A System Description and a Literature Review Survey for Rail Intermodal Container Terminal Operations

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ABSTRACT
Rail intermodal container terminals are open systems of material flow with two external interfaces: a) the track side, where containers are (un)loaded on the incoming and outgoing trains or transshipped from one train to another, and b) the landside where containers are delivered or picked-up by trucks. From an operational point of view the terminal can be divided into three parts: a) the rail side operations, b) the storage yard side operations, and c) the gate side operations. For management of the entire yard operations, informed decisions are critical for the smooth flow of the containers and trains within the terminal and the transit time of containers in the whole network. In this paper we present a detailed description of the layout and different processes of these terminals and a brief literature review of related research studies in the hope that it will promote and increase future research efforts.
INTRODUCTION

Global containerized trade is increasing and it is predicted to reach 129 Million TEU\(^1\) by year 2011, representing an increase of over 200% from 2001. The US DOT’s Federal Highway Administration predicts that the US will also be affected by this increase of trade and experience an overall doubling of international freight by 2020. This projected growth in the global trade will result in a larger volume of containers required to be handled in intermodal terminals and transported over land and will escalate congestion problems at the nodes and links of the freight transportation network. As rail yards are important components of this network and given its resulting economic, operational and environmental implications, it is evident that optimizing operations within these terminals will attract significant attention by the industry and the academic research community in the years to come.

A rail intermodal container terminal (from now on referred to as terminal) is an open system of material flow with two external interfaces: the track side, where containers are (un)loaded on the incoming and outgoing trains or transshipped between trains, and the landside where containers are delivered or picked-up by trucks. From an operational point of view the terminal can be divided into three parts: the rail side operations, storage yard side operations and the gate side operations. These operations include the management of the whole yard and the decisions are very critical for the smooth flow of the containers and trains within the terminal and the transit time of the whole network. The rail side operations consist of the scheduling of the inbound and outbound trains, breaking of the inbound trains and the creation of the outbound trains. It also includes (un)loading of the containers onto the trains which are of two major types: a) containers that are attached to a chasse (e.g. chassis on flatcars or roadtrailers), and b) containers that are not attached to a chasse. Containers can be transported on the flatcars in different ways that include: a) double stack, where the containers are stacked one on top of the other on a flat car, b) single stack with one 53ft, 48 ft, 40 ft or one or two 20ft containers, c) piggybacks on flat cars, d) roadtrailers which have rail wheels attached to the trailer to be suitable for movement on both rail and road and e) special containers (e.g. tank containers). Storage yard operations consist of decisions relating to the allocation of containers in the yard for storage and the movement of the containers between the three main areas of the terminal (i.e. the track side, the storage yard, and the gate area). Finally, the gate side operations consist of transporting the incoming containers to their respective areas in the yard and the pick-up of the outgoing containers by trucks. Each one of these three systems works independently but also interacts with the other parts and thus optimizing all of the operations within a truck-rail intermodal container terminal becomes a very challenging task.

The purpose of this paper is to provide a detailed system description of a rail intermodal terminal, and to present a summary of the major research studies on modeling and simulation efforts for the operations of these terminals, in the hope that it will promote and simplify future research efforts. The paper is partitioned into five sections. The first three sections describe in detail the operations and layout of the three terminal areas, while the fourth section presents a review of the majority of the related literature. The last section concludes the paper and suggests a very important future research direction.

TRACK SIDE OPERATIONS

Trains arrive at the terminal via the main line (also known as the feeder line) which needs to be kept free at all times to allow trains to enter and exit the terminal and thus it is never used as a waiting area for trains. The main line leads to the waiting and service tracks (fig. 1). The yard also includes maintenance tracks for the engines and the other rolling stock. The service tracks can consist of a single or multiple tracks (excluding the main line). If a train arrives on time the engine and caboose are detached from the train and the crew is relived from duty. The train then goes through the inspection process where both the train and the containers are checked for damages. The train then proceeds to the scheduled service tracks where the available handling equipment (un)load the containers or transship them from one train to another. Some of the major factors influencing the assignment of the train to specific tracks include: a) the

\(^1\) Twenty foot equivalent unit
number of tracks available in the rail yard, b) the optimum travel route of the container, c) the operations required on the train, d) its arrival time relevance to other trains etc. The scheduling of freight trains on the tracks should avoid deadlocks and minimize the number of crane moves. If the number of trains arriving on time exceeds the service tracks capacity then the trains are prioritized based on different policies (e.g. freight versus passenger priorities, arrival time or priorities or policies formulated by government). If a train arrives early or late, it is rescheduled based on the position of the other trains and availability of service tracks. If there is space in the service or the waiting tracks then the train can wait in the rail yard, otherwise it has to wait outside the terminal on a siding. Two different types of utilization are observed in the service tracks: a) the static and b) the dynamic. The former type assumes that trains do not switch between the waiting and service tracks and vice versa.

Each incoming train that enters the terminal is broken down to form a new outbound train(s). Based on the approach used to create the outbound trains from the inbound trains, the service tracks can be classified as shunting or transshipment tracks (fig. 2). In this former case each rail car from each train is directed to a track in the track yard and used to form another train with a new destination. Each train is broken according to the containers’ destinations and the track capacity, and every car is not necessarily sent to a separate track. In the latter case each line in the track yard receives as much of the train as it can accommodate in terms of length, containers are (un)loaded on the train, and the same train leaves the terminal to another destination. In both cases new rail cars can be added or existing rail cars can be removed. Some terminals may only accommodate one of the two operations, though common practice dictates, that if a terminal accommodates both operations, each takes place separately. It is also common practice that a shunting yard will never be used as a transshipment yard and vice versa in cases of limited capacity.

During shunting, the string of cars are separated and rolled down the tracks according to the destination of the container. Thus, a train is broken down into several parts according to the destination of the container forming different trains that further haul the container to the next destination. The operator decides the track each rail car (with or without a container) will be rolled onto. There are three different types of shunting yards: a) the hump yard, b) the flat shunted yard, and c) the gravity yard. In a hump yard each car is shunted to the hump and with the help of switches is rolled to its specific track. In a flat-shunted yard the same operations are carried out but without the hump and the cars have to be physically shunted with locomotives or yard engines. In a gravity yard, the string of cars is shunted by gravity.

\footnote{Loading, unloading, transshipment, shunting}
and for this type of operations terrain morphology is a very important and critical factor. Empty cars are introduced in between the loaded cars according to a weight balance and for the containers that need to be loaded from the storage yard.

**Shunting tracks**

At shunting tracks, containers are unloaded from the trains and loaded into the storage yard or transferred from one train to another. The gantry cranes are the main handling equipment to perform these operations, although other handling equipment (such as straddle carriers or front end loaders) can assist with this process. In a shunting yard trains are usually served in sets and the allocation of trains to tracks is of vital importance. It is often the case that in a set of trains served simultaneously, some will need to return for service (e.g., wait for containers arriving on another train not yet at the terminal). In this case the train does not wait on the service tracks. Instead it leaves the yard and waits to be rescheduled for service along with a set of new incoming trains. This process may be repeated any number of times until all the containers scheduled to leave with that train have been loaded.

After the new train is complete the string of cars are hauled across the yard by yard for inspection and safety testing. Full break tests are performed and a caboose (if needed) and the engines are attached to the train. A single engine can haul up to 30 to 40 rail cars (assuming that each rail car carries the equivalent weight of one full container). If more rail cars need to be hauled then additional engines are attached to the train. The assigning of locomotives, crew, caboose, is done in such a way that the string of cars are hauled with enough power at the minimum possible cost. The train then waits to be scheduled to leave the yard. Trains leaving the service tracks need to be given enough clearance in the network to avoid bottlenecks. The proper sizing of locomotive fleet, crew, and empty rail cars depend on the network, utilization of the track capacity, train routing, and several other factors. The train scheduling is the most important operation which connects the yard to the network and the throughput of the yard is dependent on it along with the other operations and infrastructure.

**Transshipment tracks**

At transshipment tracks containers are (un)loaded between the trains and the storage yard or are transferred from one train to another. The gantry cranes are the main handling equipment to perform these operations, although other handling equipment (such as straddle carriers or front end loaders) can assist with this process. In a transshipment yard trains are usually served in sets and the allocation of trains to tracks is of vital importance. It is often the case that in a set of trains served simultaneously, some will need to return for service (e.g., wait for containers arriving on another train not yet at the terminal). In this case the train does not wait on the service tracks. Instead it leaves the yard and waits to be rescheduled for service along with a set of new incoming trains. This process may be repeated any number of times until all the containers scheduled to leave with that train have been loaded.

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Loading and Unloading of the Trains

The loading and unloading sequence is one of the main factors that influences the time that trains must remain in the terminal and the time they will occupy the service tracks. As previously discussed the trains can be served one by one or more than one at a time, depending on the length of the train, yard equipment and the capacity of the track yard. Usually when gantry cranes are used to (un)load the containers on the trains, a number of trains can be served simultaneously. The equipment responsible for these operations are assigned to the train according to the service needed and availability. The operator must make decisions keeping in mind the following:

- available handling equipment and crew required to service the train,
- how and where the containers are to be loaded on the train according to weight balance,
- type of the train loading (e.g. double stack, piggy back or roadtrailers),
- location of the unloaded containers that are to be loaded on trains that have not yet arrived,
- location of the containers in the storage yard waiting to leave the terminal by trucks,
- sequence of container moves and avoidance of unnecessary moves,
- time the train needs to finish service and idling times,
- interference constraints between the handling equipment (usually the gantry cranes) and interactions of hauling equipment assisting the vertical handling equipment,
- number of cranes to be assigned to service the train and the number of blocks a train needs to be divided into for optimum output of service, and
- optimal location of empty wagons along with several other factors.

STORAGE YARD OPERATIONS

The single locomotive train typically carries 30 to 40 cars and the number of incoming containers depends on the total train hauling capacity and on the type of containers (e.g. 20 ft VS 40 ft) and the stacking method on the rail cars (i.e. single or double stack). Containers that arrive at the terminal (inbound or outbound) usually have to be stored within the terminal for a certain period of time, usually less than a week. For the time period that containers remain in the terminal they are stored at designated areas, within the terminal, known as the storage yards. These areas can be in different locations within the yard and are divided into two categories: a) storage on chassis, and b) storage on the ground. The former storage system although very space demanding, it can reduce significantly the truck turnaround time. The latter storage system is found either by the track side of the terminal where containers are stored by the tracks or within the yard (fig. 3). In the storage area by the tracks containers are usually (un)loaded directly between the stack and the train by gantry cranes, while in the storage area away from the tracks containers are moved between the storage yard and the service tracks by internal transport equipment (i.e. trucks, straddle carriers etc) and are then (un)loaded on the trains. Figure 3 shows a typical layout for a terminal with two storage areas one by the service tracks and one away. Figure 3 also shows in detail two of the most typical grounded storage operations for containers at the service track side of the terminal.

Grounded storage yard systems are solely used for containers that either cannot be stored using the latter system (i.e. container attached to a chasse) or for containers that are chosen to be stored on a chasse (i.e. containers scheduled to be picked up by a bobtail truck). They are stored like vehicles in a parking lot and occupy a lot of space but are very easy to locate and offer high performance and flexibility. They do not need the stacking equipment to make multiple moves and are more energy efficient. Usually this type of storage is utilized for trucks that pick up or drop off containers, although trucks may also go directly to the service track area to deliver or pick up the container. The chassis with the incoming containers are hauled using the yard trucks and the containers are moved into the stacks while the chassis are stored at a separate location within the yard. The storage of chassis can also be grounded or stacked.
FIGURE 3 Illustration of storage yard layout.
Grounded storage operations are mainly used at the service tracks and have the benefit of saving space, but potentially increase the operational time and complexity of the handling operations. We should note that grounded storage can also be used in the yard away from the service tracks in terminals where there is a scarcity of storage space by the tracks. Containers at the stacks are stored in blocks and space adjacent to the stacks is available for the movement of trucks and the handling equipment. The typical block has seven rows (or lanes), six of which have containers and one truck lane. A row typically has over twenty TEU container stacks stored lengthwise end to end. Stacks between the service tracks can be up to 3 rows wide while in the main yard or by the service tracks can be more than six. Unlike other intermodal terminals, intermodal rail yards work 24x7, therefore there is a continuous input of containers from the gate and the trains. Due to these characteristics reshuffling of containers stored at the stacks is seldom performed and so their position in the service track storage yard is usually fixed until they are moved to the buffer in the tracks to be loaded onto a train. The operator makes the decision on the position of the container depending on criteria such as the next destination of the container, hauling type (i.e. by train or truck), type of the container, and time interval until the next trip, etc. The position of the container needs to be in such a way that a minimum number of rehandling moves are required to access it and the handling system needs to be sequenced in a way to optimize the moves. In practice, containers scheduled to leave on the immediate trains are placed closer to the tracks, while those scheduled to leave the terminal by trucks are placed closer to the gate.

**HANDLING SYSTEMS AND EQUIPMENT**

The handling system and equipment are responsible for handling all the container movements and are the vital links that interconnect all the areas of the terminal. These operations include transporting containers between the trains and the storage yards as well as (un)loading and transferring the containers onto and between the trains. A number of different types of handling equipment exist today to handle the containers within a truck-rail terminal. Decisions on the type of equipment to be used are usually determined during the initial terminal design and are based on historic and projected freight data, and social and cultural aspects. The yards that are already in use and require upgrade of their equipment and methods must balance cost and productivity. Handling systems at a truck-rail intermodal terminal can be divided into two categories depending on the type of move: a) the hauling system (also known as the horizontal system), and b) the handling system (also known as the vertical system). The horizontal transport is used to transfer containers between the tracks and the storage yard and the receipt/delivery area. The vertical transport is used for stacking or retrieving operations, loading or unloading the trains and the trucks.

Unloading and loading equipment at a truck-rail intermodal terminal are very similar to the ones used at marine container terminals and can be broken down into three categories: a) overhead loaders, b) side loaders, and c) end loaders. Overhead loaders are used in (un)loading the containers from/to the trucks or other transporting equipment (e.g. straddle carriers, front-end loaders), (un)loading the containers from the storage blocks in between or adjacent the tracks to/from trains, and transferring containers from one train to another. Gantry cranes are, either rail or rubber mounted, are the most common handling (un)loading equipment at rail terminal. Rail mounted cranes are more productive if working on a single block and rubber tired gantry cranes are more flexible. They are arranged across the tracks and can spread across storage spaces and truck lanes along with the tracks for higher performance (fig. 3). Side loaders (un)load the containers from the side of the railcar. They require space by the tracks for their operation. They can carry the container directly from a nearby stack and put it on the railcar. They carry up to two full containers at a time but are relatively fast in motion and easy to operate. Side loaders also use spreaders to carry the container. Side lift fork cranes and front end container loaders are also used in these operations. End loaders (un)load containers by the use of fixed or portable ramps and these require space at the end of the rail car. This type of loading is usually used for containers with wheels.

Similar to the (un)loading equipment, hauling equipment can be broken down into two categories based on their ability to lift a container. Hauling equipment without the ability to lift rely on (un)loading
equipment which limits their productivity. Such equipment includes trucks with trailers, multi-trailers and automated guided vehicles. On the other hand, hauling equipment with the ability to lift and stack containers (e.g. straddle carriers, forklifts and reachstakers) are more dynamic and flexible and are very useful in the yard operations, but usually carry the containers across the yard for short distances and at lower speeds than their non-lift counterparts.

GATE OPERATIONS

Containers enter and leave the yard by trucks through the gate of the terminal. Truck arrivals at the terminal are usually random although they do tend to follow closely train arrivals and departures. Scheduling truck arrivals can help in increasing the operational capacity and efficiency of the terminal while reducing the waiting time of the trucks. As a truck enters the yard it goes through the identification units where the operator obtains all the information about the truck and the container(s) associated with it. The operator decides on the routing of the truck in an optimal way, based on the information regarding the truck and the position of the related container(s). Factors considered are the scheduling of the yard equipment to serve the truck, location of the container, weight of the container, the sequence in which it is to be served, the time taken for the truck to turn around, chassis position, and the crew serving it with the equipment, etc. Trucks arriving at the terminal can be of three types: a) delivering a container without picking up another container, b) delivering a container and picking up a container, c) arriving bob-tail or with a chassis to pick-up a container. If a truck arriving at the terminal belongs to the first category it is either routed to the service tracks or the storage area on chassis, depending on the time that the container is to be loaded on the train. After the truck delivers the container it either departs the terminal or drops off the chasse at a designated area within the terminal and then departs.

If a truck arriving at the terminal belongs to the second category it is first routed, similar to the former case, to drop off the container at the designated area at the terminal. Then, depending on if the container to be picked up is already on a chassis or not, the truck either drops off the current chassis (to be able to pick up the container already on a chassis) or a container is loaded directly onto its current chassis. If the truck arrives at the terminal as a bob tail it is directed either to the storage area to pick up the container already on a chassis or to the chassis storage area to collect a chassis and then to the storage area by the tracks where the containers not on chassis are usually stored. The container is loaded by the yard equipment and the truck reaches the gate and leaves the yard. If the truck arrives with an empty chassis it is directly routed to the location of the container in the storage area. In cases where the train has not yet arrived or the unloading is in progress there is parking space within the terminal where trucks can wait. Trucks leaving the terminal, excluding bobtails, will usually go through inspection where the container or the chasse, are checked for damage and the required paperwork is submitted. Once cleared, the truck leaves the terminal for its other destination, usually a warehouse or a cross dock facility. Figure 4 summarizes these processes in a flowchart.
FIGURE 4 Illustration of different truck processes within the terminal

LITERATURE REVIEW

In this section we present a brief literature review of selected publications on rail-truck intermodal terminal operations focusing on the objective of the paper and the optimization or simulation results. We would like to note that studies extending outside the area of the terminal, although interesting as research, were not considered. Martinelli and Teng (1) developed a train formation optimization model producing optimal or near optimal results, and in several of the examples, better results than a conventional method of solving the problem. Ferreira (2) reviewed related research and development of optimization and simulation tools for train planning, train and locomotive scheduling, and track maintenance planning. The paper concluded that optimization methods are more viable when problems are studied in isolation while simulation and expert systems are more applicable and effective when interactions between the systems need to be considered. Bostel et al (3) presented models with different levels of complexity and heuristics to solve the problem of container allocation on trains (loading and reloading after transshipment). Results showed that the application of the proposed models in conjunction with heuristic resolution approaches can reduce the bottlenecks of yard equipment (e.g. gantry cranes, shuttles, etc).

Powell and Carvalho (4) considered the problem of managing a fleet of flatcars over a network in real-time, in an attempt to include network information for decisions made at the local level at each terminal. Experimental results showed that a locally managed flatcar fleet, without using the network information, could achieve the same demand coverage as a fleet that is 10 percent smaller, using the network information. Geng et al., (5) and Geng and Li (6) proposed a knowledge-based system for railway freight loading, and a framework to integrate it to existing railway management information systems. Unfortunately, there was no evaluation of the proposed framework, and the paper was limited to presenting the architecture of the system.
Bostel and Dejax (7) proposed a model to determine the optimum placement of containers on incoming and outgoing trains, and in the short-term storage areas at a rail-rail terminal (i.e. transshipment operations) in order to minimize container handling. As the problem was complex to be solved in polynomial time by exact resolution algorithms, a heuristic was proposed that obtained good, but not optimal, solutions. Feo and Gonzalez-Velrade (8) considered the load planning in the context of a piggyback system and proposed a model for optimally assigning the trailers to wagon hitches. Results from the model estimated significant savings per train. Kozan (9) addressed the problem of allocating wagons on the transshipment tracks. Estimates of train handling times were derived based on several approximations of the intermodal operations. Using these handling times several policies for allocating trains to transshipment tracks were evaluated and compared.

He et al., (10) presented a dispatching model to assist with the coordination of multi-objective decisions in rail yards dispatching plans. Computational results showed significant improvements in the train-size limitations and delays of the outbound train, and the start-time of the classification and assembly operations. Ballis and Golas (11) and Ballis and Golas (12) evaluated technical and logistics developments that could lead to increased economic and technical efficiency of railroad transport terminals. Rizzoli et al. (13) presented a simulation model of the flow of intermodal terminal units among and within inland intermodal terminals, interconnected by rail corridors, where each terminal served inland destination via a road network and utilized gantry cranes front lifters to serve the trains and trucks arriving at the terminals. A number of simulation runs were performed to evaluate different scenarios. He et al., (14) formulated a computer-aided model to help the yard. The models decisions were based on the trade-off between benefits from reducing the staying time of cars in the yards and delay penalty costs. Computational results revealed that the average computing times mainly increased with the planning horizon while the number of yard devices had little effect.

Abacoumkin and Ballis (15) presented an expert system based modeling tool with the objective to produce alternative terminal designs, based on a number of user-defined parameters and equipment selections. The analysis presented by the authors identified the similarities and differences for various terminal configurations. Similar to Ballis and Golas (11), the main conclusion was that each design is effective for a certain cargo volume range. The authors suggested that on-going research should focus on including in the expert system additional advanced transshipment technologies. Lanigan et al. (16) identified the main inefficiencies of intermodal rail interchange operations and investigated the potential of shared intermodal facility solutions, analyzing governmental and market impediments related to the latter solution. The analysis provided a large number of published performance metrics and estimates from field practitioners that can be used in future simulation modeling efforts.

Corry and Kozan (17) proposed a model to dynamically assigning containers of equal size to slots on a train with the objectives to minimize excess handling time and optimize the distribution of the train. The rolling horizon concept was adopted to account for the uncertainty in many of the parameters of the model. The proposed model was evaluated under two different operating environments and simulation experiments showed that a significant reduction of excess handling time can be achieved with a relatively small concession in mass distribution. Boysen and Pesch (18) formulated the train scheduling problem at a rail-rail transshipment yard in order to minimize the weighted sum of the number of train revisits and the number of split moves of the gantry cranes. Computational experiments carried out indicated the appropriateness of the developed procedures to considerably improve over the traditional real world First-Come-First-Served scheduling policy. Rodrigue (19) presented and investigated the concept of a facility designed to handle high volume trans-modal rail shipments, arguing that this type of terminal can represent a step forward in the evolution of intermodal inland transport systems. The author claimed that the concept takes advantage of the strengths and weaknesses of each mode and enables them to service parts of the supply chain for which they are the most suitable. Godwin et al (20) developed a simulation model to determine the locomotive fleet size and an associated deadheading policy in a situation where there is no fixed operating schedule for freight trains. Results from simulations showed a cap on the improvement with the increase in the number of locomotives.
Marinov and Viegas (21) provided a simulation modeling methodology for the analysis and evaluation of flat shunted yard operations. The objective was to provide an adequate methodology accompanied with a reliable tool for estimating, analyzing, and performing capabilities of rail yards for the rail freight operator. The yard was divided into segments were each segment interconnects, interacts, and is influenced by the other segments as a queuing system. The proposed simulation model can provide the terminal operator with a variety of performance measures that can be used for decision-making. Bektas et al., (22) considered the problem of reducing the time that empty cars spend in classification yards of rail systems operating under real-time information and automated schedule adjustment technologies. The main contributions of the paper were a new asset-management problem statement and formulation in freight rail transportation targeting the reduction of idle-time that cars spend in a rail yards. Computational results showed that opportunities exist to reduce the waiting times of empty cars in yards and that the procedure can be efficiently used in practice. The authors also proposed that their methodology could be generalized to contexts such as intermodal container terminals for transferring containers from one mode to the other. Sayarshad and Ghoseiri (23) proposed a model formulation to integrate car fleet sizing decisions with optimization of car allocation and utilization. Freight car demands and travel times were assumed to be deterministic and unmet demands at each planning period were not transferred to the next. The model also provided rail network information like yard capacity, unmet demands, and the number of loaded and empty rail-car. Computational examples showed that the proposed resolution heuristic worked efficiently.

CONCLUSIONS

Optimizing rail intermodal terminal operations has begun attracting significant attention from the research community and the industry world. The main reason behind this interest has been the projected growth in the global trade increase in container traffic. The outburst of container movements has led to congestion problems that require advanced organized operations at these terminals in order to tackle them in a lean and extremely cost effective manner. The goal of this paper was to present a concrete and complete description of the layout of a rail intermodal terminal in order to promote a better understanding of the problems associated with the operations that take place. The terminal was broken down into three distinct areas and detailed descriptions of the processes within each area and the interactions between these areas were provided. A brief literature review of selected publications related to rail intermodal terminal operations was included, focusing on the objectives and outcomes of the studies. As a final comment we would like to note that as demand at these terminals increases, US freight railroad operators and researchers should explore the applicability of techniques, policies, models and especially resolution algorithms employed in marine container terminals. As problems encountered in both types of terminals fall under the same generic problem categories of scheduling and assignment, transfer of existing concepts from marine to rail terminals might prove very promising.

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REFERENCES


