Hindawi
Journal of Advanced Transportation
Volume 2018, Article ID 5812939, 19 pages
https://doi.org/10.1155/2018/5812939

Research Article

A Simulation Platform for Combined Rail/Road Transport in Multiyards Intermodal Terminals

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Received 28 September 2017; Revised 4 January 2018; Accepted 24 January 2018; Published 28 February 2018

Academic Editor: Francesco Corman

With the rapid development of multiyards railway intermodal terminal (MYRIT) construction in China, performance evaluation has become an important issue for terminal design and management departments. Due to the complexity of the multiyards terminal and the associated rail network, the train moving process and related terminal operations have become more complicated compared with the traditional intermodal container terminal. However, in general simulation platforms, the train moving process is simplified and train route scheduling rules are not considered in existing simulation models. In order to provide an accurate and comprehensive quantitative evaluation tool for MYRIT, a simulation platform based on the Timed Petri Net model has been developed, which can offer decision support for terminal design and management departments. In this platform, a yards and facilities layout module has been created to give simulation users access to designing the railway network on this platform. And a train route dispatching simulation method has been integrated to provide an accurate simulation of the train moving process. Based on a real case of Qianchang railway intermodal terminal that is located in Fujian Province, China, the platform is thoroughly validated against historical data. And the test scenarios show that train routes arrangement and handling equipment configuration both have a significant influence on overall terminal performance, which need to be carefully considered during terminal design and management.

1. Introduction

In the past several years, the Chinese logistics industry has undergone a rapid development. Along with the trends toward the growing demands quantitatively and qualitatively on the freight transportation system [1], *a* large-scale intermodal terminal construction plan has been implemented by China Railway Corporation. According to the official document, 33 1st-class, 175 2nd-class, and 300 3rd-class modern railway intermodal terminals will be built from 2015 to 2017. Different from the intermodal container terminals that have been widely constructed in Europe or America in the past decades, the intermodal terminal in China usually contains multiple cargo yards, which can be called a multiyards railway intermodal terminal (MYRIT). MYRIT is a kind of comprehensive intermodal terminal which comprises distinguished types of cargo yards in order to offer multimodal transport services to different types of cargoes. A typical MYRIT is shown in Figure 1, which contains a bulk cargo (e.g., coal and ore) yard, a container yard, a special cargo yard, and others.

In MYRIT, different cargo yards provide services to different kinds of cargoes and contain independent facilities (railway tracks, storage area, handling equipment, etc.), resulting in a very complex process of terminal design which involves a huge number of decisions [2]. For a better terminal design, one of the effective methods is simulation, which can provide performance evaluation of terminal design schemes based on a simulation model. In fact, intermodal terminals can be regarded as a kind of discrete event dynamic system (DEDS), of which the states only get changed at discrete points in time as a result of stochastic events [3].

Due to the complexity of the MYRIT and the associated railway network, the train moving process simulation becomes an important issue for overall terminal evaluation. With various cargo yards, the internal railway network involves more tracks, switches, and signals, and the

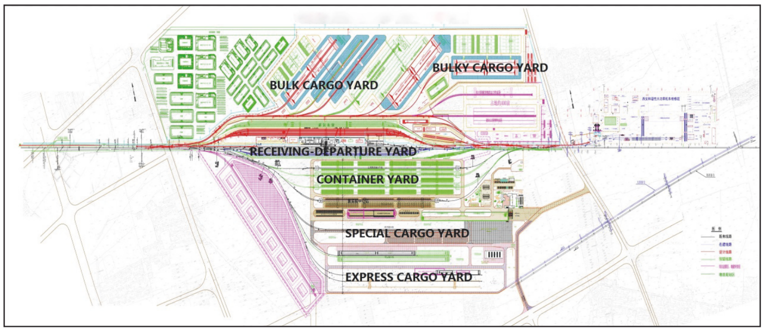


Figure 1: Typical layout of multiyards railway intermodal terminal.

interaction of train routes becomes more complicated, which has a significant influence on the train moving process. However, in existing simulation platforms, there has been a lack of simulation methods which can provide a detailed simulation of the train moving process. The train moving process has been simplified in most general simulation models, which will lead to an inaccuracy in the terminal evaluation.

In order to provide an accurate and comprehensive simulation of MYRIT, a simulation platform is developed and presented in this paper which can be used as an analysis and predictive tool for terminal design and management departments. In this platform, a yards and facilities layout module has been invented which can be used for inputting and editing the railway network of a multiyards terminal, and a train route dispatching simulation method (TRDSM) has been created to provide an accurate simulation of the train moving process considering basic dispatching rules. The architecture and the simulation model of the platform are elaborated in this paper, and it should be noted that this platform is dedicated to rail/road intermodal terminals, and terminals which involve waterway transportation like container ports are not applicable to this system.

The remaining part of this paper is organized as follows. In the following section, a literature review of intermodal terminal optimization and management based on simulation techniques is provided. Then, in Section 3, an overview of operations of MYRIT and the framework of this simulation platform are presented. In Section 4, the simulation models based on Timed Petri Net (TPN) and key simulation methods integrated in the platform are expounded. In Section 5, the function introduction of the simulation platform that we have developed is given. In Section 6, validation and some test scenarios of the simulation platform are detailed. Finally, a summary of this study follows and possible extensions on intermodal terminal simulation are identified.

2. Literature Review

Simulation techniques have been used successfully in terminal planning, design, and optimization problems, and there are many literatures in this field. Rizzoli et al. [4] built a simulation model of the flow of intermodal terminal units (ITUs) among and within inland intermodal terminals using MODSIMIII as a development tool. During the simulation, various statistics are gathered to assess the performance of the terminal equipment. Another simulation tool dedicated to model a single terminal was introduced by Benna and Gronalt [5]. Terminal layout, arrival patterns of trains and trucks, and container settings were specified as part of the input data. A general overview of the macro and micro model was provided by Ballis and Golias [6]. They tested the micro model for 17 different terminal layouts with varying numbers of tracks and cranes as well as lifting technologies. Marinov and Viegas [7] provided a yard simulation modeling methodology for analyzing and evaluating flat-shunted yard operations using SIMUL8. A comparative evaluation tool for rail/road freight transport terminals has been developed by Ballis and Golias [8], which consists of three models (an expert system, a simulation model, and a cost calculation model). Fugihara et al. [9] provided a way of simulation technology which can generate several benefits in the distribution center projects.

This paper focuses on the simulation of rail/road intermodal terminals; however, some literatures with regard to seaport terminal simulation can also be used as references. Hartmann [10] provided an approach for generating scenarios of seaport terminals which can support solving optimization problems in container terminal logistics. Vis [11] compared the use of manned straddle carriers with that of automated stacking cranes. The total travel time required to handle all container moves was applied as a performance measure to determine the yard layout for the seaport terminal. A computer simulation model with on-screen animation graphics which can simulate the operations of a container terminal equipped with straddle carriers was introduced by Ballis and Abacoumkin [12]. Based on this model, different configurations (changes in yard layout, equipment number and productivity, truck arrival pattern, and service discipline) of the simulated system can be evaluated. Shabayek and Yeung [13] developed a simulation model to simulate Kwai Chung container terminals in Hong Kong, using Witness software. The layout of the port and the incoming and outgoing routes for container vessels were considered in the model, which can provide a prediction of terminal operations with a high order of accuracy.

Petri Net is widely used for the description of the structure and dynamics of DES [14]. For more details of the Petri Net theory and modeling, refer to Peterson [15] and David and Alla [16]. A great number of successful Petri Net models have been designed for terminal simulation and optimization throughout the world. Some of the most relevant ones are expanded in the following paragraphs. Dotoli et al. [17] addressed the issue of modeling and managing Intermodal Transportation Systems (ITS) at the operational level. The system is highly complex, with various types of conveyances alongside scheduling aspects. A Timed Petri Net framework was built to model the ITS, which contains the tollbooth, highways, truck, railway, port, and ship subsystems. A similar exploration has been performed by Maione and Ottomanelli [18]. A container terminal simulation model was proposed within the theoretical framework of Petri Nets, which allows taking into account the different aspects of the considered system. Lee et al. [19] presented the development and application of simulation models for air cargo terminal operations using Timed Color Petri Net (TCPN). The TCPN is able to simulate the operations of various types of material handling equipment and is validated based on actual cargo retrieval schedules records. A high-level Petri Net model which contains timed predicate/transition net has been provided by Hsu et al. [20]. This model aims at solving the three essential operational problems (berth allocation problem, quay crane assignment problem, and quay crane scheduling problem) of container terminals simultaneously, which can result in good overall system performance. Cavone et al. [21] proposed a procedure for planning and managing resources in intermodal terminals, which integrates Timed Petri Nets and Data Envelopment Analysis. Silva et al. [22] described the modeling of a container terminal using Petri Net with predicates, which allowed the evaluation of different configurations and combinations of transport equipment, providing a very complete port system simulation. A general modeling framework based on Timed Petri Net was constructed by Dotoli et al. [23], which allowed simulating and evaluating the performance of key elements within the intermodal transportation chain. In the Petri Net model, places represent resources and capacities or conditions, transitions model inputs, flows, and activities into the terminal, and tokens represent intermodal transport units.

Previous findings show that the simulation method has been very effective and was widely used in the field of terminal optimization and management. These manuscripts provide valuable supports for our work; the simulation framework, control methods of the terminal entities, and Petri Net models of terminal activities are used as references in our simulation platform. However, there has been a lack of simulation methods considering multiple cargo yards, and most papers focus on container terminal simulation. With only one type of cargo, the structure of the container terminal and the associated railway network is relatively simple compared with MYRIT. The simulation model of the train moving process is simplified to a single discrete event in great majority of existing studies, and detailed train route scheduling rules are not considered. However, due to the complexity of the rail network in MYRIT, the interaction of train movements can have a significant influence on the train moving process and terminal performance. Therefore, a detailed simulation method of the train moving process considering train route dispatching rules has been considered as an important element in this platform.

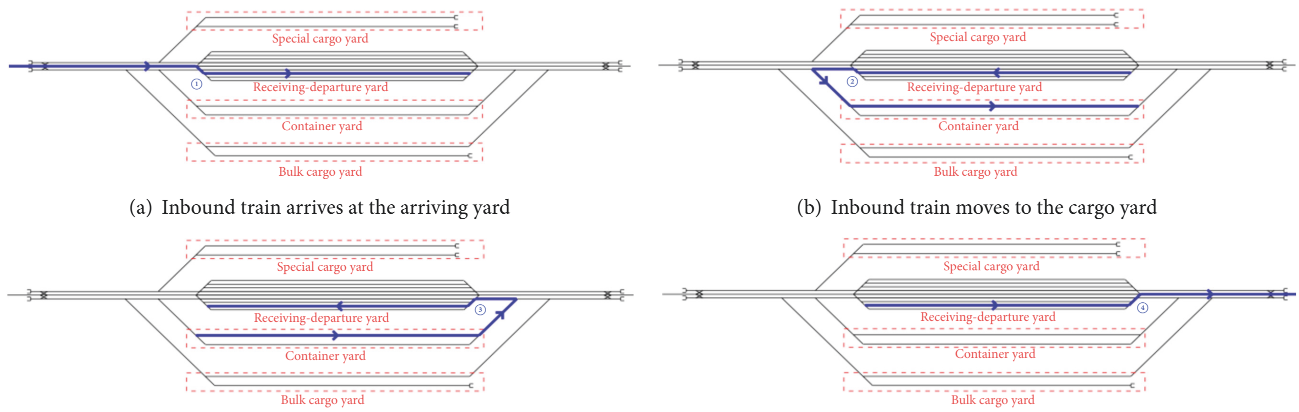
3. Framework Design

MYRIT is a kind of multimodal freight hub where different types of cargoes are delivered and picked up by trains or trucks. Cargoes arrive at terminal by trains/trucks and are unloaded in corresponding yards by cargo-handling appliances (gantry cranes, forklifts, reach stackers, etc.). Certain goods are picked up by trains/trucks directly, while some goods need to be processed and stored within the terminal for a period of time before they are picked up. Various facilities and equipment are needed to finish these tasks, such as railway tracks, platforms, handling machineries, truck parking lots, and repertories, which constitute a large-scale intricate logistics system. In this section, the main operations of MYRIT which are considered in the TPN model are introduced, and the framework of the simulation platform is described as well.

3.1. Overview of MYRIT Operations. The main operations in MYRIT can be divided into three components, namely, the train operations, the truck operations, and the cargo-handling operations.

3.1.1. Train Operations. There are four prime steps of train operations. When an inbound train arrives at the terminal, it enters the receiving-departure yard (or arriving yard) first and then undergoes an arrival inspection (cargo information check, safety inspection, etc.) conducted by a surveyor. After that, according to the type of goods carried by the train, the occupancy states of tracks in the corresponding cargo yard are checked. If there are idle side tracks within the yard, the inbound train will move into the target yard under the command of the train dispatching office. The cargo loading/unloading operations are implemented inside the cargo yard by means of certain cargo-handling appliances. The type and mechanical model of appliances depend on the physical nature of the cargoes. In case the loading/unloading machine is busy, the train will stay on the side track and wait to be served. When the cargo loading/unloading task is finished, the outbound train will move back to the receiving-departure yard (or departure yard), and a departure inspection will be carried out. At last, the outbound train leaves the terminal at the time required by the timetable. It should be noted that, sometimes, the outbound train can leave the terminal from the cargo yard directly without entering the departure yard. The typical trajectories of train operations are shown in Figure 2.

3.1.2. Truck Operations. Trucks arrive at MYRIT to deliver cargoes to outbound trains or to pick up cargoes from inbound trains. When a truck arrives at the entrance gate of the terminal, it joins a first-in first-out (FIFO) queue and waits for arrival inspection which is implemented by the gate system. The arrival inspection includes collecting



(a) Inbound train arrives at the arriving yard

(b) Inbound train moves to the cargo yard

(c) Outbound train moves to the departure yard

(d) Outbound train departs from the terminal

FIGURE 2: Trajectories of train operations.

information of trucks and goods through a high-resolution camera, weighing arrival trucks, and providing guidance information for truck drivers. Several factors can influence the work efficiency of arrival inspection, such as the number of gates, the number of entrance channels, the location of gates, and the degree of automation of gate information management system.

After the arrival inspection, the arrival truck moves to the corresponding cargo yard according to the guidance information from the gate system. When the truck enters the cargo yard, in the majority of cases, it will join a FIFO queue in the loading/unloading area. If there are available cargo-handling machineries, the truck loading/unloading procedure begins. When the truck has been loaded or unloaded, it will move to the exit gate of the terminal. Similar to the entry process, the departure truck needs a departure inspection at the exit gate.

In addition to the trucks mentioned above, there is another type of trucks which are called the shuttle trucks. Shuttle trucks work inside the terminal and are used for transporting goods between different cargo yards. The number of shuttle trucks is much lower than the number of external trucks which will leave the terminal when the loading and unloading tasks are completed. Shuttle trucks can be regarded as a kind of equipment resources of MYRIT. The sketch map of the truck operations within MYRIT is shown in Figure 3.

3.1.3. Cargo-Handling Operations. There are multiple types of handling machineries in MYRIT, such as gantry cranes, front lifters, reach stackers, and forklifts. Each kind of machinery has different mechanical properties and serves different types of cargoes in diverse cargo yards. The cargo-handling operations can be divided into two types according to the delivery direction of the goods: the train-truck operation which represents the handling operation of goods delivered by trains and picked up by trucks and the truck-train operation which represents the handling operation of goods delivered by trucks and picked up by trains. In this section, the train-truck cargo-handling operation is introduced as a representative.

When the cargo which is delivered by inbound trains is about to be unloaded within the cargo yard, one of the following three circumstances is given:

(i) If the corresponding truck which is used for picking up the cargo has arrived at the cargo yard, the cargo will be unloaded directly from the inbound train to the truck. In this situation, only one loading/unloading operation is required.

(ii) If the corresponding truck cannot catch up with the deadline (the time when the inbound train has been unloaded and must leave), the cargo will be unloaded to the storage area inside the cargo yard and stored there. After that, when the corresponding truck arrives at the cargo yard, the cargo will be loaded from the storage area to the truck. In this case, two loading/unloading operations are required.

(iii) If the cargo needs special storage condition (e.g., refrigerated container) or the cargo needs to be processed inside MYRIT (e.g., express parcels need to be sorted in the sorting workshop of MYRIT before they are picked up by shippers), it will be unloaded to the shuttle truck and delivered to the corresponding area (as shown in Figure 3).

The process of truck-train operation is basically contrary to the process of the train-truck operation and also can be divided into three cases. Due to the limitation of the space and avoidance of repetition, the details of this procedure are not discussed here.

3.2. Framework of Simulation Platform. Based on the operations overview of MYRIT, the framework of this simulation platform is shown in Figure 4. The framework has four layers, namely, the Petri Net layer, the simulator layer, the layout layer, and the user layer, which are elaborated as follows:

(i) Petri Net layer: the Petri Net layer is the basis of the simulation platform which composes three TPN models, that is, the train operation model, the truck operation model, and the cargo-handling model.

(ii) Simulator layer: the simulator layer contains the core simulation modules and key methods integrated in this platform, including the train generation method,

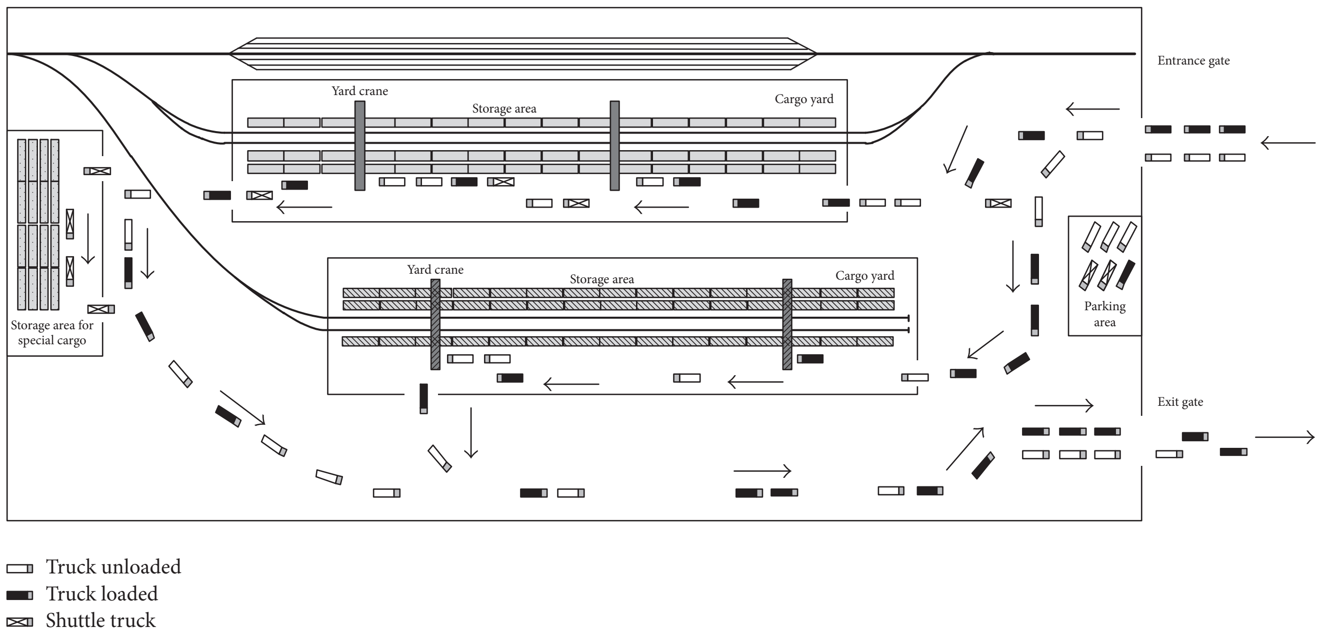


FIGURE 3: Scheme of truck operations in multiyards railway intermodal terminal.

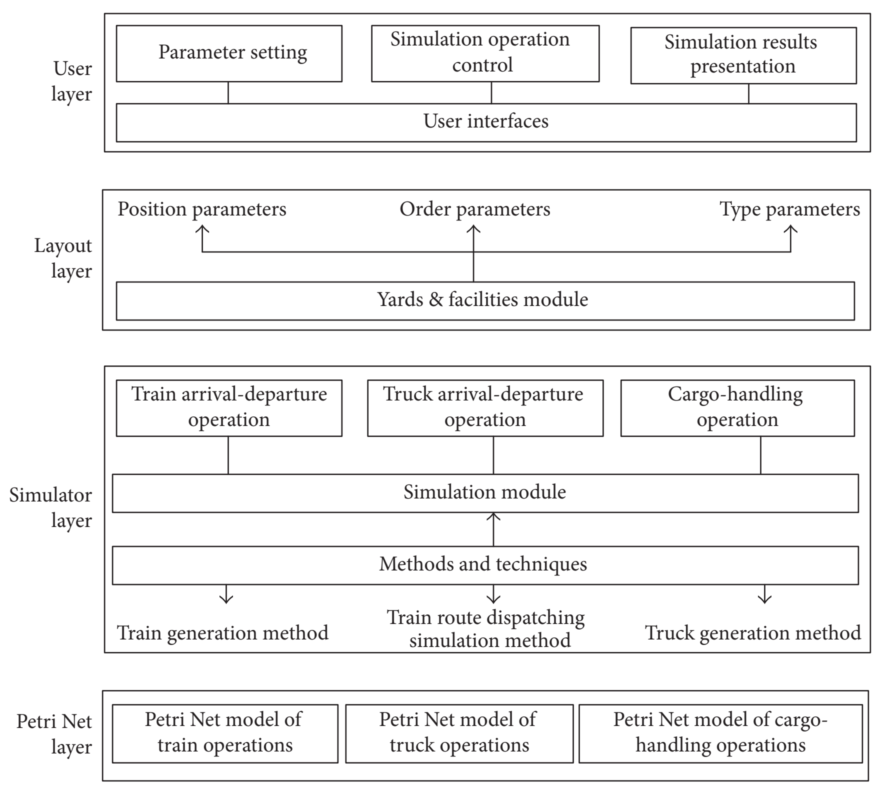


FIGURE 4: Framework of simulation platform.

the truck generation method, and the train route dispatching simulation method.

(iii) Layout layer: the layout layer contains the yards and facilities layout module which allows users to design or modify the yards and facilities (tracks, switches, signal machines, etc.) locations by adjusting certain parameters. Three types of parameters are designed as follows:

(a) Position parameters, which determine the relative position relation (horizontal and vertical) between certain cargo yard and the receiving-departure yard.

(b) Order parameter, which determines the relative position relation among different cargo yards.

(c) Type parameter, which determines the type of certain cargo yard. According to the layout of rail tracks, cargo yards can be classified into 3 types: through-type cargo yard, stub-end-type cargo yard, and mixed-type cargo yard.

(iv) User layer: the user layer contains the operation control module, the simulation project database, the simulation results database, and related interfaces. Simulation users are able to access this layer to set up a simulation project, control the simulation progress, and obtain the simulation analysis results via user-friendly interfaces.

4. Simulation Model

Petri Net is a widely used tool using graphic elements as a representation to describe the structure and dynamics of DEDS, such as computer systems and manufacturing systems. TPN is a bipartite diagraph described by the five-tuple as shown in the following formula:

$$\text{TPN} = (P, T, \text{Pre}, \text{Post}, F), \tag{1}$$

where P represents the set of places with $|P| = m$, T is the set of transitions with $|T| = n$, Pre is the preincidence matrix with Pre: $P \times T \rightarrow N^{m\times n}$, Post is the postincidence matrix with Post: $P \times T \rightarrow N^{m\times n}$, and the function F: $T \rightarrow R^{+}$ specifies the timing associated with each transition.

A simulation model has been established based on TPN in this study. There are three types of transitions used in this model: immediate transition, stochastic transition, and deterministic timed transition. Corresponding to the operations of MYRIT, the TPN model is segmented into three submodels which are the train arrival and departure model, the truck arrival and departure model, and the cargo-handling model.

4.1. Train Arrival and Departure Model

4.1.1. Train Generation Method. This platform provides two types of train generation methods. The first one is to generate inbound trains according to a fixed timetable input by simulation users. Each train arrival time is generated based on a historical record of train arrival events. This method applies to the terminals which have been put into use and is particularly useful to perform trace-driven simulation.

The second method is to generate inbound trains arrivals according to a stochastic mathematical distribution which is specified by simulation users. This generation method applies to the terminals that are still in the stage of design or construction, and it can be used to test alternative arrival patterns.

4.1.2. Train Route Dispatching Simulation Method. As introduced above, TRDSM is created to simulate the train dispatching operation which can provide an accurate simulation

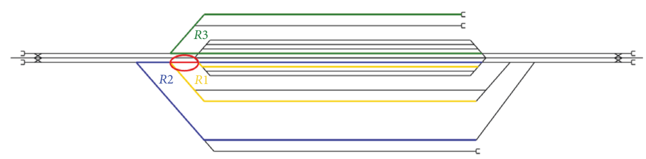


Figure 5: Diagram of train route samples.

of the train moving process. According to the relationship between two different train routes, train routes pairs can be divided into two types: conflicting train routes pair (CTRP) and parallel train routes pair (PTRP). Train routes in CTRP contain some of the same equipment. As shown in Figure 5, train route $R1$ (the golden line) shares a section of track (marked by the red circle) with train route $R2$ (the blue line), which means if train route $R1$ is occupied by a train, then train route $R2$ becomes unavailable as well because it is impossible for two trains to move on the same track simultaneously.

Contrary to the CTRP, there is no space conflict in PTRP. Train route $R1$ is independent of train route $R3$ (the green line), which means if one train occupies $R1$, another train can occupy $R3$ at the same time.

Based on the analysis of different types of train routes pairs, the framework of the TRDSM is presented in Figure 6, and the main steps are as follows.

Step 1 (train route database presetting). There are various train routes in MYRIT. The train routes of different types of trains and different train move events are diverse. All train routes should be set by simulation users in advance according to the station operation regulations, and all the preconfigured train routes are stored in the database.

Step 2 (generating train move request). Train move request is generated from the trains which have finished the preceding operation and are ready to move to the next operating location or the trains which have been added to the waiting queue for available train route. When a train move request is generated, the corresponding train route will be invoked from the train route database.

Step 3 (examining the availability of train route). The availability of train route is determined by the availabilities of the key points (switches and signal machines) within it. To be specific, only when all key points of the train route are not occupied can this train route be available. Otherwise, this train route is unavailable and the corresponding train will join the FIFO queue.

Step 4 (generating train move event). If the train route is available, it will be occupied by the train and a train move event will be generated. The occupancy states of the key points in this train route will be updated based on the real-time location of the moving train.

Step 5 (examining the waiting queue). If all train move requests have been executed, the method stops. Otherwise, another train move request is generated according to the FIFO rules, and the method returns to Step 2.

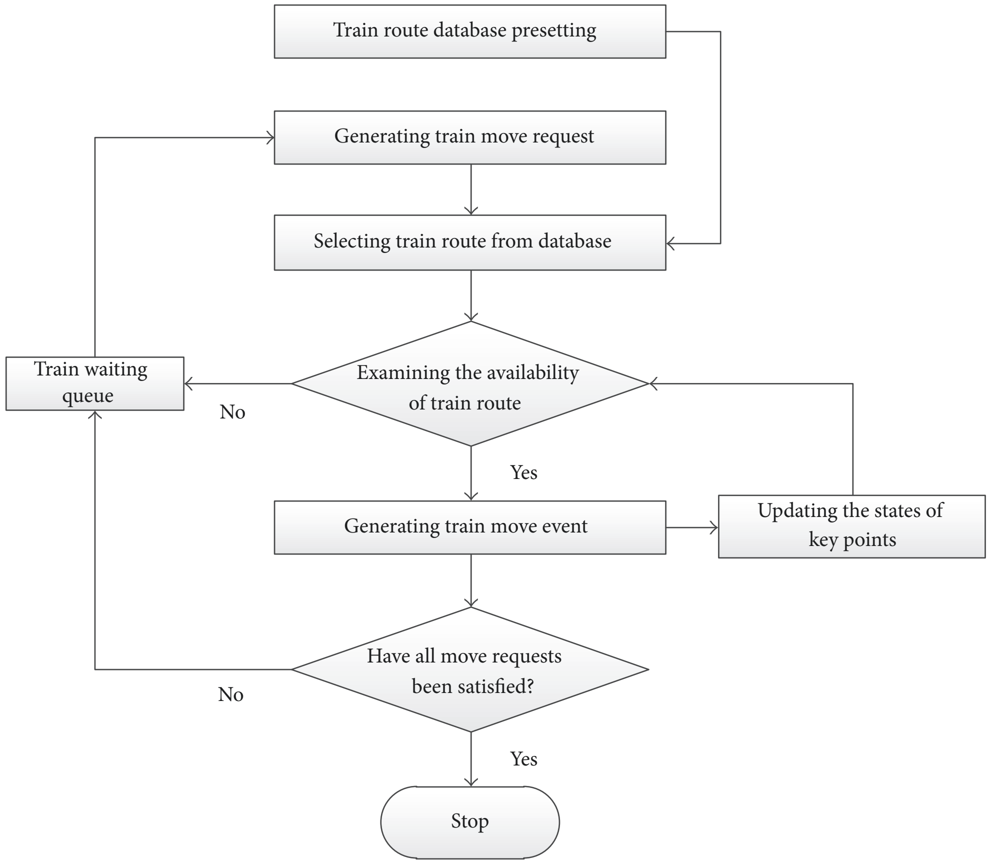


Figure 6: Framework of train route dispatching simulation method.

4.1.3. Description of Train Arrival and Departure Model. The TPN model of train arrival and departure process is presented in Figure 7. Train generation is represented by a stochastic transition T1. For an inbound train (P1), when it is about to enter the arriving yard (or the receiving-departure yard) (T2), the availabilities of the destination track and the corresponding train route must be checked; places P3 and P4 are added to represent the available destination track and the available train route, respectively. Similarly, for each train moving event (T4, T7, T8, and T9), the availabilities of tracks and train routes must be checked. The availability inspection of train route is realized based on TRDSM, which is represented by an immediate transition T10. To check the availabilities of train routes, the real-time location information of the train which is expressed by several places (P17, P19, P20, and P22) needs to be acquired. Places P5 and P6 represent the empty inbound train and the loaded inbound train, respectively. Correspondingly, P7 indicates the train which has been loaded and P8 indicates the train which has been unloaded.

For outbound trains, two places (P9 and P10) are added to represent trains with different departure modes. Place P9 indicates the trains which can leave the terminal directly without moving to the departure yard (or the receiving-departure yard), while place P10 indicates the trains which need to finish the departure inspection at the departure yard before leaving the terminal. Transition T6 is added to distinguish different train departure modes.

4.2. Truck Arrival and Departure Model

4.2.1. Truck Generation Method. A truck generation method is designed to generate stochastic arrivals of trucks according to certain mathematical distribution. According to the study by Rizzoli et al. [4], the truck arrival pattern can be approximately described by the negative exponential distribution.

4.2.2. Description of Truck Arrival and Departure Model. When a truck is generated by the truck generation method (T11), it joins a FIFO queue at the entrance gate. An arrival inspection (T12) will begin if there is a free entrance channel which is represented by the place P38.

Considering that the time cost of the truck moving process is not fixed, the truck moving process inside the terminal (from the terminal gate to a certain cargo yard and vice versa) is represented by two stochastic transitions (T14 and T17). And the time cost of truck moving is produced based on stochastic distribution. Place P37 indicates the available parking spaces within the cargo yard. And T18 is a deterministic timed transition which represents the departure inspection of outbound trucks. The TPN model of truck arrival and departure process is also presented in Figure 7.

4.3. Cargo-Handling Model. Corresponding to the cargo-handling operations, the cargo-handling model can also be divided into two submodels, the train-truck cargo-handling

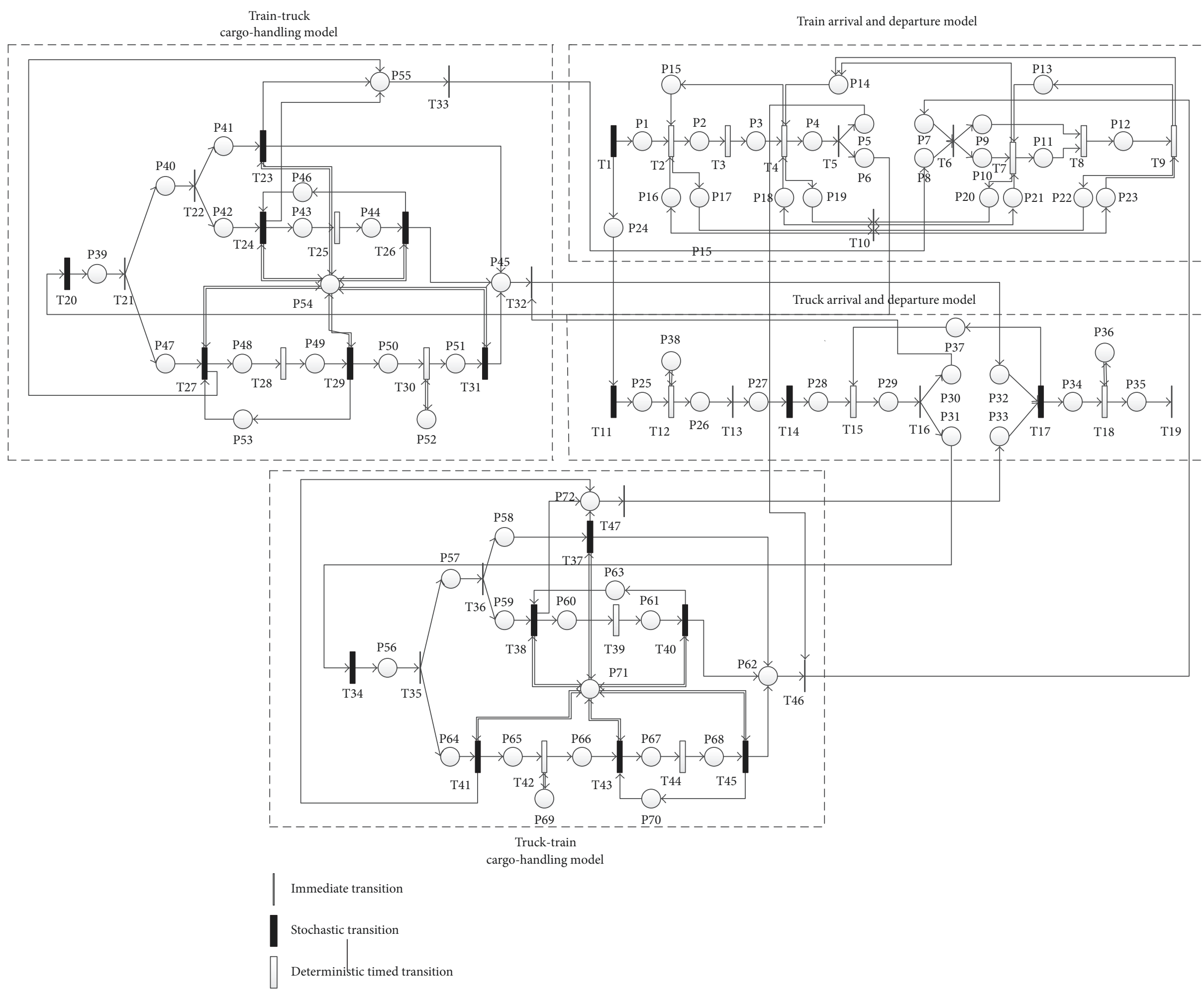


Figure 7: TPN model of multiyards railway intermodal terminal.

model and the truck-train cargo-handling model which are shown in Figure 7. In this section, the train-truck model is introduced as a representative.

The cargo which needs processing operation in MYRIT (or needs to be stored in a special area) is represented by place P47. This kind of cargo needs to be picked up by the shuttle trucks and carried to the corresponding area (T28). Three deterministic timed transitions (T27, T29, and T31) are added to represent the cargo unloading event from trains to shuttle trucks, the cargo unloading event from shuttle trucks to the machining region (or storage area for special goods), and the cargo loading event from machining region (or storage area for special goods) to consignee's trucks, respectively. The processing operation is represented by transition T30. Place P52 represents the resources for processing operation and P53 represents the available shuttle trucks.

Normal cargo which does not need to be machined or stored in the special area is represented by place P40. Place P41 represents the cargo as described in case (i) in Section 3.1.3 which can be picked up by trucks directly. Place P42 represents the cargo which needs to be stored within the terminal temporarily. The cargo unloading event and the storage process are represented by transitions T24 and T25, respectively. Place P48 indicates the available storage space.

Four transitions (T32, T33, T46, and T47) are added to connect different submodels. T32/T46 indicates the event of generating loaded outbound truck/train when the loading operation has been finished, and T47/T33 represents the event of generating empty outbound truck/train when the unloading operation is completed.

5. Multiyards Railway Intermodal Terminal Simulation Platform

Based on the TPN model, a multiyards railway intermodal terminal simulation platform is developed, using C# as a development tool. The MYRIT simulation platform can provide realistic reproduction of the main logistic activities and entities flows (e.g., trains, trucks, and cargoes) which occur inside the terminal. It can be used to evaluate the terminal design scheme and management strategies based on the quantitative analysis of simulation results and to provide decision support for terminal planning and design. In this section, a brief introduction of this platform is presented.

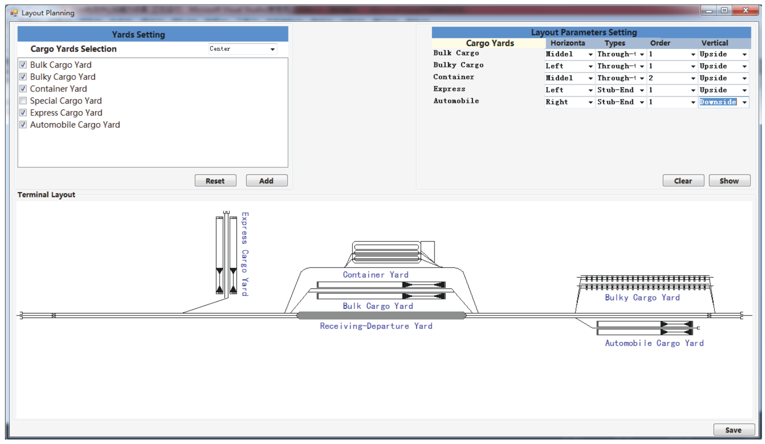


Figure 8: Interface of terminal layout planning.

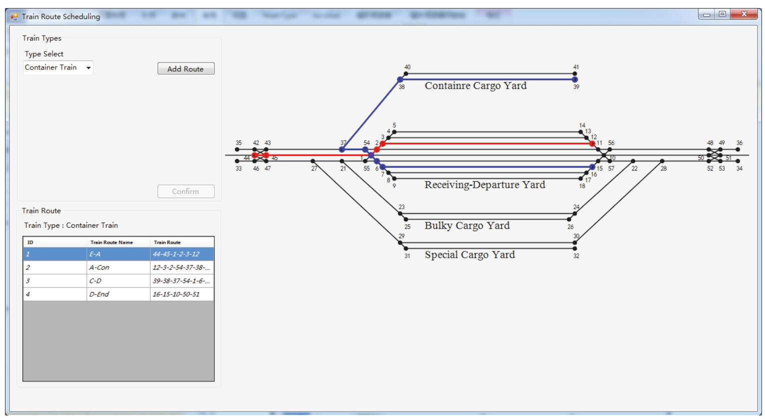


Figure 9: Interface of train route presetting.

As mentioned above, terminal layout has a significant impact on the train operations and should be determined from the very beginning of setting up a simulation project. In this platform, a graphical interface (as shown in Figure 8) for layout planning of MYRIT is provided, where simulation users can design or modify the terminal layout by setting the parameters as introduced in Section 3.2.

Once the terminal layout has been identified, the structure of the internal railway network of MYRIT can be determined. Simulation users should preset train routes according to the station operation regulations via an interface of train route presetting as shown in Figure 9. The internal railway network of MYRIT is described by the lines which represent the rail tracks and the points with unique ID numbers which represent the center points of the turnouts. Each train route can be represented by a sequential list of ID numbers as shown in Figure 9 (e.g., the red train route is represented by the numeral string "44-45-1-2-3-12"). The intersections among various train routes may cause train congestion in the rail yard and can lead to efficiency decline of train operations.

A statistical analysis of the performance of storage area can be provided by the platform. As shown in Figure 10, a sketch map of the operation in cargo yard during the simulation is reported. A train is being unloaded within the cargo yard and a truck arrives to pick up cargo. The real-time volume curve of the cargoes which are stored in the storage area is displayed. Based on the detailed records of the cargo volumes, the utilization ratio of storage area in a certain cargo yard can be calculated, as shown on the right side of Figure 10.

In Figure 11, several indexes of the cargo volumes are reported. The pie chart shows the proportion of the quantity of each type of goods to the total volume of goods during the simulation period. And from the histogram, the volume of each type of goods delivered by trains and trucks and the volume of each type of goods picked up by trains and trucks can be obtained. A group of line charts show the relationships between the volumes of inbound cargo and outbound cargo.

Based on the TRDSM, this platform can provide elaborate reproduction of the train moving process within the terminal, and major time information of the train moving process can be accessed by users via the interface as shown in Figure 12. A detailed statistical analysis of train performance can be obtained on the platform based on the simulation results. Several statistical charts about train operation time are reported in Figure 13. Among them, the first chart shows the number of trains and the time consumption of trains staying at the cargo yard.

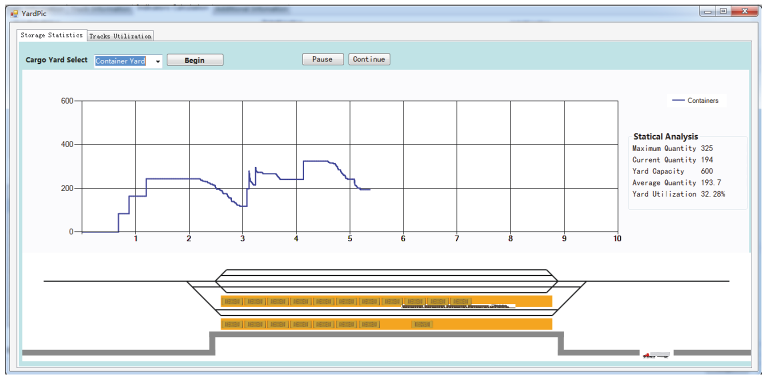


Figure 10: Snapshot of the platform interface during simulation.

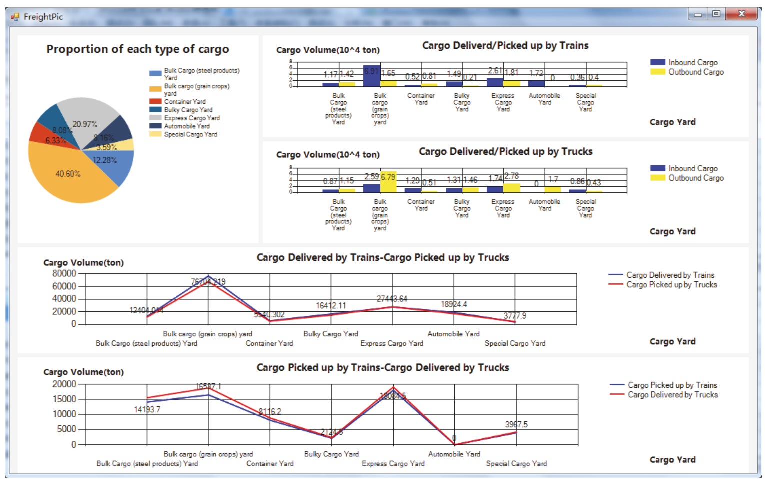


Figure 11: Statistical analysis of cargo volumes based on the simulation results.

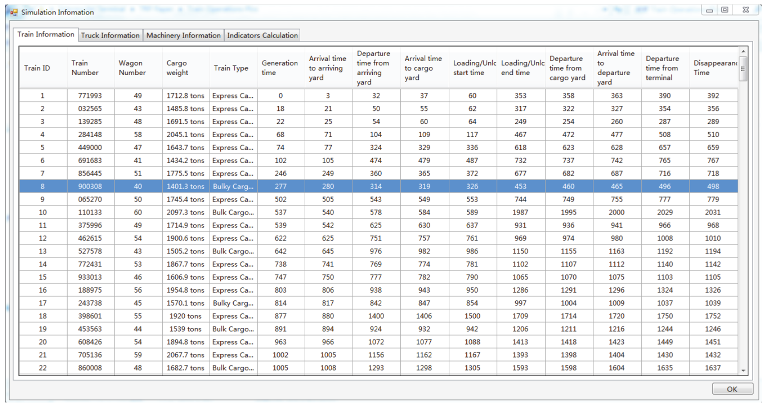
The utilization ratio of handling equipment can also be analyzed. An example of the historical record of the crane utilization ratio in the container yard during the simulation period is shown in Figure 14. Utilization ratio is one of the key indicators of handling equipment, which reflects the busy degree of the equipment resources. In general, low utilization ratio may indicate that there is a problem of equipment redundancy, and high utilization ratio (in a reasonable range) means the handling equipment is fully used. Therefore, from the perspective of investment benefit, high utilization ratio is more likely to be beneficial for the investors. However, exorbitant high utilization ratio also means possibility of having lengthy truck queue in the cargo yard. Therefore, the queue length of trucks needs to be analyzed as well. The sample result of truck queue length in cargo yard is presented in Figure 15.

6. Validation and Test Scenarios of Simulation Platform

Validation is extremely important in the validation phase to ensure that the result of the simulation model is able to reproduce the reality under different conditions [24]. In this section, a simulation case of Qianchang railway intermodal terminal has been performed to verify the capacity of the platform of reproducing the real terminal behavior. And two test scenarios are presented to investigate the impact of variations of train route arrangement and handling equipment configuration on terminal performance.

6.1. Simulation Case Setup. The simulation case is set up based on the Qianchang railway intermodal terminal which is located in Fujian Province, China. Qianchang railway intermodal terminal provides transport services of various types of cargoes, including commercial vehicles, electromechanical equipment, steel products, and cold chain goods. The intermodal terminal covers an area of more than 2 square kilometers which contains one receiving-departure yard and seven independent cargo yards. These cargo yards consist of a bulk cargo yard for steel products, a bulk cargo yard for grain crops, a container yard, a bulky cargo yard, an express cargo yard, an automobile cargo yard for commercial vehicles, and a special cargo yard for cold chain cargoes. The layout of Qianchang terminal edited by the yards and facility module of the simulation platform is shown in Figure 16.

The initial data used in the validation is provided by the Qianchang railway intermodal terminal based on a monthly statistical report. The dataset spans a 30-day period and



Simulation Infomation

Train Information | Truck Information | Machinery Information | Indicators Calculation

Train ID	Train Number	Wagon Number	Cargo weight	Train Type	Generation time	Arrival time to arriving yard	Departure time from arriving yard	Arrival time to cargo yard	Loading/Unlc start time	Loading/Unlc end time	Departure time from cargo yard	Arrival time to departure yard	Departure time from terminal	Disappearanc Time
1	771993	49	1712.8 tons	Express Ca...	0	3	32	37	60	353	358	363	390	392
2	032565	43	1485.8 tons	Express Ca...	18	21	50	55	62	317	322	327	354	356
3	139285	48	1691.5 tons	Express Ca...	22	25	54	60	64	249	254	260	287	289
4	284148	58	2045.1 tons	Express Ca...	68	71	104	109	117	467	472	477	508	510
5	449000	47	1643.7 tons	Express Ca...	74	77	324	329	336	618	623	628	657	659
6	691683	41	1434.2 tons	Express Ca...	102	105	474	479	487	732	737	742	765	767
7	856445	51	1775.5 tons	Express Ca...	246	249	360	365	372	677	682	687	716	718
8	900308	40	1401.3 tons	Bulky Carg...	277	280	314	319	326	453	460	465	496	498
9	065270	50	1745.4 tons	Express Ca...	502	505	543	549	553	744	749	755	777	779
10	110133	60	2097.3 tons	Bulk Cargo...	537	540	578	584	589	1987	1995	2000	2029	2031
11	375996	49	1714.9 tons	Express Ca...	539	542	625	630	637	931	936	941	966	968
12	462615	54	1900.6 tons	Express Ca...	622	625	751	757	761	969	974	980	1008	1010
13	527578	43	1505.2 tons	Bulk Cargo...	642	645	976	982	986	1150	1155	1163	1192	1194
14	772431	53	1867.7 tons	Express Ca...	738	741	769	774	781	1102	1107	1112	1140	1142
15	933013	46	1606.9 tons	Express Ca...	747	750	777	782	790	1065	1070	1075	1103	1105
16	188975	56	1954.8 tons	Express Ca...	803	806	938	943	950	1286	1291	1296	1324	1326
17	243738	45	1570.1 tons	Bulky Carg...	814	817	842	847	854	997	1004	1009	1037	1039
18	398601	55	1920 tons	Express Ca...	877	880	1400	1406	1500	1709	1714	1720	1750	1752
19	453563	44	1539 tons	Bulk Cargo...	891	894	924	932	942	1206	1211	1216	1244	1246
20	608426	54	1894.8 tons	Express Ca...	963	966	1072	1077	1088	1413	1418	1423	1449	1451
21	705136	59	2067.7 tons	Express Ca...	1002	1005	1156	1162	1167	1393	1398	1404	1430	1432
22	860008	48	1682.7 tons	Bulk Cargo...	1005	1008	1293	1298	1305	1593	1598	1604	1635	1637

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Figure 12: Time information of the train moving process.

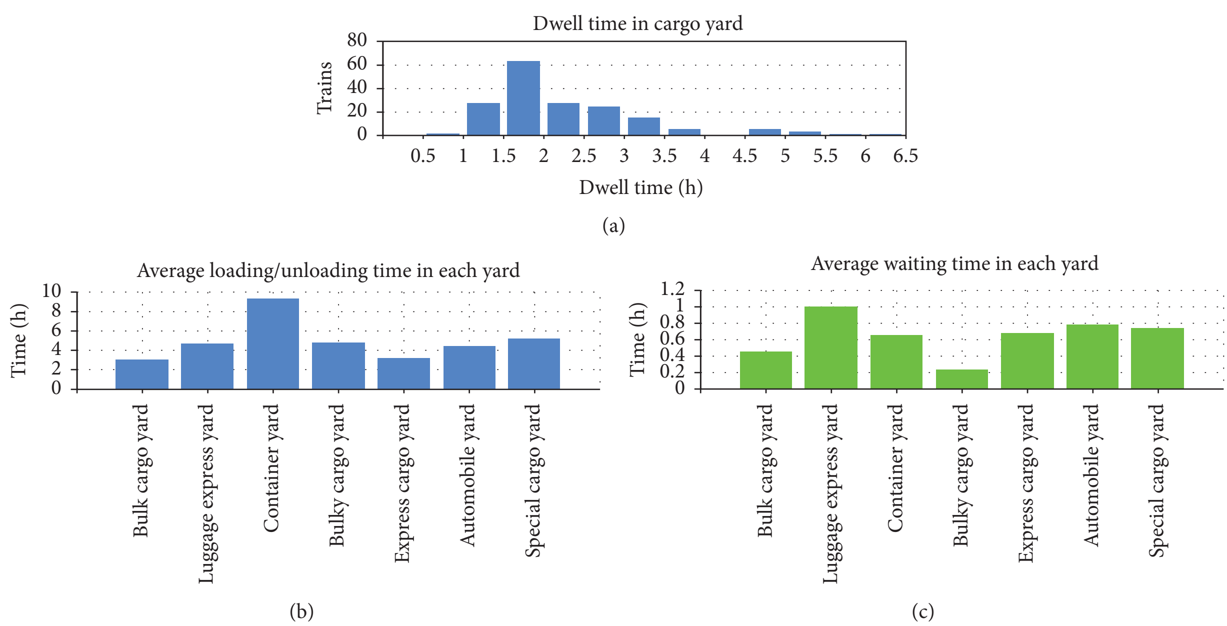


Figure 13: Statistical analysis of train performance.

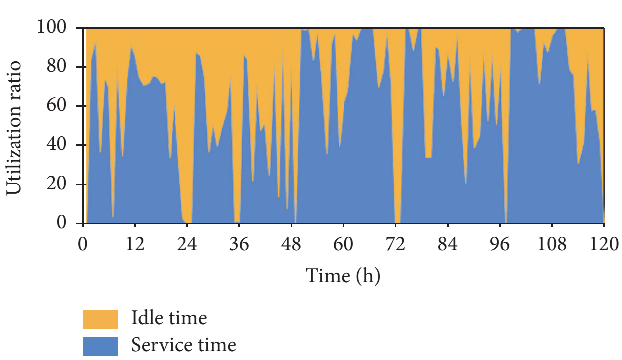


Figure 14: Crane utilization ratio in container yard.

records detailed information on several key performance indicators which include the cargo volumes, average train loading/unloading time, average truck terminal dwell time, and utilization rate of handling machineries.

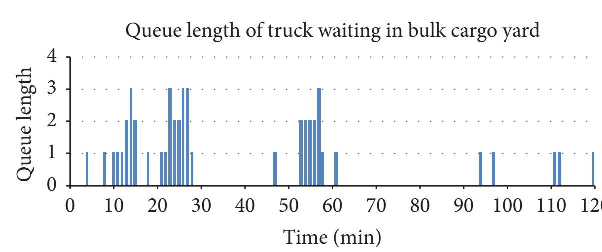


Figure 15: Queue length of trucks in bulk cargo yard.

6.2. Results and Analysis. Considering the variability in the simulation procedure, the results used for validation are summarized from a set of 500 simulations, which provide reliable simulation statistics of the activities within the intermodal terminal. The efficiency of the constructed simulation framework ensures that a single repetition costs about 4.7 seconds on a 2.5 GHz i5-3210M dual-core processor with

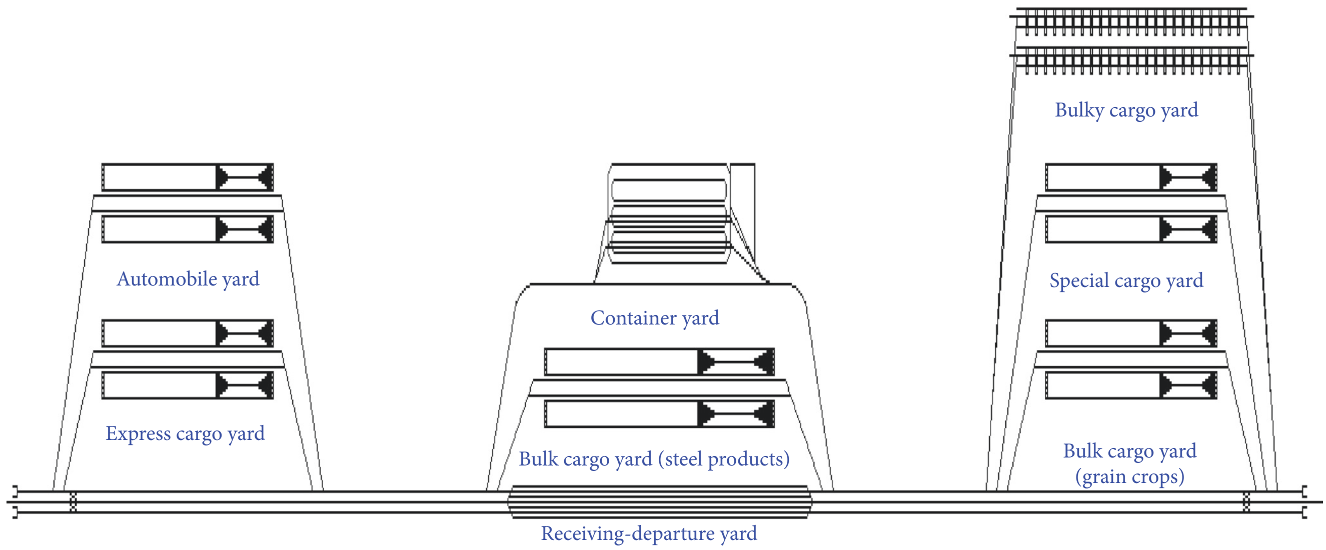


FIGURE 16: Yards layout of Qianchang railway intermodal terminal.

FIGURE 17: Normalized cargo volumes from historical and simulation datasets.

4 GB of RAM. To provide intuitive comparative analysis results in the validation phase, most simulated values are normalized with respect to the values in the historical dataset, which means the value of 1 corresponds to the actual value in the real life system.

In Figure 17, we present a bar plot of the normalized cargo volumes (the total volume and the respective volumes for each type of cargo) of the historical data and the simulation data which are in the 95% confidence interval. The black bars on histograms indicate the minimum and maximum of the simulation data. Although the trains and trucks are generated according to the historical record, the specific capacity of each railway wagon and truck and all types of delays (the delays that are related to the lack of railway tracks, handling equipment, and warehouses) introduce variabilities in the quantity of cargo volume. The differences between the simulated and actual data are very limited. The biggest difference of simulated data in 95% confidence interval is below 2%, which suggests good agreement with the historical dataset.

A similar study is performed in the case of utilization rates of handling machineries, as presented in Figure 18, where the bars also indicate the limits of the 95% confidence interval. The utilization rates of machineries in seven cargo yards are measured and displayed in the histograms, which vary widely from yard to yard. The utilization of handling equipment in the express cargo yard almost reached 50%, while the utilization rates in grain crops yard and special cargo yard are below 20%. Returning to the analysis of the validation, the similarity of handling machineries utilization is again noticeable. As shown in Figure 18, the differences between the simulated utilization rates and real utilization rates are below 2%, and 95% of the simulation results lie within 5% of the expected value, which means the simulation platform can reproduce the activities of handling machineries accurately.

Figures 19 and 20 display the normalized train loading/unloading time accumulated by each train from the historical and simulation dataset in the same order. In specific, each loading/unloading time is normalized with respect to the actual mean loading/unloading time which is 266.0 minutes. As shown in Figure 19, most data points are scattered in the interval from 0.3 to 2.0 and have no apparent patterns. However, a noticeable feature is that some data points are concentrated on the horizontal line with the value of 0.4 (as shown by the orange dotted line in Figure 19) and are relatively far from the rest of the points. These data points correspond to the container trains which can be loaded or unloaded with higher stevedoring efficiency with the support of gantry cranes. In fact, the historical average loading/unloading time of container trains is 100.3 minutes which is only 37.6% of the overall mean loading/unloading time.

These characteristics are all reflected in the simulated results as shown in Figure 20. To verify the similarities

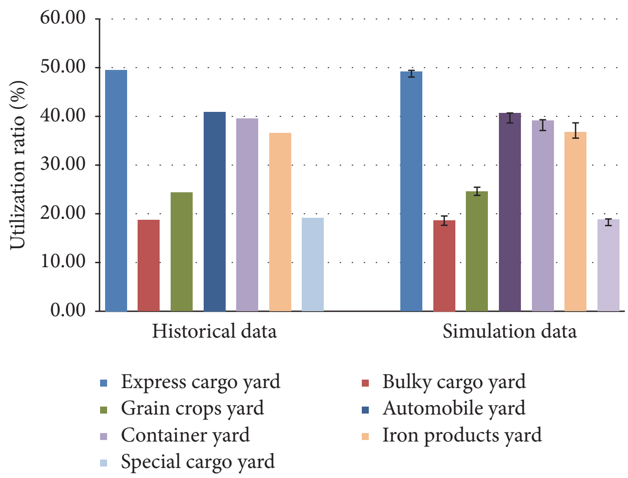


FIGURE 18: Historical and simulated utilization ratio of handling machineries.

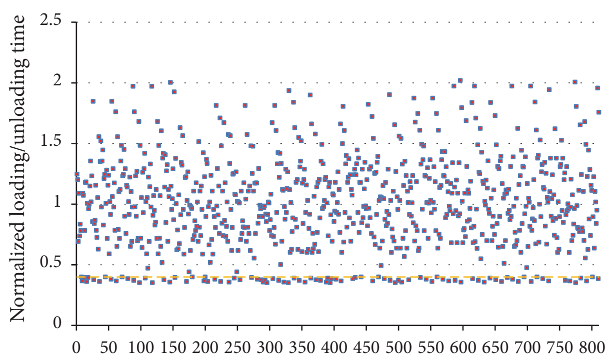


FIGURE 19: Historical train loading/unloading time distribution.

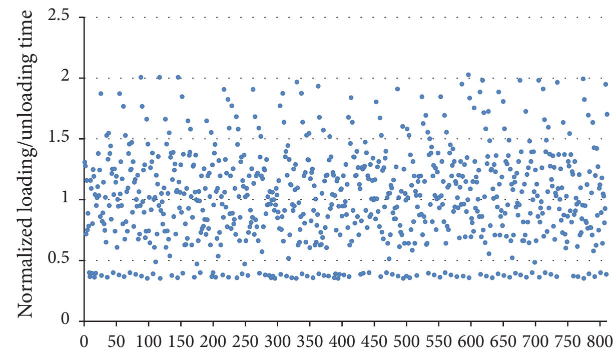


FIGURE 20: Simulated train loading/unloading time distribution.

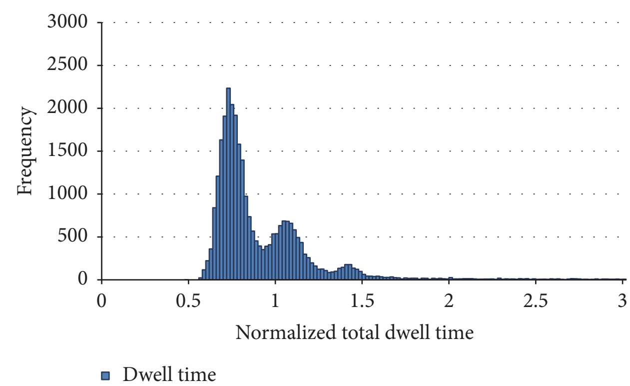


FIGURE 21: Historical distribution of total terminal dwell time of trucks.

between the historical data and simulation data in the future, we employ the two-sample Kolmogorov-Smirnov test to assess the quantitative differences between the distributions. The progressive significance coefficient (p value) is 0.553 which is significantly higher than the typical mark of 0.05. This verification indicates that the simulated train loading/unloading time distribution is statistically not different from the historical record and hence describes an accurate representation.

To verify the simulation accuracy of truck operation procedures, the total dwell time at the intermodal terminal is calculated as one of the key performance indicators. Considering the large quantity of trucks which are more than 30,000, it is difficult for the scatter plot to display the inherent law of the data intuitively. Therefore, histograms are used to describe the distribution of the total truck dwell time, which are shown in Figures 21 and 22. Similarly, the dwell time of each truck has been normalized with respect to the historical mean dwell time, and the simulated distribution is drawn based on the simulation results which are in the 95% confidence interval.

As shown in the histograms, the simulated dwell time distribution is very similar to the actual time distribution overall. Both distributions have multipeaks, and great majority of data points are clustered in the section from 50% to 150% of the mean dwell time. It is easy to explain this relatively strong variation in the dwell time distribution. In Qianchang intermodal terminal, there are multiple types of trucks. Due to the differences in cargo characteristics, the dwell time of different types of truck tends to have obvious differences. In fact, the historical mean dwell time of container trucks is 23% less than the average dwell time of special cargo trucks. In Figure 22, the red continuous vertical line indicates the value of the historical mean dwell time, and the green dotted line illustrates the average simulated dwell time within the 95% confidence interval, and the difference is negligible. The two distributions have been again compared in terms of the two-sample Kolmogorov-Smirnov test, with p value of 0.484, which is significantly larger than 0.05. The test result indicates that the simulation platform reproduces the activities of the real life system accurately.

In order to further verify the effectiveness of the simulation data, the mean error $D(Q)$ which is proposed in the literature [25] (defined in (2)) is introduced to quantify the mean absolute percentage error. In (2), Q is defined as a quantity of one indicator, Q_h is introduced as notation for the historical value of this indicator, and Q_s is defined as the value of the respective indicator obtained in the ith simulation. Furthermore, the percentage error between the simulated

Table 1: Simulation error coefficient results.

Cargo type	Error coefficients	Indicators			
		Cargo volume	Utilization rate	Loading/unloading time	Dwell time
Express cargo	$D(Q)$	0.012944	0.011589	0.018251	0.008871
	$E(Q)$	0.50%	0.94%	1.81%	1.75%
Bulky cargo	$D(Q)$	0.016761	0.035432	0.015348	0.015244
	$E(Q)$	0.65%	0.98%	1.53%	1.52%
Grain crops	$D(Q)$	0.020680	0.022395	0.021014	0.012596
	$E(Q)$	0.82%	0.70%	2.10%	1.26%
Automobile	$D(Q)$	0.011556	0.015392	0.000179	0.048468
	$E(Q)$	0.80%	0.59%	0.02%	3.83%
Container	$D(Q)$	0.011646	0.012187	0.000863	0.003889
	$E(Q)$	0.22%	1.01%	0.09%	1.53%
Iron products	$D(Q)$	0.012918	0.020601	0.014844	0.003483
	$E(Q)$	0.92%	1.62%	1.48%	1.88%
Special cargo	$D(Q)$	0.011461	0.019520	0.010384	0.034711
	$E(Q)$	0.69%	1.70%	1.04%	3.47%

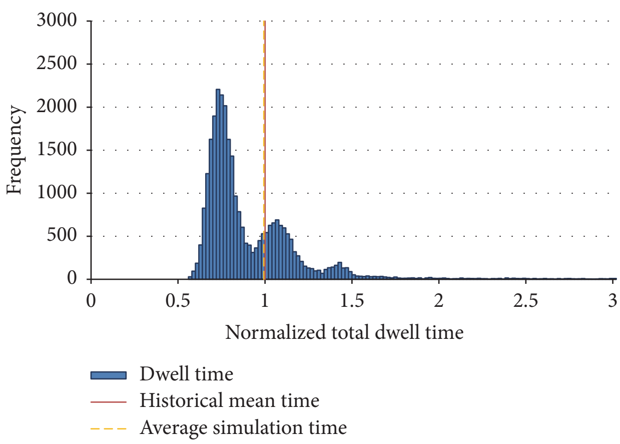


Figure 22: Simulated distribution of total terminal dwell time of trucks.

data and the historical value is described by $E(Q)$, which is defined in (3).

$$D(Q) = \frac{1}{n}\sum_{i=1}^{n}\frac{\left|Q_s(i) - Q_h\right|}{Q_h}, \tag{2}$$

$$E(Q) = \left|1 - \left(\frac{1}{n}\sum_{i=1}^{n}\frac{Q_s(i)}{Q_s}\right)\right| \cdot 100. \tag{3}$$

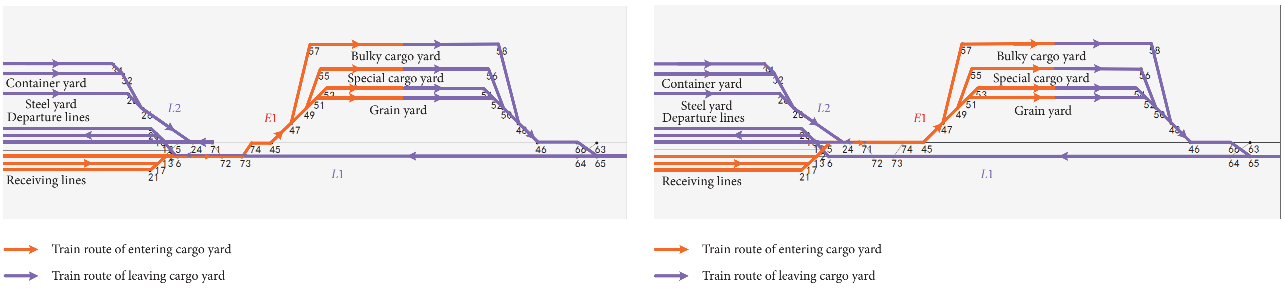
A detailed error coefficient analysis of the four key performance indicators is summarized in Table 1. The mean error $D(Q)$ and the percentage error $E(Q)$ of each type of cargo are calculated based on the historical record and the simulation data which are in the 95% confidence interval. The mean errors of the cargo volumes are obviously small, which is consistent with the results in Figure 17. The error coefficients of truck dwell times are relatively higher, which can be explained as follows. Since there is no fixed timetable for truck activities (which is different from trains), the trucks are designed to mainly follow the principle of FIFO rule in the simulation model, which is mentioned in Section 4.2. However, in practice, the queuing rule is more flexible and is easy to be artificially changed, which obviously affects the dwell time of trucks. As for trains, the arrival and departure time of trains are determined by the timetable, which reduces the variabilities in the simulation process to a certain extent. This deviation can be narrowed by introducing more flexible queuing rules into the simulation model in the future.

In general, the similarities between the simulation data and the actual record are noticeable. The biggest percentage error is smaller than 4%, and the percentage errors of most performance indicators are less than 2%. Following the comprehensive analysis of both qualitative and quantitative features, the simulated results have been proved to have good agreements with the historical values, which is able to verify the validity of this simulation platform.

6.3. Test Scenarios. Having established the convincing performance of the model via several validation studies, we now aim to use the platform as a decision-support and predictive tool. Some test scenarios of relevance for the activities in MYRIT have been formulated.

In Section 6.3.1, we describe the impact of train route arrangement on train operation efficiency. Two train route schemes are analyzed based on simulation results. Then, in Section 6.3.2, we pursue to investigate the effects of handling equipment configuration variation on loading/unloading operations. Some suggestions on equipment management are given according to the simulation analysis.

6.3.1. Train Route Arrangement. Train moving procedure is one of the most important terminal activities within MYRIT. This process has an instant impact on the train operations and can influence all relevant workflows of the terminal. Inside the MYRIT, each train must move in accordance with the prescribed train route. Due to the complexity of the railway



(a) Scheme A (b) Scheme B

FIGURE 23: Two local train routes' arrangement schemes of Qianchang railway terminal.

TABLE 2: Performance indicators of the train moving process based on simulation tests.

Train type	Scheme A		Scheme B	
	MDTRY (min)	MDTCY (min)	MDTRY (min)	MDTCY (min)
Bulky cargo	31.8	323.8	33.7	318.7
Grain	31.7	217.8	33.9	212.6
Container	31.9	428.2	34	422.5
Steel	32	120.8	33.1	130.7
Special cargo	117.4	392.4	121.2	422.5

line topology in MYRIT, train route arrangement can have a significant influence on train moving efficiency and is an important issue in the field of terminal management.

The goals of train route arrangement include reducing routes conflicts and improving train moving efficiency. Based on the simulation platform, the performance of certain train route arrangement can be analyzed, and different arrangement schemes can be compared and selected based on simulation results. In this section, we construct a simulation test which contains two partial train route arrangement schemes of Qianchang railway intermodal terminal. The detailed train route schemes are shown in Figures 23(a) and 23(b).

The two train route schemes shown in Figure 23 show part of the overall train route arrangement scheme of Qianchang terminal, which mainly contain the train routes of entering cargo yards and leaving cargo yards. According to the direction, the train routes which are shown in these two schemes can be divided into three types: the train routes of entering bulky, special, and grain cargo yards which are named $E1$, the train routes of leaving bulky, special, and grain cargo yards which are named $L1$, and the train routes of leaving container and steel cargo yards which are named $L2$. The detailed arrangements of $E1$ routes in Scheme A and Scheme B are different, while other train routes in the two schemes are the same. To investigate the influences of these two train route schemes on the efficiency of the train moving procedure, simulation experiments are implemented. With the exception of the train routes variation, all other parameters are designed in the same manner as in the validation study.

Table 2 summarizes the results of the investigation. Two indicators are used to analyze the train operation efficiency, which are the mean dwell time in receiving yard (MDTRY) and the mean dwell time in cargo yard (MDTCY). Each indicator is calculated based on the values from 500 simulation repetitions which are in the 95% confidence interval. Since the inspection time in receiving yard and the loading/unloading rates in cargo yards are the same in the two simulation experiments, the indicators of dwell time can reflect the performances of train moving efficiency. Figures 24 and 25 present the visualizations of the findings in Table 2, which show the value differences on indicators between Scheme A and Scheme B.

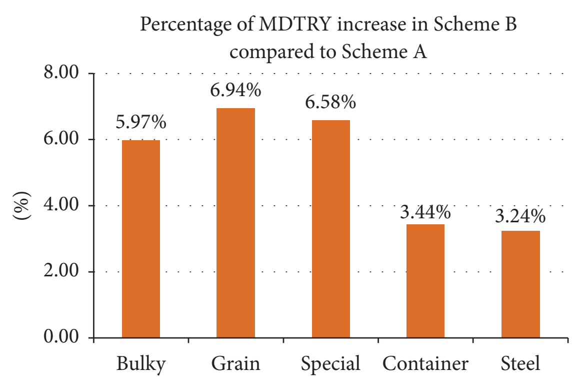


FIGURE 24: Differences of MDTRY between Scheme A and Scheme B.

We notice an obvious increase on MDTRYs when using Scheme B as shown in Figure 24. Compared with Scheme A, the MDTRYs of bulky, grain, and specially cargo trains have been extended by about 6%, which indicates that the routes $E1$ in Scheme B have more conflicts with other train routes. The train routes of entering cargo yard for container and steel cargo trains are the same in both Scheme A and Scheme B. However, the MDTRYs of container and steel cargo trains in Scheme B are still about 3% larger than the MDTRYs in

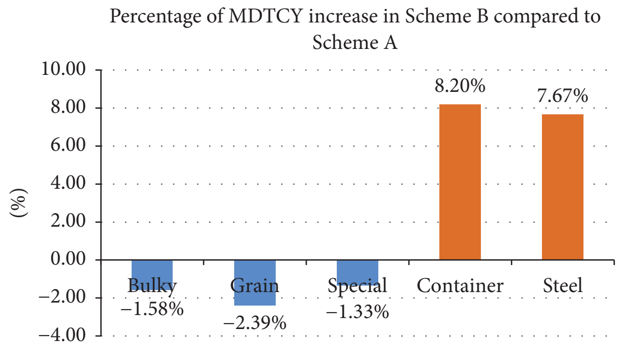


Figure 25: Differences of MDTCY between Scheme A and Scheme B.

Scheme A. In terms of dwell time in cargo yard, the MDTCYs of container and steel cargo trains in Scheme B have increased sharply compared with the MDTCYs in Scheme A, while the MDTCYs of bulky, grain, and special cargo trains have been reduced. This phenomenon indicates that, in Scheme B, the performance of $L1$ train routes has been improved compared to Scheme A; however, the conflicts between $L2$ and other train routes have become more serious.

The reason of the simulation results needs to be analyzed. There are train routes conflicts in both Scheme A and Scheme B. In Scheme A, routes $E1$ mainly have conflicts with routes $L1$, while in Scheme B, routes $E1$ mainly have conflicts with routes $L2$. However, the number of trains which need to occupy $L1$ and the number of trains that need to occupy $L2$ are different. In fact, the total number of container and steel cargo trains is 52% larger than the total number of bulky, grain, and special cargo trains, which makes the conflicts between $E1$ and $L2$ much more serious than the conflicts between $E1$ and $L1$. Hence, the MDTRY of bulky, grain, and special cargo trains and the MDTCY of container and steel cargo trains are all increased when using Scheme B. In addition, since the MDTCY of container and steel cargo trains increased, these types of trains need to wait more for available side tracks in the receiving yard, which leads to an increase in the MDTRY of container and steel cargo trains. Although the MDTCY of bulky, grain, and special cargo trains decreased when using Scheme B, the MDTCY of all trains in Scheme B is still 3.9% larger than that of Scheme A.

Therefore, in general, Scheme A has advantages over Scheme B in train operation efficiency. And in reality, Scheme A is adopted by the dispatch department of Qianchang terminal. The simulation tests show that the number of trains is one of the key factors in train route dispatching. It can be inferred that when the quantity of trains changes greatly, train routes schemes need to be adjusted accordingly.

6.3.2. Handling Equipment Configuration. The second set of investigations is constructed in order to study the impact of varying handling equipment configuration on performance indicators of loading/unloading operation. Generally, increasing the quantity of handling equipment can reduce the loading/unloading time and improve the operation efficiency. However, the quantitative relationship between the performance indicators of loading/unloading operation and the equipment quantity needs to be analyzed, which can provide decision-support information for the terminal managers.

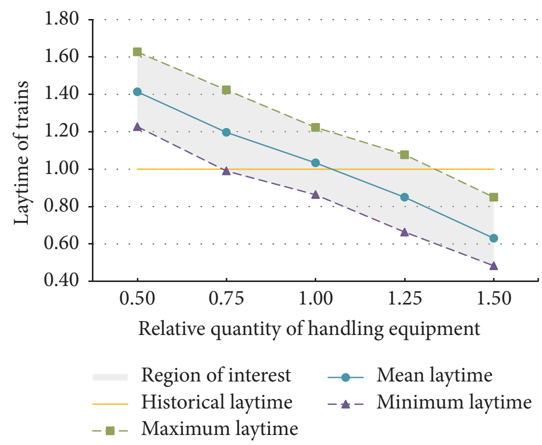
Considering the realistic quantity limitations of the machineries, we are interested in what happens when the quantity of handling equipment is varied from 50% to 150% of the current value in Qianchang terminal. The increment is set to 25%, leading to a total of 5 studies, each designed to collect statistics from 500 simulations. The performance indicators include the mean laytime of train (MLT_Train), the mean laytime of truck (MLT_Truck), the mean waiting time for handling operation of train (MWT_Train), and the mean waiting time for handling operation of truck (MWT_Truck), which are calculated from the 95% confidence interval of the simulation results and are normalized with respect to the historical values. The results are shown in Figure 26, where we present the lower, upper, and mean values of the relevant indicators obtained from the simulation tests.

It can be observed that increasing the handling equipment quantity can lead to a decrease in laytime and waiting time of trains and trucks. However, the sensitivities of the four indicators are different.

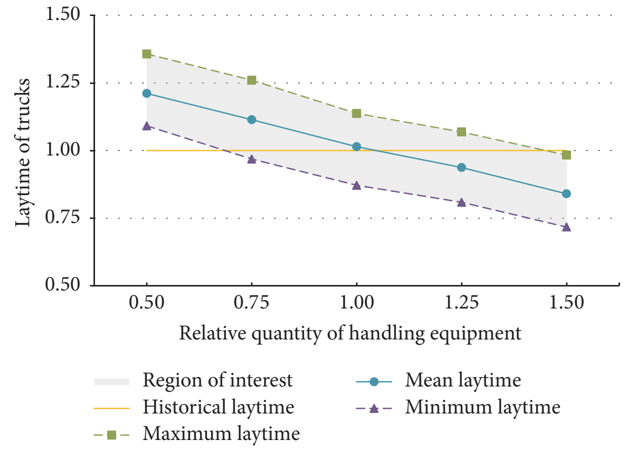
As the machinery quantity increases, the decreases of MLT_Train and MLT_Truck are both almost linear, which is easily understood. However, the variation of MLT_Train is much bigger than the variation of MLT_Truck. This phenomenon is caused by the difference between the equipment usage pattern of trains and that of trucks. In general, most types of trains can be unloaded/loaded by multiple handling machineries at the same time. Therefore, with the increase of handling equipment, the loading/unloading rates of trains rise simultaneously. Nevertheless, except for bulk cargo trucks and express cargo trucks, many types of trucks (e.g., bulky cargo trucks, container trucks, and automobile trucks) can only be served by one handling machine due to the characteristics of goods. Thus, with the increase of handling equipment quantity, the growth of the overall loading/unloading rate of all types of trucks is more moderate compared with trains. And little variation of MLT_Truck can be observed with the increase of handling equipment.

We notice a strong link between the MWT_Train/MWT_Truck and machinery quantity dynamics. A 50% decrease of handling equipment can cause almost 130% increase of the waiting time of trains and almost 100% increase of the waiting time of trucks. Very large variation of waiting time indicates that reduction of available machineries can significantly reduce the efficiency of loading/unloading operation. Hence, maintaining an efficient stevedoring servicing is vital to the terminal system.

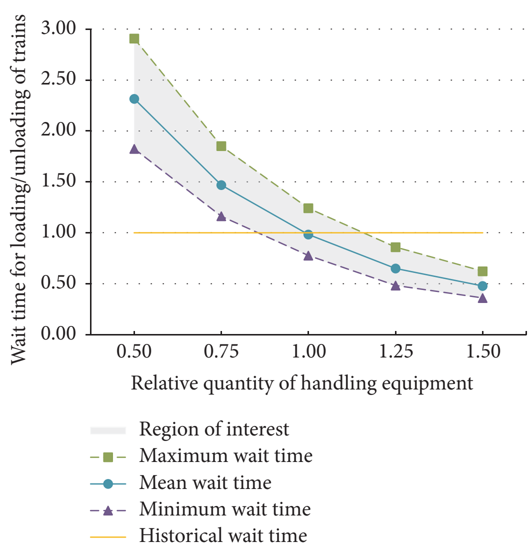
As the handling equipment quantity increases, both the means and variations in MWT_Train and MWT_Truck decrease obviously. However, the rates of decline gradually slow down. It can be inferred that, even with more handling machineries, the waiting time of trains and trucks in the terminal does not completely disappear. In fact, with another 50% increase of handling equipment (200% of the current value), only 8% decrease of MWT_Train and 5% decrease of MWT_Truck can be obtained. We can conclude that,



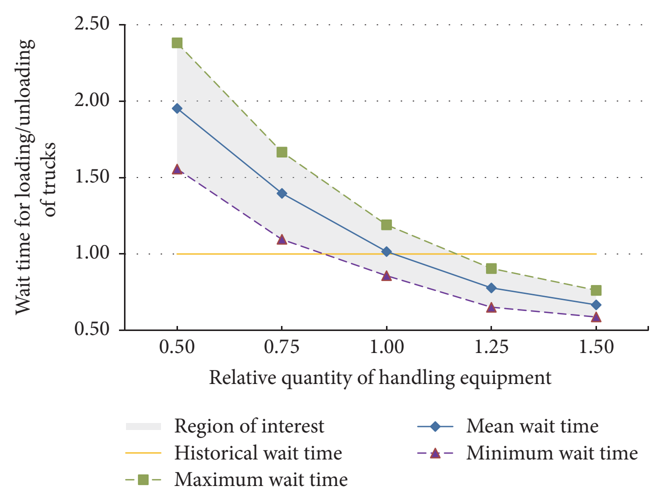
(a) Laytime of trains



(b) Laytime of trucks



(c) Wait time for loading/unloading of trains



(d) Wait time for loading/unloading of trucks

Figure 26: Impact of handling equipment configuration variation on loading/unloading operation efficiency.

in Qianchang intermodal terminal, increasing the handling equipment to more than 150% of the current value would only lead to negligible improvements of loading/unloading efficiency. With this conclusion, future investment and management of handling equipment can be considered in a reasonable and efficient manner.

7. Conclusions and Future Work

A simulation platform for providing a quantitative evaluation of MYRIT has been presented. The simulation model includes three sub-TPN models which correspond to the three major operations of MYRIT. In this platform, a yards and facilities layout module has been created where users can flexibly design or modify the terminal layout, and a TRDSM has been designed to provide an accurate simulation of the train moving process. Based on a comprehensive simulation analysis of Qianchang railway intermodal terminal, the simulation platform has been proved to be able to reproduce the activities of the real life system accurately. In addition, useful suggestions for terminal design and management can be obtained based on simulation tests of train route arrangement and handling equipment configuration.

Compared with existing simulation models, this platform has advantage in providing a detailed simulation of train moving process considering train routes dispatching rules. The results in the case study indicate that integrating the control method of train route dispatching can significantly improve the simulation accuracy of MYRIT. In general, this simulation platform can be used as an evaluation and analysis tool for terminal planning and design departments. Moreover, with the support of the yards and facilities module and the TRDSM, it can also be used as a management decision-support tool for dispatching managers.

Some limitations of the current simulation platform and the simplification procedure within the TPN model need to be analyzed, which can be considered as suggested improvements to the platform in future research.

Firstly, in the TPN model, the truck moving process has been simplified as one discrete event, and the connections between adjacent trucks and truck congestion circumstances are not considered, which will lead to inaccurate simulation results when the truck flow rate of the terminal is huge. This could be improved by integrating a car-following model into the simulation platform. Secondly, the basic queuing rule adopted by the platform is FIFO policy. Nevertheless, in some circumstances, the EDD (earliest due date) or WSPT (weighted shortest processing time first) rules can be used to reduce the delay time, and sometimes queuing rules are artificially determined. In most situations, this is a suitable assumption, since most of the terminal activities are required to follow the principle of FIFO rule. However, a study of mixed queue policy might provide possible improvement. Finally, an optimization mechanism is not taken into account in the framework, which can be improved. For example, numerous optimization methods have been proposed in the field of train route scheduling [26–28]. Some of the methods can be integrated into the platform to perform a simulation-based train route optimization for terminal managers. And in terms of determining equipment configuration or terminal layout, developing an integral approach considering multiple input scenarios can be a valuable future research direction, which can assist the terminal designers in a good terminal design.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This research is jointly supported financially by the National Natural Science Foundation of China (no. 61374202), National Key R&D Program of China (2016YFE0201700), the Research Project of China Railway Corporation (2017X004-D, 2017X004-E), and the Fundamental Research Funds for the Central Universities (2017YJS098).

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