviation performance, and minimum and maximum performance, are also included.

By using work unit history files and processor activity files of the generated detail, it is possible to build up a large population of terminal activity observations for use in analyzing the simulation results. Such results should be treated statistically because they are generated by using the Monte Carlo techniques of the simulation. The sample report in Figure 1 shows the results of a run in terms of the utilization and productivity of packer crews. The same report could be produced for a single crew, for traffic from a single train, or other options. Such man-machine diagrams are extremely useful in developing or changing crew shifts, breaks, personnel levels, and machine maintenance time.

Figure 2 shows the processing times for an arriving train on a ±90 percent scale of the observed

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.

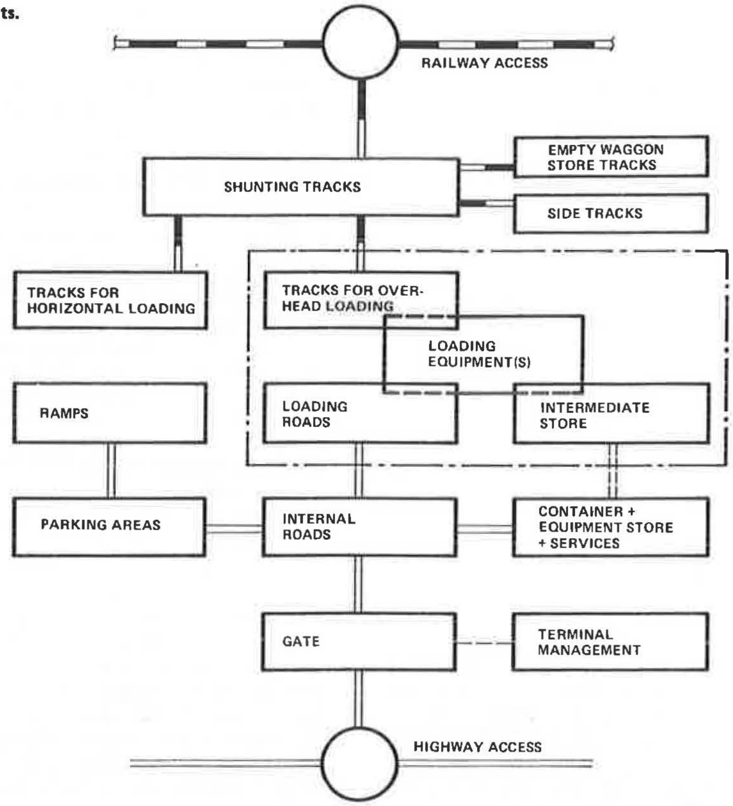
Once the basic terminal description has been captured in the series of TSM input tables, use of the model becomes a simple matter of identifying the change to be made to trains and traffic, to terminal layout, or to work crews and work schedules, and making this change in the input table. A separate 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

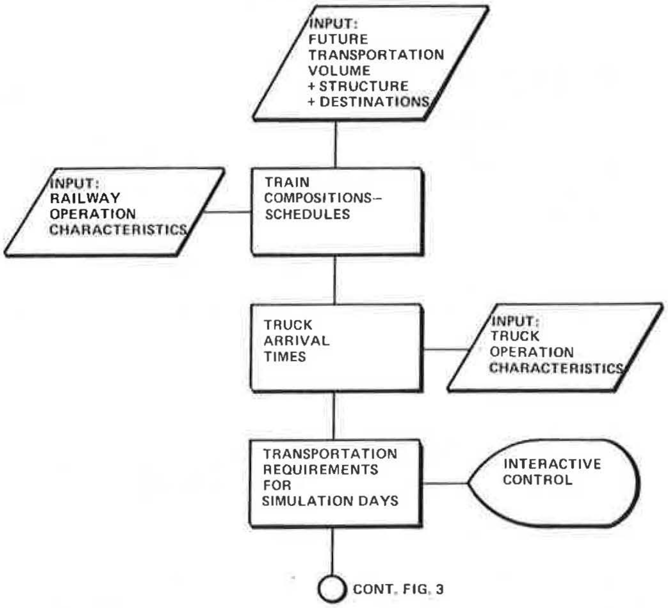
1. How far can the capacity of existing terminals be raised where there are limits to spatial capacity concentration?
2. What is the optimum relation between capacity and main design parameters, such as number and length of loading tracks, road lanes, and type, dimension, and number of equipment types?
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.

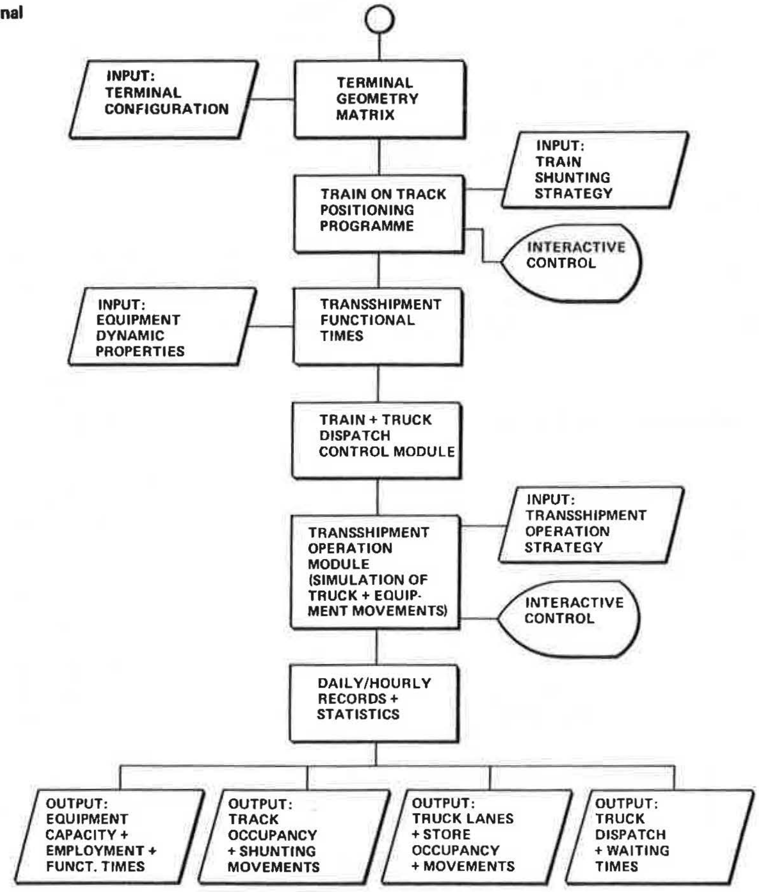
The program is of strictly modular design. It runs on a medium-sized process computer. A number of design alternatives can be tested at reasonable cost.

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.

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 4. Typical train operating characteristics.

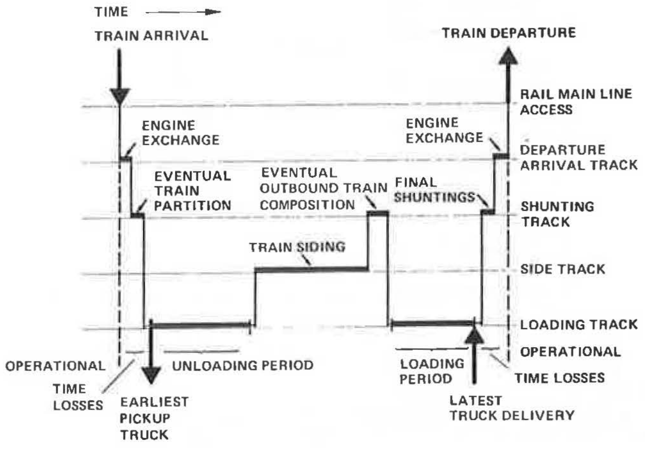


Figure 5. Typical unloading and truck pickup operation.

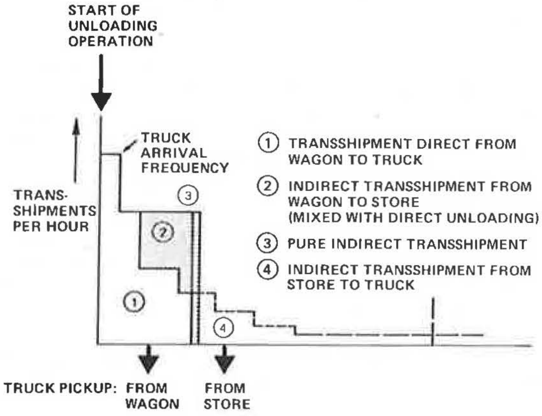
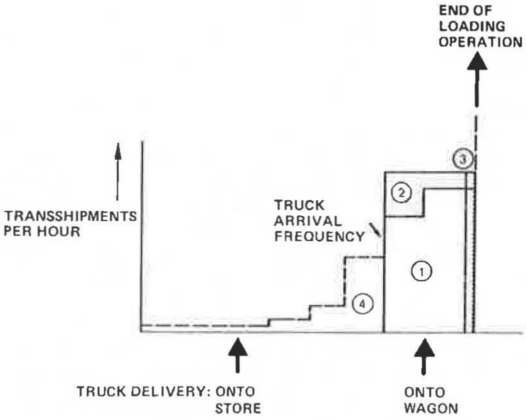


Figure 6. Typical truck delivery and loading operation characteristics.



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

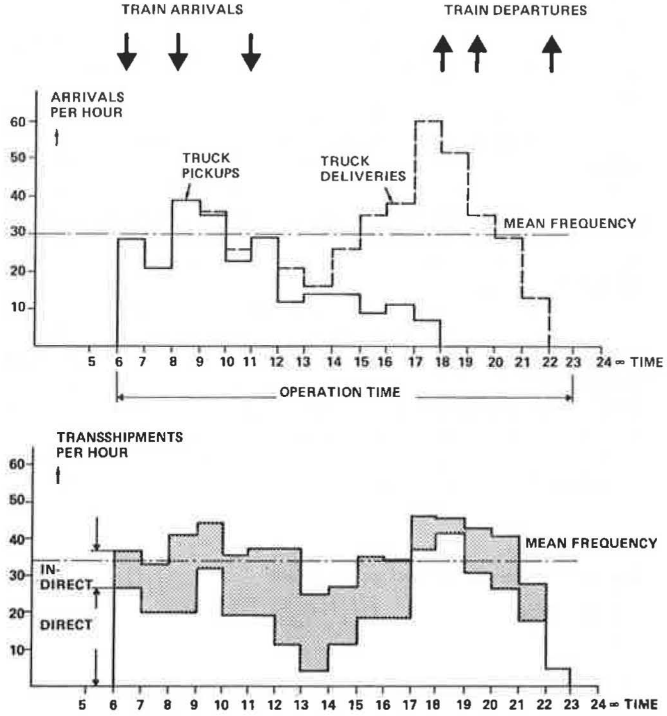
Figure 5 shows a typical unloading operation scheme. Just after train marshaling to the loading track, most of the load is unloaded directly onto the arriving trucks ("serve-the-truck" phase). Approaching the end of the standing time with less trucks to be served, parallel stripping of the train onto 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.

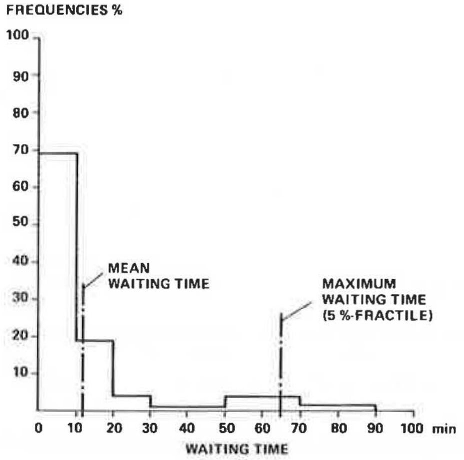
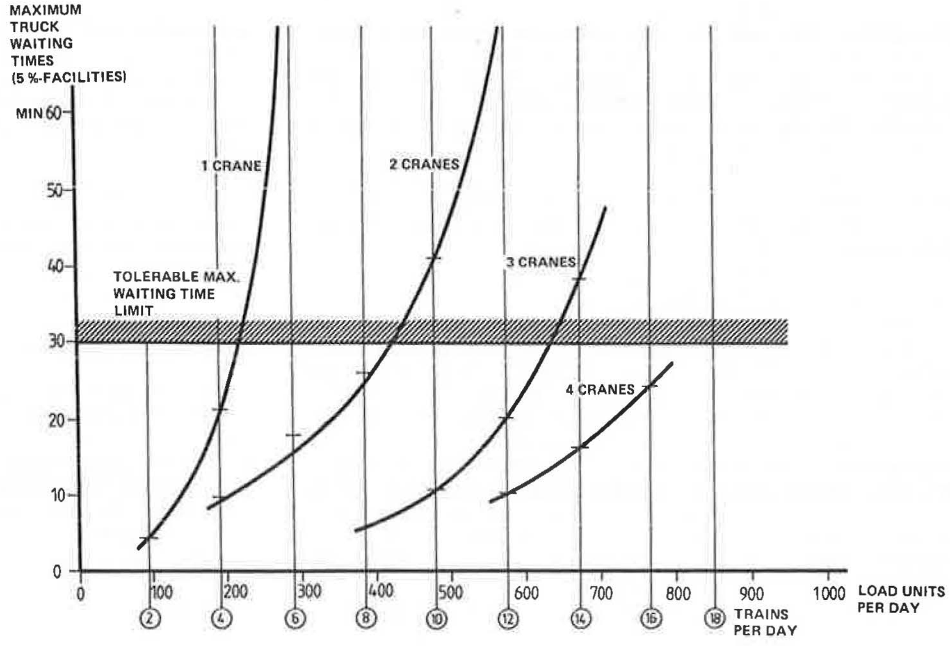


Figure 9. Truck waiting times over terminal throughput and crane number (two-track module).



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 10. Typical configurations for rail-mounted cranes.

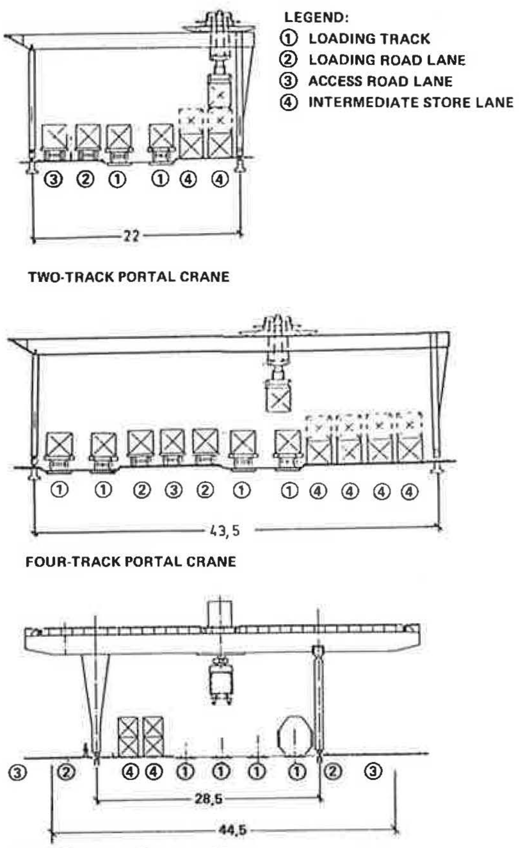


Figure 11. Terminal capacity over crane number for two different configurations.

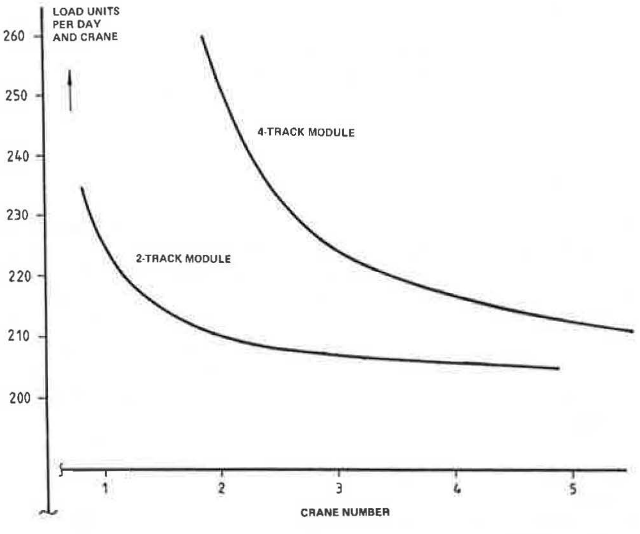
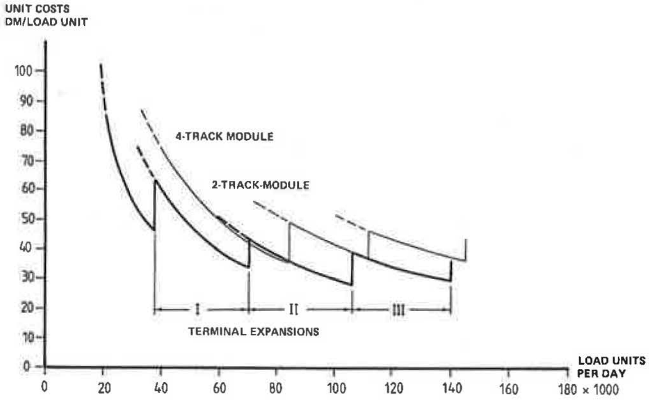


Figure 12. Terminal unit costs over throughput for different terminal capacities.



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.

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 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.

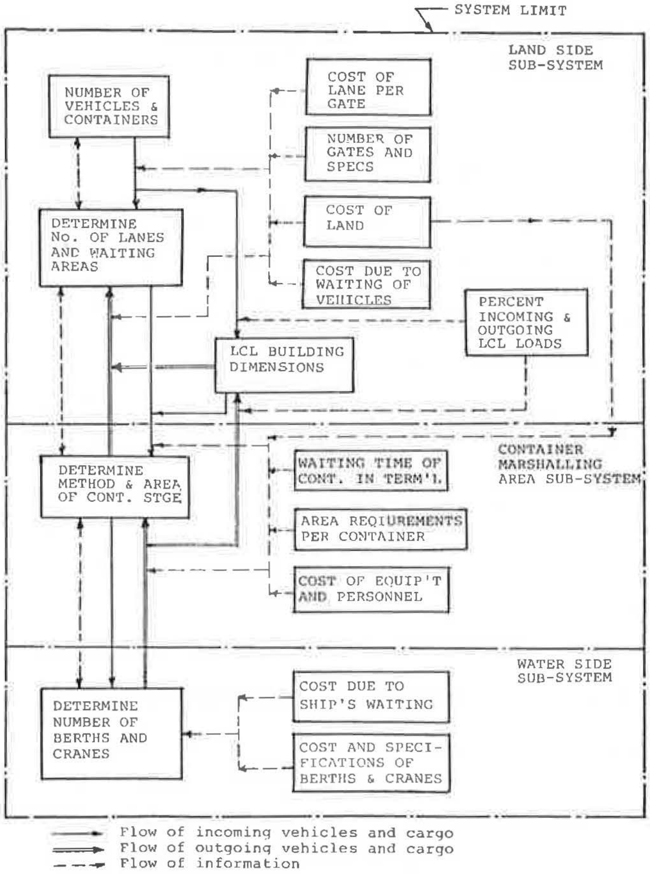
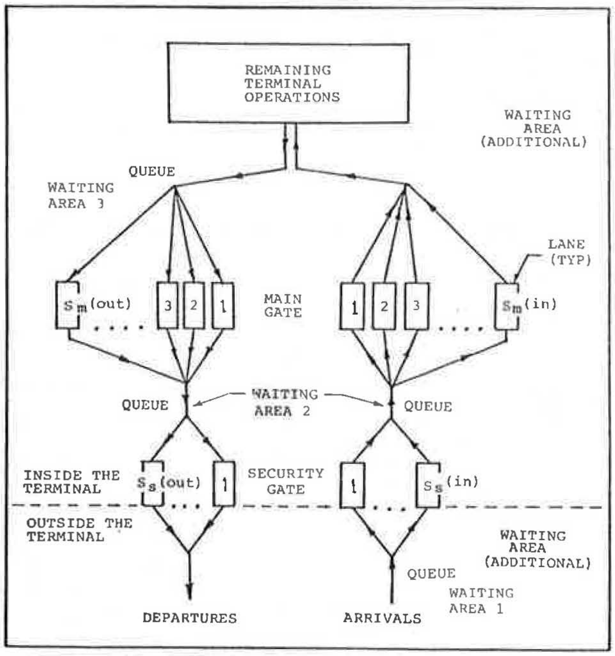


Figure 2. Terminal gate flow representation.



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:

$$\rho = \lambda/S\mu \qquad (1)$$

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

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

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

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

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

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

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:

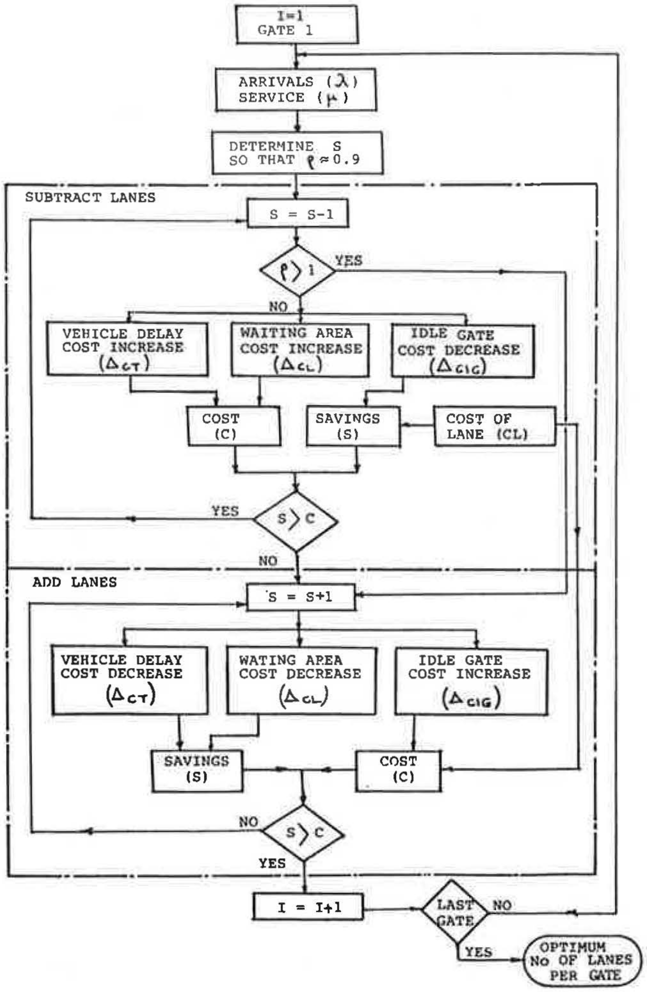
$$\Delta_{CT} = \pm [\Sigma V_i \cdot T_i \cdot HW \cdot D \cdot CD \cdot (1/60)]_S \mp [\Sigma V_i \cdot T_i \cdot HW \cdot D \cdot CD \cdot (1/60)]_{S\pm 1} \quad (5)$$

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.

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



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 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

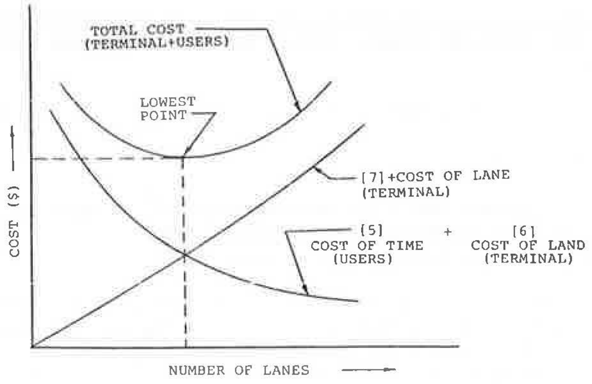
$S = 160/(0.9 \times 12) = 14.81$, or 15 lanes for gate B,

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 $\rho = 0.952$, which is less than 1. In the case of gate A, the reduction by one lane in gate A ($S = 2$) is impossible because $\rho = 1.33$.

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 ft^2 (10x50 ft),
3. The cost of land is $2.00/ft^2/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

JOAN AL-KAZILY

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

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

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

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

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

EFFECT OF CONTAINER HANDLING RATE ON SYSTEM PRODUCTIVITY

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

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

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

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

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

h = number of container moves made per crane by one crane working alone (base crane efficiency),
h_c = number of containers discharged and loaded per hour by all cranes assigned to a vessel during the time that a vessel is at berth,
h_b = number of TEUs discharged and loaded per hour during the time the vessel is at berth, and
h_p = number of TEUs discharged and loaded per hour of vessel time in port.

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

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

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

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

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

TYPICAL CONTAINER HANDLING RATE

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

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

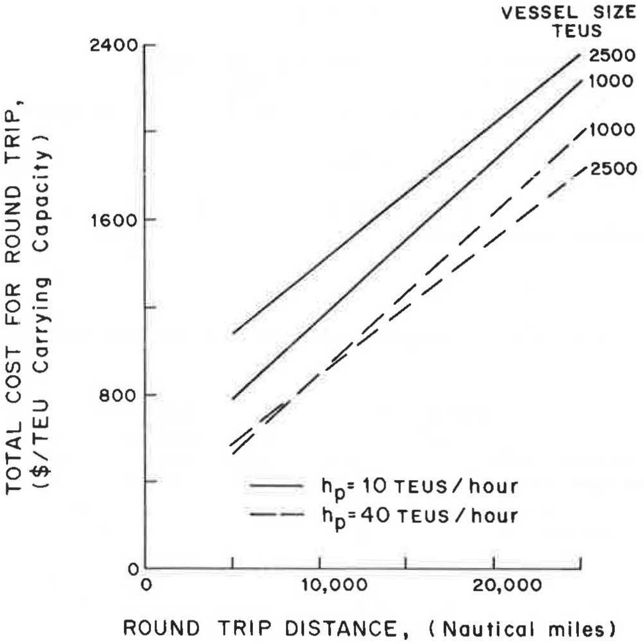
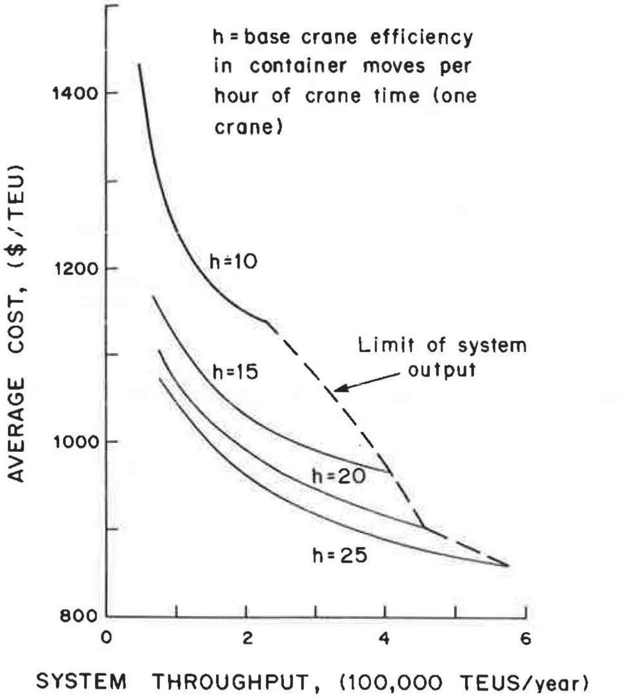


Figure 2. Variation of cost with base crane efficiency.



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

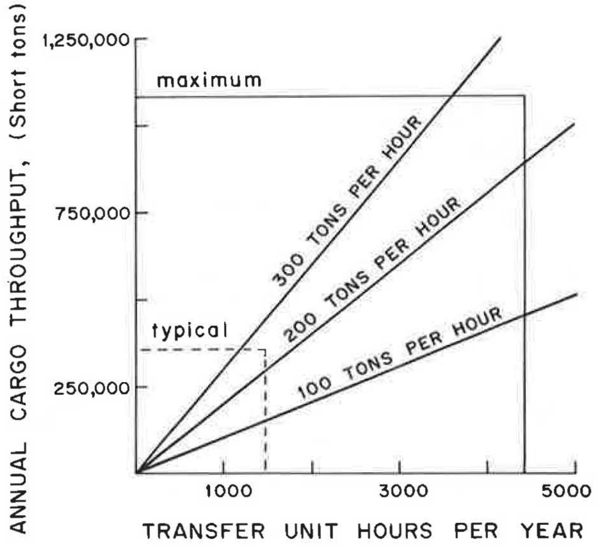
A similar range of container handling rates is demonstrated in data for 1 year of operation of a two-crane container terminal in Oakland, California (Table 1). The average for the terminal is 26 containers/hr of vessel time at berth, and the range is 9.0 to 47.4 containers/hr.

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

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

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

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



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

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

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

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

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

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

Figure 4. Container handling rates at existing terminals.

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

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

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

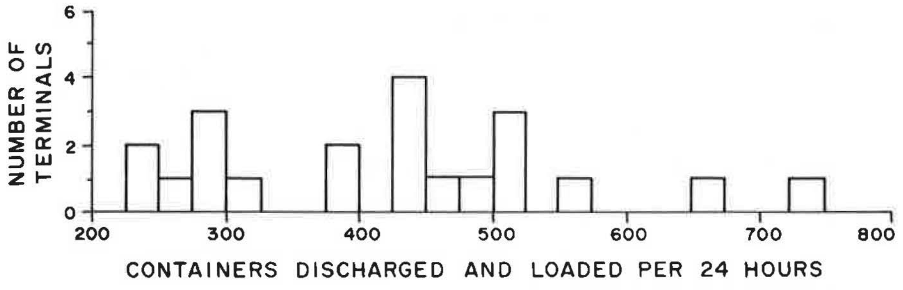


Table 2. Cargo handling rates reported by world ports.

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

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

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

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

been developed and is demonstrated in the following section.

MODELING THE CONTAINER HANDLING RATE

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

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

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

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

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

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

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

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

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

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

where

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

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

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

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

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

NEED FOR FURTHER RESEARCH

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

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

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

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

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

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Handling and Storage of Empty Chassis

SCOTT S. CORBETT, JR.

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

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

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

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

INTERMODAL GROWTH

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

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

Thus, tools have been developed and are available to fit into the intermodal segments of the various modes. By rapidly passing over the other individual advances in this industry (i.e., container ships, larger trailers) to arrive at what is happening today virtually ignores an intense period of material handling development by the individual segments of this industry and the various manufacturers. From this development comes material handling equipment used by rail, truck, and ship that is efficient and relatively economical, which has allowed the industry to expand. This expansion is natural because of the economic values this method of material handling offers; however, expansion has been accelerated by the energy crises. Deregulation has also stimulated some innovative ideas and interchange agreements; the land-bridge, minibridge, and microbridge concepts are prime examples.

All indicators point to continued growth. This industry grew rapidly in the late 1950s, and even had a steady increase during the 1981 to 1982 depressed era. However, today some major problems have arisen, such as space, room, and area in which to operate the intermodal business in interchange areas.

NECESSARY STEPS TO EXPANSION SOLUTIONS

The intermodal industry has to grow, yet it is tied to the transfer points of packages--primarily railroad terminal yards and ports. Most were originally built to solve the problems of the individual modes, with no real understanding of other modal problems or foresight of the expansion that has taken place.

It is recognized that a new terminal design in a new location can meet many of the problems of logistical space construction. However, it is also recognized that this can constitute some capital investment problems that are in some cases almost insurmountable. Thus, current terminal designs, if possible, should be modified. Also, all modes need new tools in order to increase efficiency and allow for continued expansion. Therefore, it is imperative that management seek and recognize these new technocracies for immediate profitability and possibly survival.

EMPTY CHASSIS PROBLEM

Tens of thousands of containers and trailers are handled every day. When a container is put aboard a ship or on a railroad flatcar, its chassis or undercarriage is left behind. Within the railroad industry today there is a massive program of development of specialized railcars to handle these containers. An example is the "double pack" of the Southern Pacific Railroad and the "10-pack" of the Santa Fe Railroad. In fact, it is believed that domestic containerization is inevitable, which will compound the storage problems at these interchange points, including the problem of storing the empty chassis.

In theory, the use of a container requires a chassis at each end of the haul or, on a worldwide basis, at each port. Many approaches are being taken to handle cargo and empty container problems, yet few terminals can handle the storage problems of empty chassis.

An empty chassis is an undesirable item: it does not produce any income, is easily damaged, needs to be repaired often, takes up space, and, when one is wheeled out of the way or stacked on top of another one, it creates continuous operational labor problems.

If customers are pressured to move a chassis out of the yard before they are prepared to do so, a customer-relations problem is created, and the problem of what to do with the chassis is intensified. Increasingly, the owner or shipper is asking that this problem be faced by the actual intermodal unit itself, whether rail, truck, or ship.

CURRENT APPROACHES TO EMPTY CHASSIS HANDLING AND STORAGE

Some firms have reached the conclusion that, because of the logistical problems of empty chassis and delivery practices, when the container is off-loaded from the ship and in domestic use it should be locked to the empty chassis. When the terminal storage area is large enough, there are many advantages to this method. However, there are also some major disadvantages, which will continue to create the same operational problem of storage space. Ultimately, the storage of the empty container, whether or not on an empty chassis, has to be approached and looked at in a method other than that of the single horizontal technocracies that exist today. Even so, there must be a group of empty chassis, usually no less than 300, in order to start unloading a ship. And 300 empty chassis in a single horizontal position take up 210,000 ft^2, or 5 acres.

The owners' approach to the handling of empty chassis is usually influenced by the number that they are responsible for or the size or location of the fleet. Many owners have so many chassis that they operate their own terminals for empty chassis storage and repair. Others depend on what are known as satellite or privately owned storage yards, which operate in most port areas. Thus, an owner can have the container, trailer, or empty chassis handled by a third party. Bear in mind that the problem of space, although it is accentuated at the terminals (whether rail or port), also exists at the privately owned third-party yard. The use of these satellite yards is a common method, yet it is puzzling that the owners of chassis are not more aware of the problems of the handling by some of these private yards from the standpoint of chassis repair costs.

The technology of handling chassis in most areas consists of putting them in the air in a highly unsafe manner by a front-end forklift truck and stacking them on top of each other. In addition, chassis owners will send a truck to get a chassis and tolerate as much as a 3- to 5-hr wait while a chassis is dug out of storage.

Basically, what takes place today, whether it is in a private satellite yard or in a large owner's yard, is that chassis are stacked on top of each other by forklift trucks in a horizontal plane or parked in a single horizontal system with random access.

In the discussion of storage, it is beneficial to have some knowledge of the physical characteristics of empty chassis. There are at least five major chassis manufacturers. Commonalities of measurements include the same frame heights and widths. However, frame depths vary by as much as 100 percent. There are other factors related to the empty chassis that affect storage, no matter what method is used. The primary one is axle setting, which is the most variable factor. Although axle setting is not too important when using the horizontal-type storage system, it is of major importance for some mechanical systems when chassis are stored on top of each other. Basically, there are some chassis that are so specialized that there is only one way to handle them, and that is to leave them flat on the ground. There are also variations in chassis lengths: the basic 40-ft chassis down to the basic 20 ft, with 24- and 35-ft chassis in between, and also the new 45- and 48-ft chassis. However, the chassis used today are usually 20 and 40 ft and are easily handled by the mechanical devices described in this paper.

Following is a study of current conventional storage systems used for empty chassis, both 20 and

40 ft. All of the examples have allowed for working room and use a 40x8-ft chassis in the diagrams.

System 1: Conventional Random-Access, Ground-Level, Horizontal System

The advantages of system 1 are as follows:

1. No lifting (handling) equipment is needed,
2. It is sometimes possible to have owners park and pick up their chassis,
3. There is minimum chassis damage, and
4. It is relatively safe.

The disadvantages of this system are as follows:

1. It uses a great deal of space,
2. Inventory control is difficult,
3. Hostling search time is high, and
4. Security is poor.

The space used for system 1, based on 40-ft chassis (which are generally used throughout the industry) with access and roadways also accounted for, is 677 ft²/chassis. Figure 1 shows system 1, which is for 48 chassis and uses 32,500 ft².

System 2A: One-on-One Stacking and Side Pick

One-on-one stacking and side pick are horizontal systems. The advantages are as follows:

1. It reduces the space requirement of system 1 by at least 50 percent or more,
2. It is relatively safe when compared to stacking higher,
3. No stickers are needed because of reduced weight, and
4. There is better security.

The disadvantages of system 2A are as follows:

1. More labor and equipment are needed;
2. There is some damage to chassis; and
3. Three chassis may have to be moved in order to get to one.

Side pick uses a standard 15,000- to 20,000-lb forklift. The space used for system 2A is 430 ft²/chassis. Figure 2 shows system 2A, which is for 96 chassis and uses 41,300 ft². (Note that in Figure 2, each line represents two chassis, one on top of the other.)

System 2B: End Pick

System 2B, like the one-on-one concept, is horizontal. It is necessary to have a chassis flipper for this method (the flipper is illustrated later), and to move only one chassis to get to any other one. This system allows the possible use of land that is not normally accessible. The space used for system 2B is 313 ft²/chassis. Figure 3 shows system 2B, which is for 96 chassis and uses 30,000 ft².

System 3: Two-on-One

System 3 is also a horizontal system. It has similar space requirements to systems 2A and 2B, except that in system 3 the chassis are stacked in a two-on-one configuration (see Figure 4). [System 3 is subdivided into 3A (side pick) and 3B (end pick).] The main advantage of system 3 is that it takes up 33 percent less space than either system 2A or 2B. The disadvantages of the system are as follows:

1. Stickers are needed (dunnage);
2. More damage is done to chassis;
3. It is more dangerous;
4. More time is spent on operations; and
5. Five chassis may have to be moved in order to get to one chassis in 3A, and two chassis may have to be moved in order to get to one chassis in 3B.

Therefore, system 3A (side pick) needs 270 ft²/unit for stacking chassis three high and system 3B (end pick) needs 200 ft²/unit for stacking

Figure 1. Diagram for system 1.

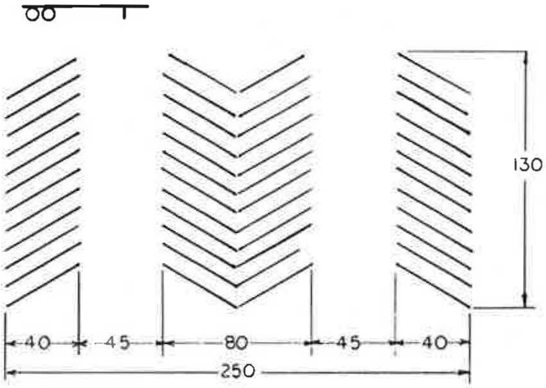


Figure 2. Diagram for system 2A.

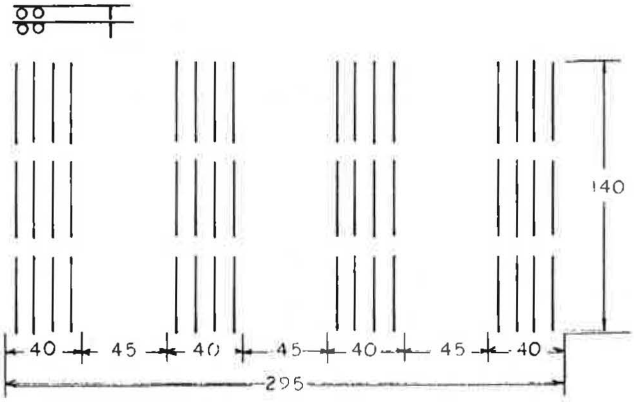


Figure 3. Diagram for system 2B.

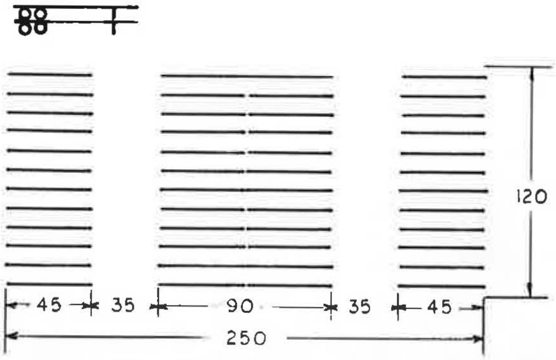


Figure 4. Diagram for system 3.

three high. Sometimes the procedure of stacking chassis four high is used, but it is not recommended because it could be damaging and dangerous.

Discussion of Systems

The manpower required in all three examples is approximately the same. The only capital equipment required to get chassis on top of each other is the aforementioned 15,000- to 20,000-lb forklift truck. There is a damage factor that increases proportionately, and there are time and labor factors, depending on density.

By placing chassis in a tighter density, there may be situations in which as many as 30 to 40 chassis may have to be moved in order to get to a particular one. In general, the practice of seeking a specific chassis is not common. It is common for a general storage yard to keep an individual customer's chassis together in one group, which is the sensible procedure. Therefore, in using an acre of land as the criterion--whether it is leased land or land that is needed for the horizontal method--count on 60 chassis (40x8 ft) to an acre; when stacked two high, 120 chassis; and when stacked three high, 180 chassis.

With respect to the application of land costs, obviously costs vary in different areas. On the East Coast, an annual rental of $17,000/acre is common, and on the West Coast, and in Seattle in particular, it is $47,000/acre. Thus, if all factors were maximal--if there was the ability to store 180 chassis/acre, the annual rental was $47,000, and the requirement was for storing 1,000 chassis--there would be probably about 6 or 7 acres involved, 2 or 3 forklifts, and an annual rental cost of $300,000 to $350,000 for the land. On the other hand, by using system 1, as much as 17 acres and $900,000 in rental costs could be involved.

In most port areas, putting chassis one on top of the other is not acceptable because of the time factor involved in getting them up and down, and also because of the search and storage requirements. In most port areas the single storage system is used. However, as ports become more crowded, chassis have to be placed on top of each other.

Figure 5. Chassis flipper system.

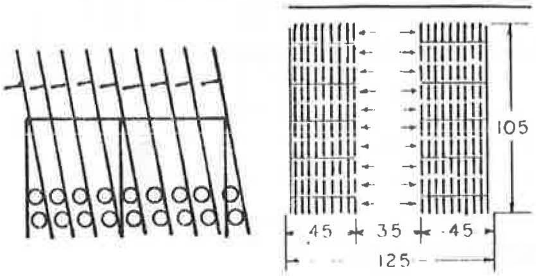


Figure 6. Chassis flipper attachment.

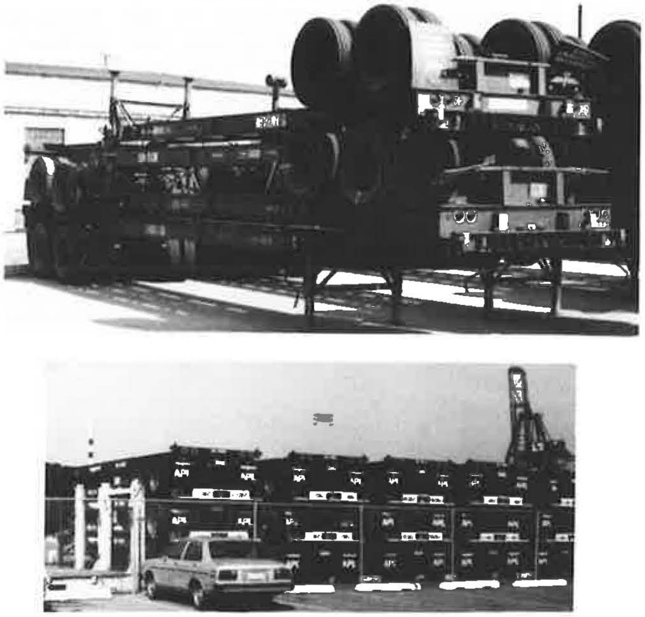
NEW EMPTY CHASSIS STORAGE CONCEPT

The mechanical system described in this section is an improved method from the standpoint of land use and least damage to chassis. The value to customers of this system is based entirely on how they view the acquisition of new land. If, for example, a major railroad wanted to put more volume through a

Figure 7. Flipper picking up a unit.

Figure 8. Placement in storage rack.

Figure 9. Chassis in a bundler.



piggyback terminal, this could mean new business for the company. But for a stevedoring company, it could also mean a reduction in the amount of land needed for handling chassis.

With respect to labor, the farther the traveling distance (if using a single system) and the more hostling tractors used, the more time that is needed to search because of inventory control. In putting chassis on top of each other, there is the factor of labor in hoisting them up by the lift trucks and then taking them down. Also, although there may be savings on a hostling tractor, more will be spent on labor for the forklift truck operator, and there will be a higher damage factor.

The turnover time, or the ratio of time spent taking a chassis from storage to its final use, varies immensely--from as much as four or five months between uses to four or five times a month.

The system described below is the chassis flipper system, which is manufactured by Multi-Sort, Inc., of Portland, Oregon. The advantages of this system are as follows:

1. It has the best possible land use,
2. It is the best system for safety reasons,
3. There is reduced hostling time,
4. There is no stacking damage, and
5. There is better security and inventory control.

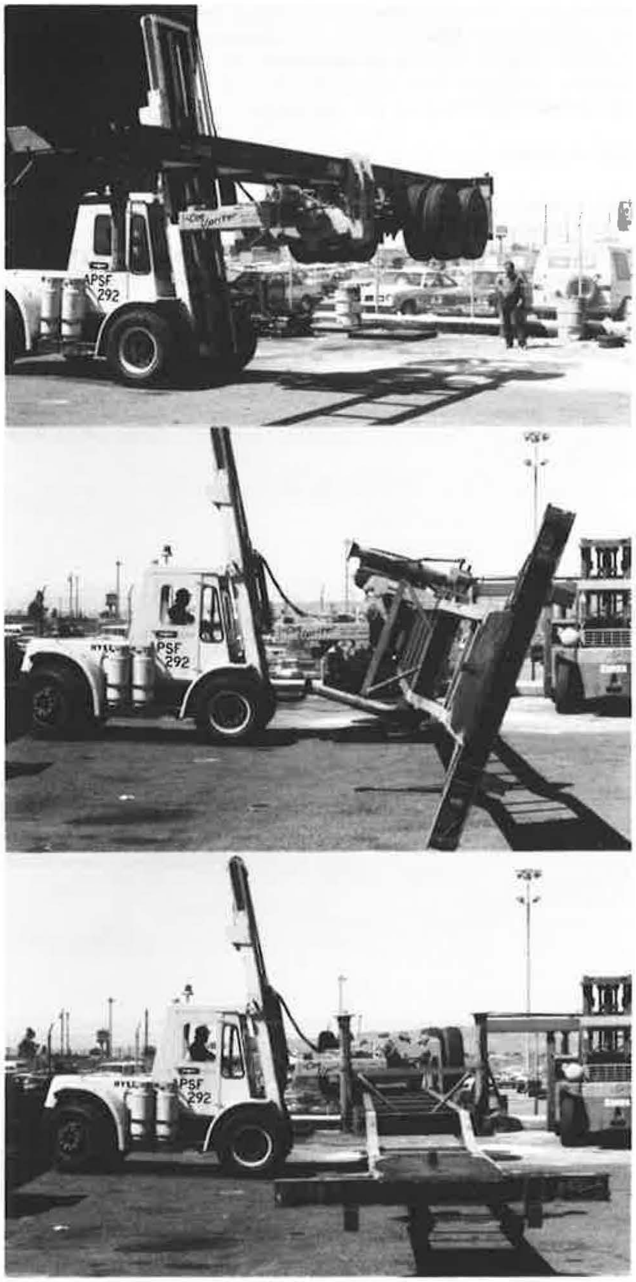
The disadvantages of the system are the costs for the storage racks and the requirements for moving several chassis in order to get to a specific one.

The space used for this system, which is designed for 8- to 10-ft-wide front-axle forklift trucks with a T-bar rack design, is 74 ft^2/chassis. Figure 5 shows the system for an 8-ft-wide lift truck. It can handle 180 units and uses 13,000 ft^2.

Figure 6 shows the chassis flipper attachment, which will fit on any standard forklift truck of 30,000 lb or more, as it approaches the chassis when the chassis is in the horizontal position. Figure 7 shows the flipper picking up the unit, and Figure 8 shows the chassis being placed in a storage rack.

In this system, each individual chassis in the upright position takes up 55 ft^2. However, to allow for the open working space needed to get the chassis in and out of storage, an estimate of 650 chassis/acre is used. For example, in Seattle a little less than 2 acres is used as compared to 17 acres, and at $47,000/acre, this is a significant factor. On the other hand, there is a capital investment required for the larger lift truck, the flipper attachment itself, and the storage racks. The storage racks operate automatically, so that ground personnel are not needed. The racks should be good for many years, and probably can be amortized on a 7-year schedule. They also are movable; however, this would necessitate the building of new footings for the next location. The advantages of this system from the standpoint of inventory control are obvious. However, capital investment is considerably greater when compared to other systems.

Figure 10. Rotator or uprighter at work.



Some operators need to move chassis from one location to another because of an imbalance, and they usually move the chassis in bundles. Rotating or turning over a chassis can present labor and damage problems. The following figures depict the rotator or uprighter that helps alleviate these problems. Again, these are manufactured by Multi-Sort, Inc. Figure 9 shows the chassis in a bundler, and Figure 10 shows the rotator or uprighter in action.

CONCLUSIONS

The handling and storage of chassis are factors that have been greatly neglected in the planning and thinking of most operational entities, whether by the owner or the operator. Extra efforts in this area can be of material advantage to the company that seizes the opportunity to use the available tools to enhance its own position in the field of intermodalism, whether for obtaining new business, reducing current costs, or supplying customers with needed facilities.