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Design and Simulation of a New Intermodal Automated Container Transport System (ACTS) Considering Different Operation Scenarios of Container Terminals

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Abstract: In this study, we have designed a new intermodal automated container transport system (ACTS) via a roll-on/roll-off method that connects a logistics hub between a port and inland. Further, we have presented the development of a simulation model and the results of the simulator development. A simulation program was developed using a general-purpose simulation system (GPSS)/H to predict the processing capacity of the ACTS system and derive the optimum input equipment size and operation method. Additionally, the PROOF5 program was used for the visual verification of the system algorithm and for users to intuitively view and monitor events occurring in the terminal. The simulation program developed in this study can be used in the future as a tool to compare and analyze the efficiency of the existing road-transport-based system and the proposed ACTS system when the latter is implemented in a specific region.

Keywords: automated container transport system (ACTS); discrete event simulation; GPSS/H; PROOF5; container terminal

1. Introduction

Ports are vital hubs for freight import and export across the sea. In countries such as Korea that depend highly on trade, large volumes of container freight enter and exit ports. Importing and exporting via rail is not possible in Korea because of the political predicaments of North Korea—a situation that has consequently led to a large volume of sea freight in national imports and exports, amounting to 1312 million tons per year (99.6% of the total trading volume). Furthermore, because the country is small and the economic competitiveness of road transport is generally high, most of the import and export of container freight is conducted via road.

In recent times, the greenhouse gas and fine dust emission problems caused by freight cars have gained national importance. The government is seeking various ways to encourage ecofriendly rail transportation as opposed to road transportation. Typically, the economic competitiveness of rail transportation is lower than that of road transportation because of the significant infrastructure construction costs, additional transshipment times, and associated costs involved therein. Therefore, to promote rail transportation, the cost of infrastructure construction must be reduced, and the additional transshipment costs or transshipment times must be minimized.

To this end, the Korean government launched a research project to study the development of a new intermodal automated container transport system (ACTS) via a roll-on/roll-off (RO/RO) method that connects ports to hinterlands or uses a logistics hub between ports and the inland. The project is supported by the government research and development fund and a private matching fund and is due for completion by 2021. Because the project requires a substantial investment in construction and involves costs of transformation, the existing operating systems (e.g., ports, or changes in facility or operation plans) are examined in advance via simulation models that reflect reality. Simulation models can be used to examine the outcomes of new alternatives in advance, which can be useful in verifying the performance of new systems [1].

Various simulation techniques have recently been employed to study the transport systems of port terminals [2–5]. Simulation models have been developed to compare the performances of equipment such as cranes, vessels, and trucks in docks by analyzing the characteristics of the equipment [6]. Ottjes et al. [7] developed a simulation model for a sailing container terminal in the Netherlands to evaluate the feasibility of a system that could reduce the transshipment time of a container (via ship). Liu et al. [8] performed a numerical simulation to compare the performance of four different automated container terminal concepts: automated guidance vehicles (AGVs), a linear motor conveyance system, an overhead grid rail system, and a high-rise automated storage and retrieval structure. However, few studies have investigated the design and simulation of an intermodal ACTS connected by an RO/RO type rail system.

This study aimed to design a new intermodal ACTS via an RO/RO method that connects ports and an inland logistics hub to develop a model for simulating the system in consideration of various operation methods for container terminals. Through the development of the discrete event simulation model, the processing capacity of the system was predicted, and the optimal input equipment scale and operation method were derived. In this paper, we describe the concept and operating system of the newly designed intermodal ACTS and then discuss the development of a simulator with a general-purpose simulation system/H (GPSS/H), ultimately presenting the visualized outcomes of the simulation results using the PROOF5 program.

2. Materials and Methods

2.1. Concept of New Intermodal ACTS and Comparison with Existing Systems

Most existing ports and hinterland complexes transport freight via road or on-dock rail. In these systems, the consequent traffic congestions or emissions often become a social problem when a large volume of freight enters or exits a port via road. As an alternative to existing systems, an on-dock rail system was considered; however, this has not been implemented widely, owing to the high cost of installation of railway infrastructure, as well as the additional transshipment costs of using the lift-on/lift-off (LO/LO) railway.

The new intermodal ACTS proposed herein applies the RO/RO method to unload freight simply by connecting the chassis of a tractor, without the need for transshipment equipment such as cranes or reach stackers that are required in the LO/LO method of a general on-dock rail. Thus, the proposed ACTS can reduce transshipment times and costs, as no additional equipment is required. Moreover, the cost of installing railway grounds and piers can be eliminated by employing a freight car that is lighter than existing RO/RO container freight railways such as Modahlor, Flexiwaggon, and Cargo Speed [9]. Additionally, the installation cost of terminal platforms can be reduced by implementing the proposed ACTS, as freight cars are mechanically rotated and stopped, reducing the length of the platform and thus eliminating the need for an additional power source (as the existing railway requires).

2.2. Design of New Intermodal ACTS

The ACTS is composed of a portside terminal, a landside terminal, and a rail transportation system connecting these terminals, as shown in Figure 1. A stopping station was not considered here. In each terminal, the setup is such that neither the yard tractor (or private tractor) transporting containers nor the ACTS freight car is operated by transferring and receiving a chassis loaded with a container.

It is assumed that transportation between terminals occurs periodically as per a pre-determined schedule via rails and that it can be designed in one direction, two directions, or one direction with the implementation of avoidance methods in the planning stage, according to the required capacity.

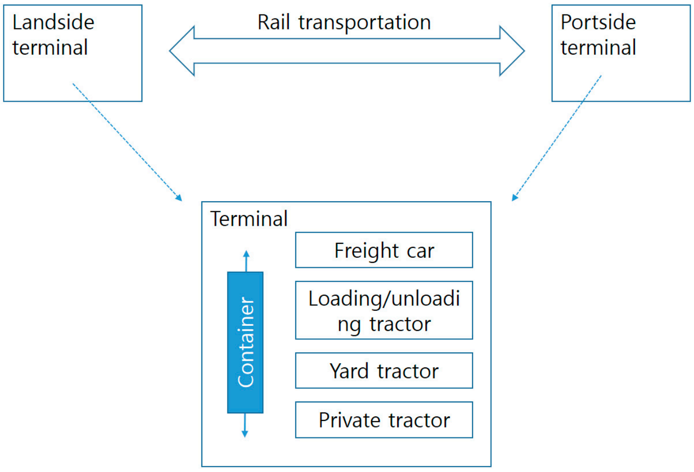


Figure 1. Conceptual diagram of the automated container transport system (ACTS).

The terminal infrastructure includes a platform, loading or unloading waiting areas, a chassis waiting area, a transshipment yard, roads, and gates. The platform is where the freight car enters the terminal; on both sides of the platform, there are loading and unloading waiting areas in which tractors wait to load and unload the chassis containers into the freight car.

Roads are spaces for terminal equipment, such as a private tractor and a yard tractor for traveling. A gate is a space for a private tractor to enter or exit a terminal. A transshipment yard is a space for transferring containers between a private tractor and a yard tractor.

Terminal equipment includes yard tractors, private tractors, loading and unloading tractors, transshipment equipment, the private chassis, and the yard chassis. The yard tractor travels only in the terminal, and it either transships the container loaded on the private chassis brought by a private tractor to the yard chassis and transports it to the loading waiting area or transfers the container to the private chassis of a private tractor by bringing the yard chassis unloaded from a freight car. A private tractor carries containers from outside the terminal to the inside or transports containers from the inside of the terminal to the outside. The transshipment equipment exchanges containers between the private chassis brought by the private tractor and the yard chassis of the terminal yard tractor. In this study, we assumed that the transshipment equipment was a crane.

Because the new intermodal ACTS was designed from the standpoint of practical use, it assumed the use of general freight tractors and yard tractors, as in most port operation cases. Additionally, the terminal entry and exit for both types of chassis were assumed by considering the cases where both a yard chassis and a private chassis are used. AGVs, which have been widely used in the recent development of automated container terminals, were not considered in this study, because they can be regarded as yard tractors moving the chassis in the proposed ACTS system.

As for the infrastructure of the rail transportation system, there is a rail connecting the terminals. As regards the equipment, there is an ACTS freight car, which transports containers between terminals by rail. The infrastructure each piece of equipment uses to transfer freight in the ACTS is shown in Figure 2.

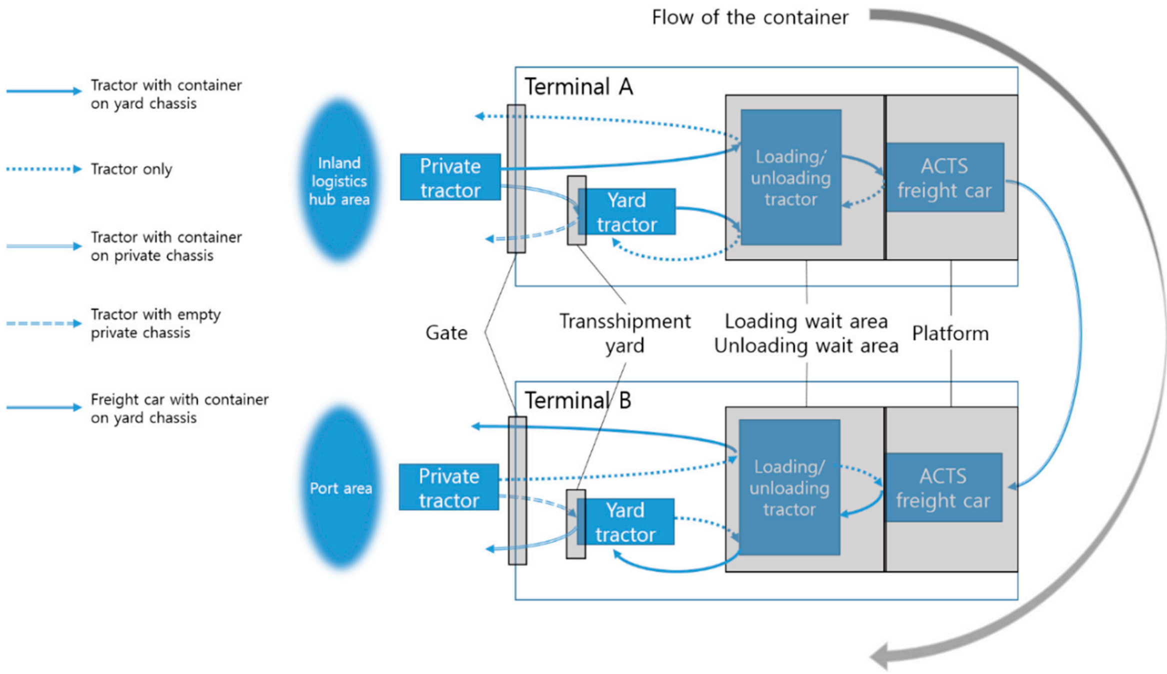


Figure 2. Freight transport system of ACTS.

The tractor loads and unloads the freight car on the platform via the RO/RO method. As shown in Figure 3, the ACTS freight car is arranged via rotation as it enters the platform. Tractors wait for a loaded chassis to be unloaded from the freight car upon the arrival of the car. Similarly, they wait for a loaded chassis to be loaded onto the freight car when the unloading finishes. Once all the chassis have been loaded, the ACTS freight cars depart and enter the platform of the opposite-side terminal by rail, and unloading or loading is performed in the same process. To generalize these activities in the terminal and apply them in the system design, the standard terminal layout was drawn as shown in Figure 4.

Figure 3. Conceptual diagram of freight unloading and loading in ACTS.

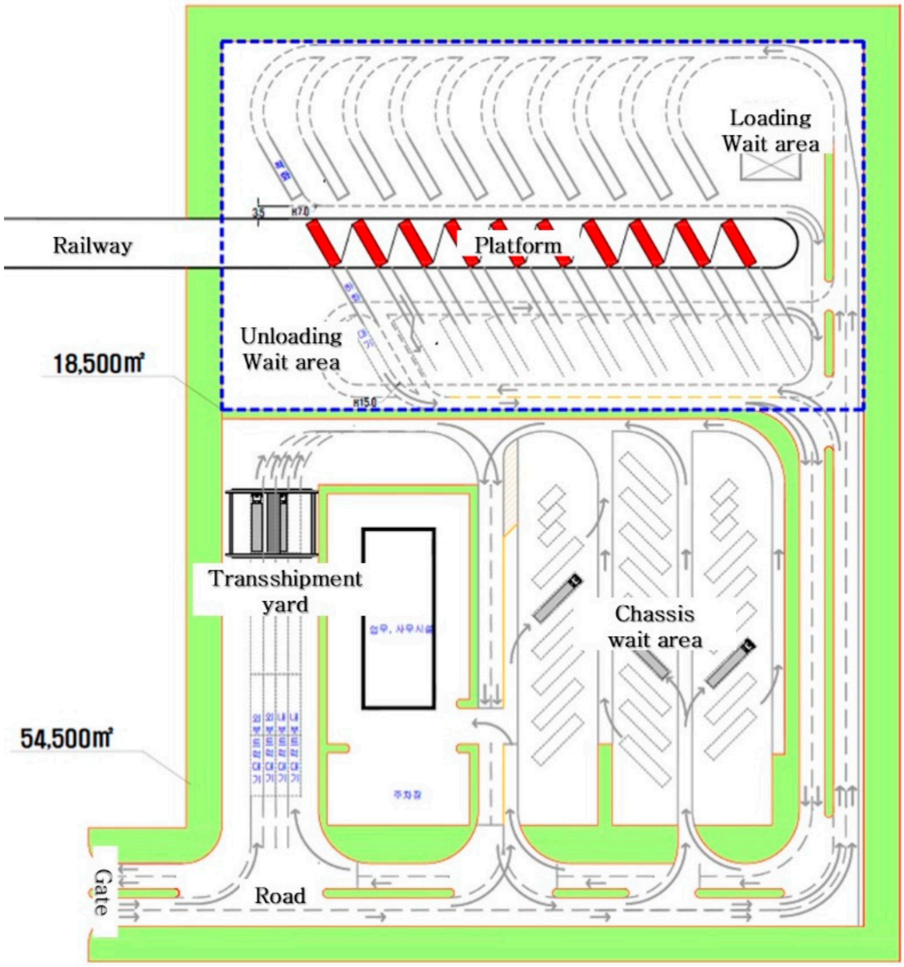


Figure 4. Standard layout of ACTS terminal.

2.3. Development of Simulation Model Using GPSS/H

In this study, we developed a new simulation program for ACTS using GPSS/H. GPSS/H provides a general, flexible, and powerful simulation environment and is widely used in various industries, such as transportation, logistics, and mining [10]. Its advantages include the following: it enables the understanding of the program logic, it allows for the quick and concise writing of a program, and it can be used on a personal computer. Because GPSS/H can model a real-world system comprising discrete events, it can be useful for simulating container terminals similar to the ACTS terminals of this study. GPSS/H was used in studies by Merkuryev et al. [11] and Alattar et al. [12] to evaluate the feasibility of a new system.

2.4. Visualization of Simulation with PROOF5

In this study, the PROOF5 program was used for the animation of the container transportation system. PROOF5 can illustrate complex systems in two or three dimensions. Two types of input files (layout and trace) are needed to implement an animation using PROOF5. The layout file defines the objects that compose the animation and the travel paths of the objects. The layout file can be created by directly drawing in PROOF5 or converting a computer-aided design (CAD) file. Trace files can be represented in codes by defining dynamic events that occur during the animation. In the trace file, the objects that appear, move, and disappear in the animation over time are specified [13].

As shown in Figure 5, we demonstrated a method for integrating the PROOF5 program and the simulator developed with GPSS/H to visualize the simulation results in the animation. The GPSS/H code (.GPS file) was created so that the simulator could output the major indicator values (.CSV file) of the transport system and input the trace file (.ATF file) to the PROOF5 program. Moreover, the trace file generated by the simulator and the layout file (.LAY file) created by the user can be input to the PROOF5 program to implement the animation.

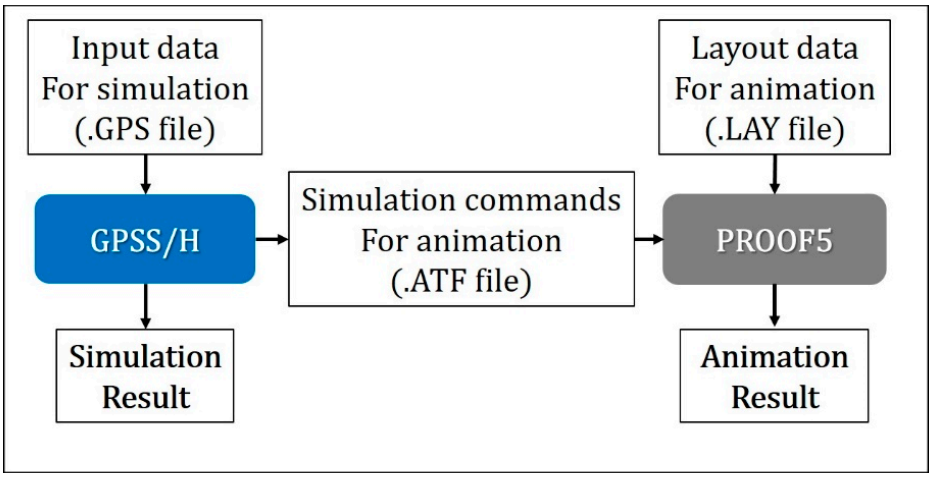


Figure 5. Method of integrating general-purpose simulation system/H (GPSS/H) simulation with PROOF5 animation.

3. Results

3.1. Simulator Development

The ACTS simulation involves two primary aspects: the freight car operation system and the terminal system. The freight car operation system performs the function of the ACTS freight car traveling back and forth between the two terminals, and the car remains in the terminal for a specific time for the loading or unloading of the chassis. In this case, it is assumed that only the loading or unloading tractors can load a freight car.

The input parameters related to running the freight car are presented in Table 1. The set-up factors are the type of rail, number of freight cars dispatched, dispatch interval of the freight cars, dispatch time of the first freight car, freight-car length (load), freight-car stay time, number of operating days, and daily operation time. The performance factors include the freight-car avoidance time on a one-direction rail and the freight-car travel time between terminals. The output factors include the mean terminal utilization and the average queue length of the freight car. The outcome factor is the maximum freight throughput.

Table 1. Indices for the intermodal automated freight transport system simulator.

Infra of terminal and tractor		Train system	
Time	**Condition**	**Time**	**Condition**
Travel time	Number of cranes	Waiting time of platform entrance	Number of trains
Transshipment time	Number of yard tractors in waiting area	Staying time of train	Number of tracks
Loading time	Number of yard tractors	Travel time between terminals A and B	Number of containers in waiting area
Unloading time	Number of private tractors	Loading time in track	Number of containers in train
Spotting time	Number of chassis	Unloading time in track	

The configuration object that operates the freight car operation system is the freight car. The operating procedure of the freight car proceeds in the following order: unloading the chassis upon arrival of the freight car in terminal A; waiting during loading; and, when loading is completed, departing to terminal B. Private tractors and yard tractors are also loaded and unloaded with containers in the waiting area.

This can be expressed as an operation algorithm, as shown in Figure 6. The working condition is defined by the tractor involved in the events occurring in the terminal. The terms indicating the working status include the work time, terminal location, type of tractor, working status, and working position. The terms for the work time include the check time (CT), travel time (TT), waiting time (QT), loading time (LT), and detachment time (DT). The terminal locations are A and B. The types of tractors include the PT (private tractor), YT (yard tractor), and WT (yard tractor in waiting area).

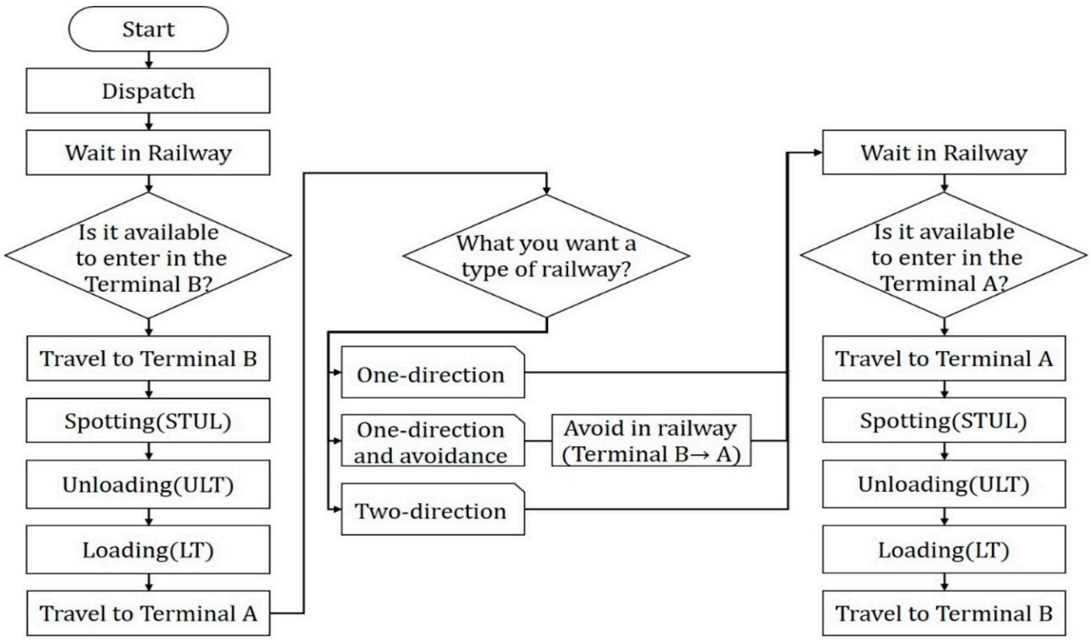


Figure 6. ACTS freight car operation algorithm.

In the terminal system, components such as the yard tractor, private tractor, loading and unloading tractors, and transshipment equipment operate according to the respective operation logic to transport containers. The terminal system is based on the following assumptions.

- Terminals A and B have the same number of components and operation logic.
- The number of tractors performing loading or unloading work is smaller than the number of freight cars.
- The yard tractors do not enter the terminal from the outside or exit the terminal from the inside.
- The private tractor moves between the transshipment yard and the loading or unloading waiting area according to the time when the freight car enters, at the rate desired by the user.
- The private tractor traveling to the transshipment yard loads the private chassis, and the private tractor traveling to the loading or unloading waiting area loads the yard chassis and departs.
- The number of chassis in the chassis waiting area is sufficient.
- In the loading or unloading waiting area, there is a yard tractor that is unloading containers with freight cars. The yard tractor first unloads the containers in the freight car and then starts loading the containers in the loading waiting area into the freight car.

The objects that transport the containers from the terminal system include private tractors, yard tractors, and loading or unloading tractors. When the ACTS arrives, the loading or unloading tractor unloads the chassis into the unloading waiting area from the freight car that arrived first. Subsequently, the chassis waiting in the loading waiting area are loaded into the freight car.

The chassis unloaded in the unloading waiting area can be divided into the yard chassis to be carried by a private tractor and those to be carried by a private tractor transshipped to the private chassis. For the yard chassis, the private tractor with no chassis loaded enters the terminal, travels to the unloading waiting area, loads the chassis, and travels outside of the terminal. For the latter case, a yard tractor carries the empty private chassis, traveling to the transshipment yard, and concurrently, a private tractor carries the empty private chassis, traveling to the transshipment yard. Thus, the transshipment of containers occurs from the yard chassis to the private chassis. The private tractor carries the container's private chassis and exits the terminal. The yard tractor, which has transshipped the container, carries the empty yard chassis and travels to the chassis waiting area.

A chassis waiting in the loading waiting area can be a yard chassis brought by a private tractor or a yard chassis transshipped by a private tractor that was loaded with container freight into a private chassis. In the former, the private tractor carries the yard chassis into the terminal, travels to the loading waiting area, and unloads the chassis, and only the tractor leaves the terminal. In the latter case, a private tractor loads a container into a private chassis, enters a terminal, and travels to a transshipment yard. Concurrently, a yard tractor carries an empty yard chassis and travels to a transshipment yard, where the transshipment of the container freight occurs from the private chassis to the yard chassis. The yard tractor transports the container-loaded yard chassis to the loading waiting area, and the yard tractor travels to the unloading waiting area to unload the chassis, as described above. The private tractor that transshipped the container freight in the transshipment yard carries an empty private chassis and exits the terminal. The operation scenario of a private tractor that directly brings the yard chassis into the loading waiting area or removes it from the unloading waiting area considers both cases of the vehicles only bringing in or removing the chassis (scenario 1). The vehicle that brings in the chassis also removes the chassis (scenario 2). These operation scenarios are shown in Figures 7–10.

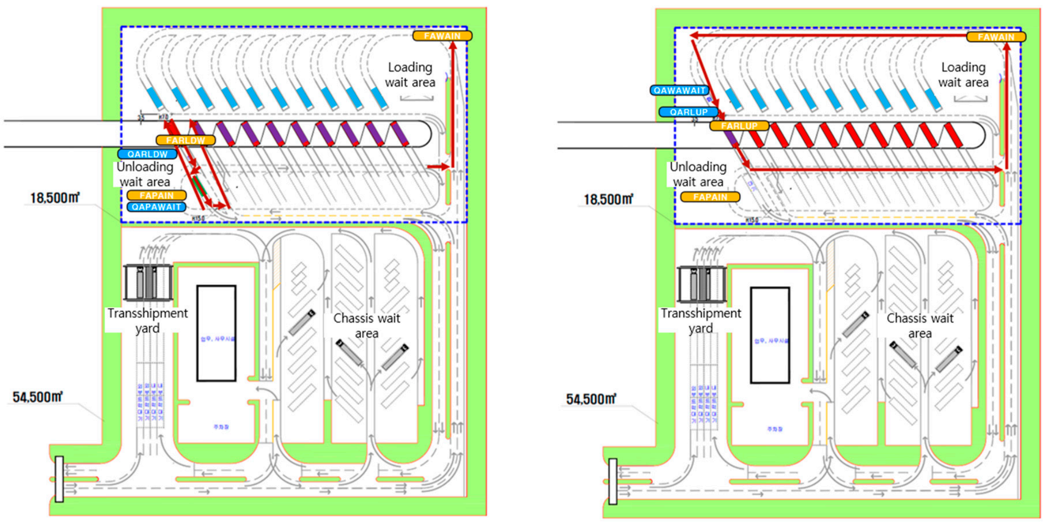


Figure 7. Operation logic for loading or unloading tractors (left: unloading; right: loading).

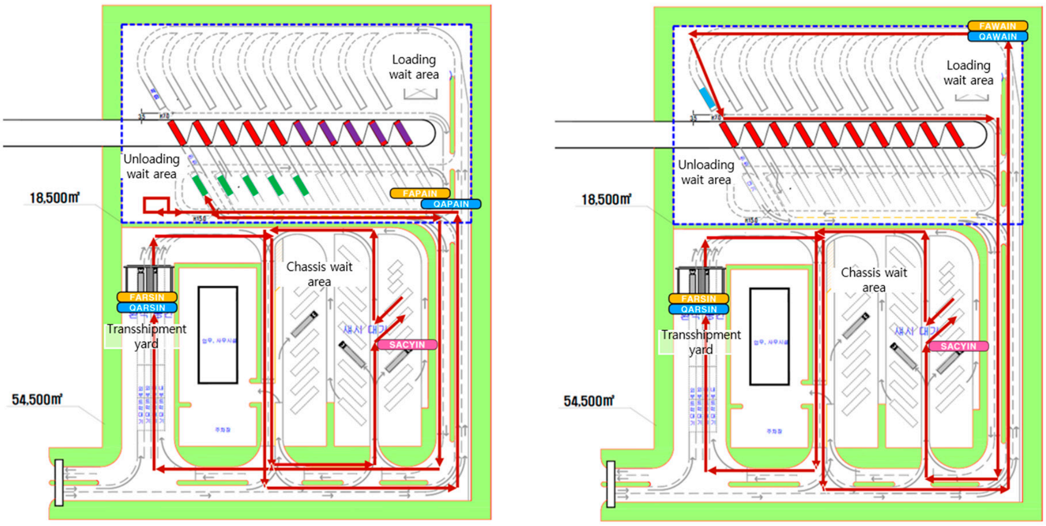


Figure 8. Operation logic for yard tractor (left: unloading; right: loading).

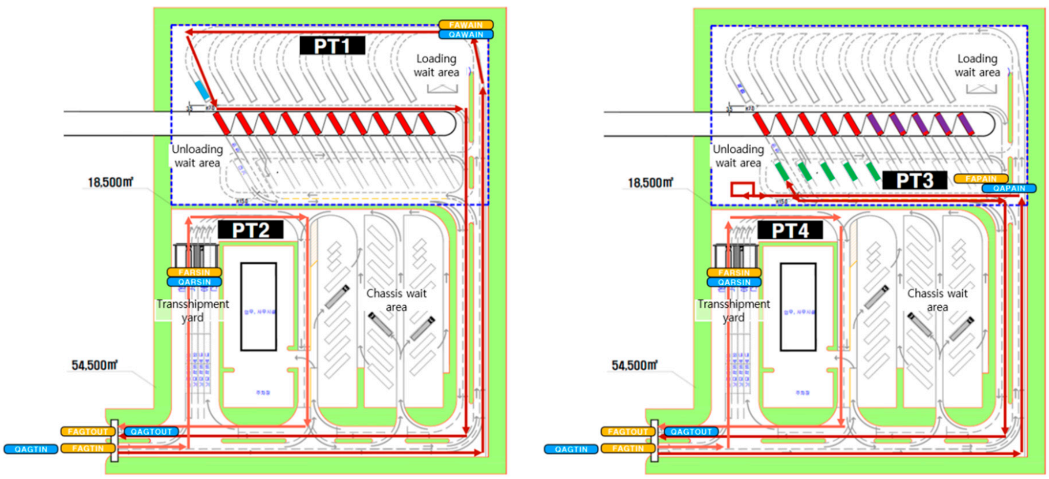


Figure 9. Operation logic for private tractor (left: loading; right: unloading).

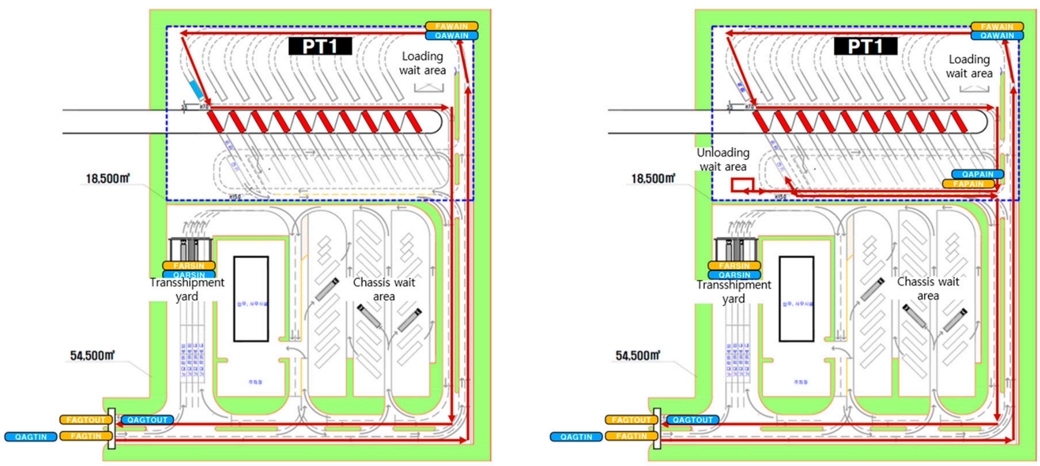


Figure 10. Operation logic for private tractor (left: loading scenario 1; right: loading and unloading scenario 2).

The operation method of each tractor object, defined previously, was modeled as follows.

- The yard tractor performs container loading or unloading operations in the waiting area.
- The work status is defined according to each tractor for events occurring in the terminal.
- The terms indicating the work conditions are expressed in the following order: the work time, terminal location, type of tractor, work status, and work location.
- The terms indicating the work time include the CT (check time), TT (travel time), QT (waiting time), LT (loading time), and DT (detachment time). The terminal locations are A and B.
- The types of tractors include PT (private tractor), YT (yard tractor), and WT (yard tractor in the waiting area).
- The work status is represented by the numbers 1–4.
- Private tractors for unloading are presented in 1 and 2, and private tractors for loading are presented in 3 and 4.
- For the yard tractor, "1" indicates the unloading work, and "2" indicates the loading work. For the yard tractor in the waiting area, "1" represents the unloading work, and "2" represents the loading work.
- Depending on where each piece of equipment works, the work location is represented as G (gate), T (transshipment yard), R (freight car platform), P (unloading waiting area), W (loading waiting area), or C (chassis waiting area).

To develop the simulation program, the work conditions of the terminal system components are defined with the following variables.

(1) Unloading operation

Private tractor (yard chassis)

- CTAPT1G: A private tractor with no chassis loaded waits at the entry gate for the entry process.
- TTAPT1P: Travels from the entry gate to the unloading waiting area.
- STAPT1P: Approaches before entering the unloading waiting area.
- LTAPT1P: Loads the chassis container unloaded in the unloading waiting area.
- TTAPT1G: Travels from the unloading waiting area to the exit gate.
- CTAPT1G: Waits at the exit gate for the exit process.

Private tractor (private chassis)

- CTAPT2G: A private tractor without a loaded chassis waits at the entry gate for the entry process.
- TTAPT2T: Travels from the entry gate to the transshipment yard.
- STAPT2T: Approaches before entering the transshipment yard.
- LTAPT2T: Transshipment of the chassis container in the transshipment yard or chassis container of a yard tractor.
- TTAPT2G: Travels from the transshipment yard to the exit gate.
- CAPT2G: Waits at the exit gate for the exit process.

Yard tractor

- TTAYT1P: A yard tractor with no chassis loaded travels to the unloading waiting area.
- STAYT1P: Approaches the unloading waiting area.
- LTAYT1P: Loads the chassis container unloaded in the unloading waiting area.
- TTAYT1T: Travels from the unloading waiting area to the transshipment yard.
- UTAYT1T: Transshipment of the chassis container to the private tractor or to the transshipment yard.
- TTAYT1C: Travels from the transshipment yard to the chassis waiting area.

Yard tractor in the unloading waiting area.

- QTAWTPP: A yard tractor with no chassis loaded waits in the unloading waiting area.
- TTAWTPR: Travels from the unloading waiting area to a freight car.
- STAWTR: Approaches before entering the unloading waiting area.
- LTAWTR: Loads the chassis container of the freight car.
- TTAWTRP: Travels from the freight car to the unloading waiting area.
- UTAWTP: Detaches the chassis container in the unloading waiting area.
- TTAWTPW: Travels from the unloading waiting area to the loading waiting area.

(2) Loading operation
Private tractor (yard chassis)

- CTAPT3G: Private tractor with a loaded chassis waits at the entry gate for the entry process.
- TTAPT3W: Travels from the entry gate to the loading waiting area.
- STAPT3W: Approaches before entering the loading waiting area.
- UTAPT3W: Detaches the chassis container in the loading waiting area.
- TTAPT3G: Travels from the loading waiting area to the exit gate.
- CTAPT3G: Waits at the exit gate for the exit process.

Private tractor (private chassis)

- CTAPT4G: A private tractor loaded with the chassis waits at the entry gate for the entry process.
- TTAPT4T: Travels from the entry gate to the transshipment yard.
- STAPT4T: Approaches before entering the transshipment yard
- UTAPT4T: Transshipment of the chassis container in the transshipment yard or chassis container of a yard tractor.
- TTAPT4G: Travels from the transshipment yard to the exit gate.
- CTAPT4G: Waits at the exit gate for the exit process.

Yard tractor

- TTAYT1T: Yard tractor with no chassis loaded travels to the transshipment yard.
- LTAYT1P: Transshipment of a chassis container in the transshipment yard or a chassis container of a private tractor.
- TTAYT1W: Travels from the transshipment yard to the loading waiting area.
- STAYT1W: Approaches before entering the loading waiting area.
- UTAYT1W: Detaches the chassis container in the loading waiting area.
- TTAYT1C: Travels from the loading waiting area to the chassis waiting area.

Yard tractor in the loading waiting area

- LTAWTW: Loads the chassis container in the loading waiting area.
- TTAWT1WR: Travels from the loading waiting area to the freight car.
- STAWTR: Approaches before entering the freight car.
- UTAWTR: Detaches the chassis container of a freight car.
- TTAWTRW: Travels from freight car to the loading waiting area

The algorithm for the development of the simulation program is described in Figures 11–14.

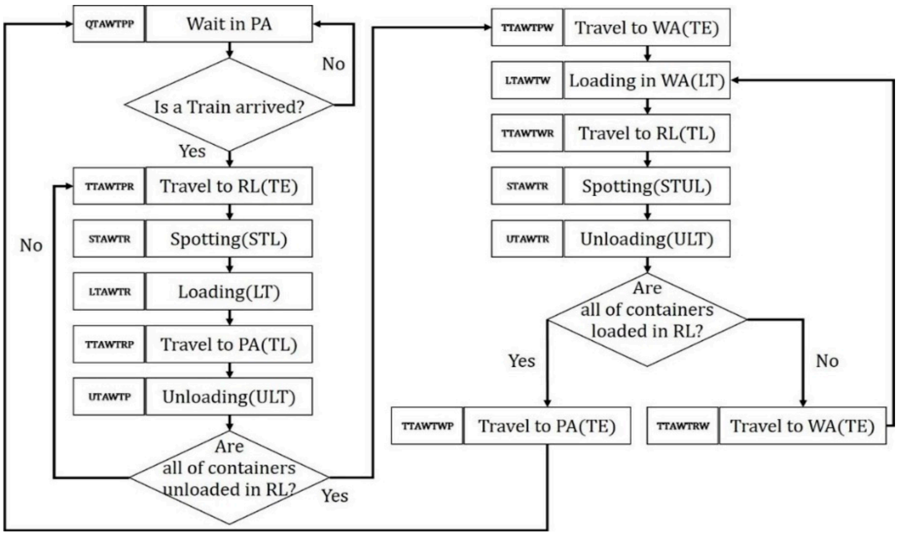


Figure 11. Simulation algorithm for loading/unloading tractor.

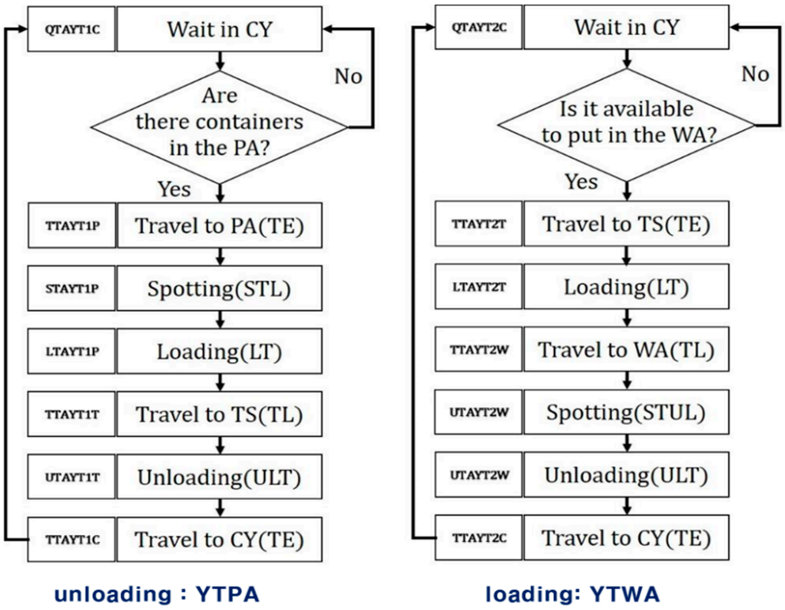


Figure 12. Simulation algorithm for yard tractor. YTPA and YTWA represent the yard tractors at the unloading and loading waiting areas, respectively.

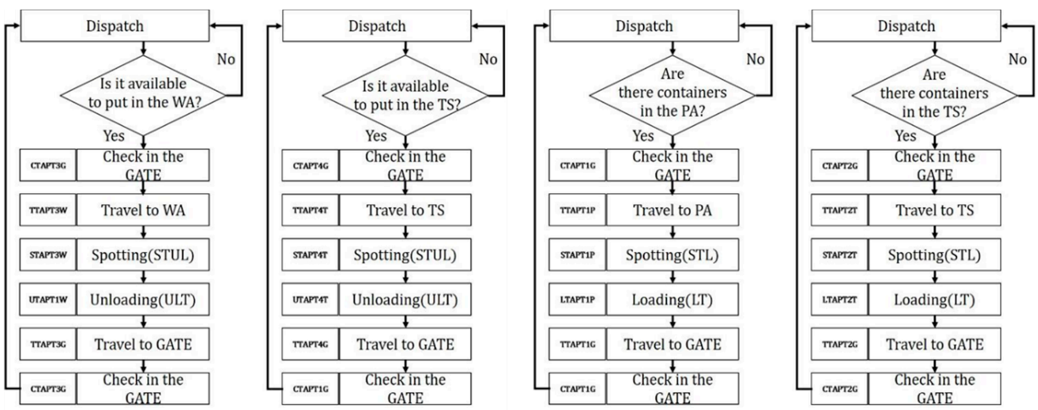


Figure 13. Simulation algorithm for private tractor (PT) (scenario 1 for yard chassis).

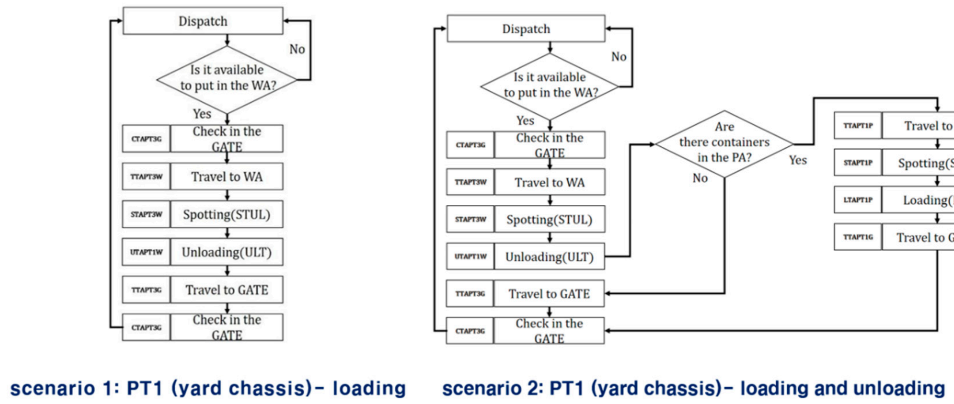


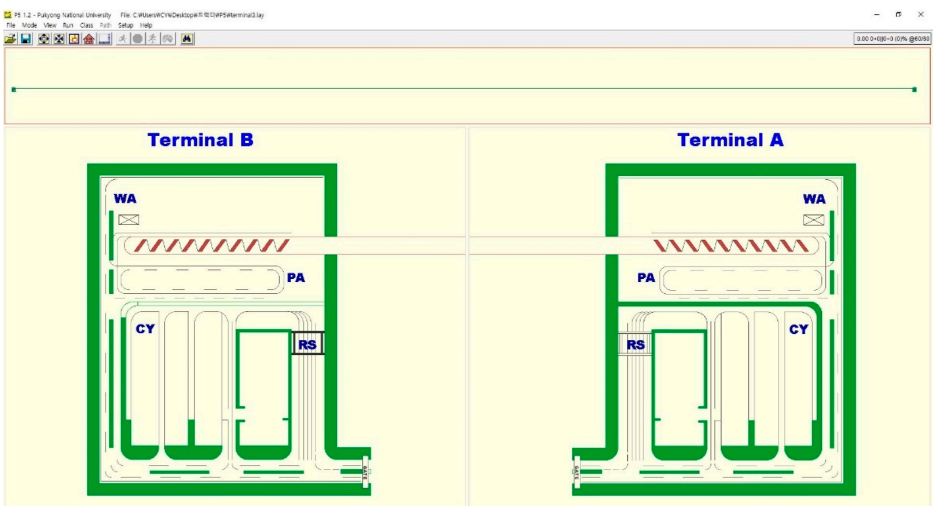
Figure 14. Simulation algorithm for private tractor (scenarios 1 and 2).

3.2. Visualization of Simulation Results

With GPSS/H, a simulation model was constructed by setting the parameters of the freight car operation system for the intermodal automated freight transport system and the tractors of the container terminal. The trace file generated as a result of the simulation was input to the PROOF5 program, and the events that appeared over time were visualized via animation (Figure 15). The schematics of container terminals A and B and the rails of the freight car are shown in Figure 15a. In this study, the events occurring in container terminals A and B were assumed to be identical; thus, we focused the demonstration on container terminal A to obtain a more detailed animation.

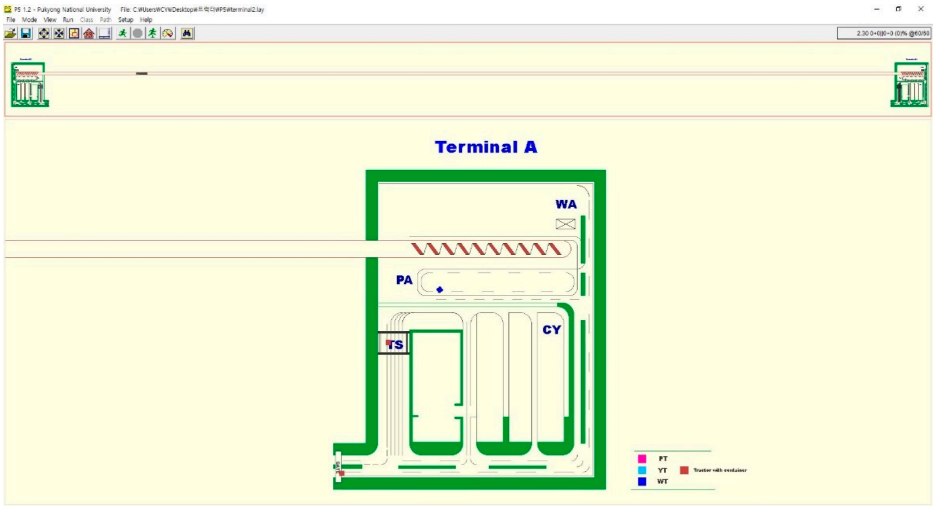
The situation in the terminal before the arrival of the freight car is as follows. To transport the container to Terminal B, the private tractor travels with the container to the loading waiting area. At this time, because the private tractor travels to the transshipment yard with a private loaded chassis, only the container is unloaded using the transshipment equipment (Figure 15b). If there is a container in the transshipment yard, the yard tractor loads the yard chassis, transships the container, travels to the loading waiting area, and unloads (Figure 15c,d)). When the freight car arrives, the yard tractor in the unloading waiting area unloads the container.

When the containers in the freight car are all unloaded, the freight car travels to the loading waiting area and loads the container in this area (Figure 15e). Thus, before and after the arrival of the freight car, tractors perform events according to the flow of the work in the container terminal.



(**a**)

Figure 15. *Cont.*



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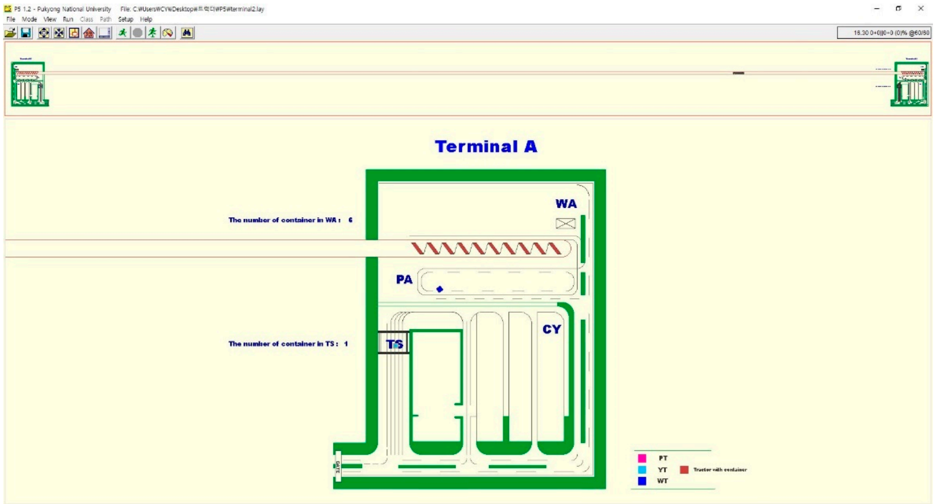

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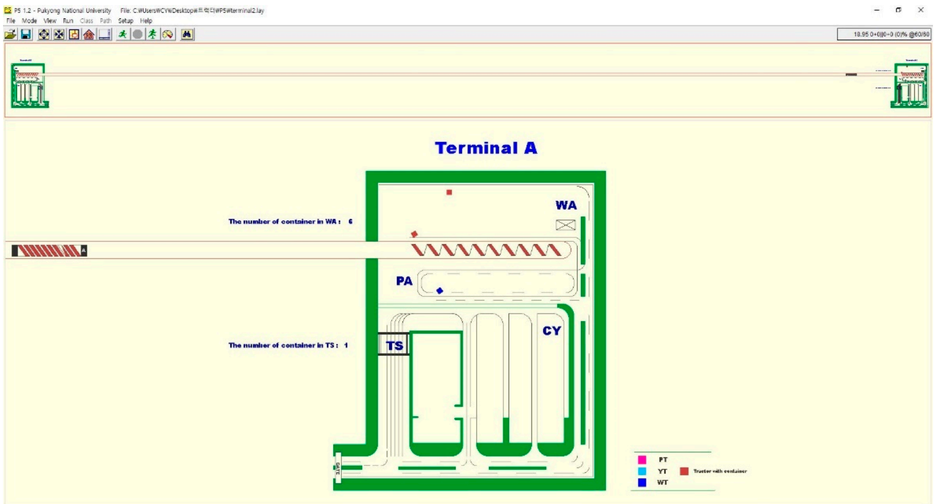
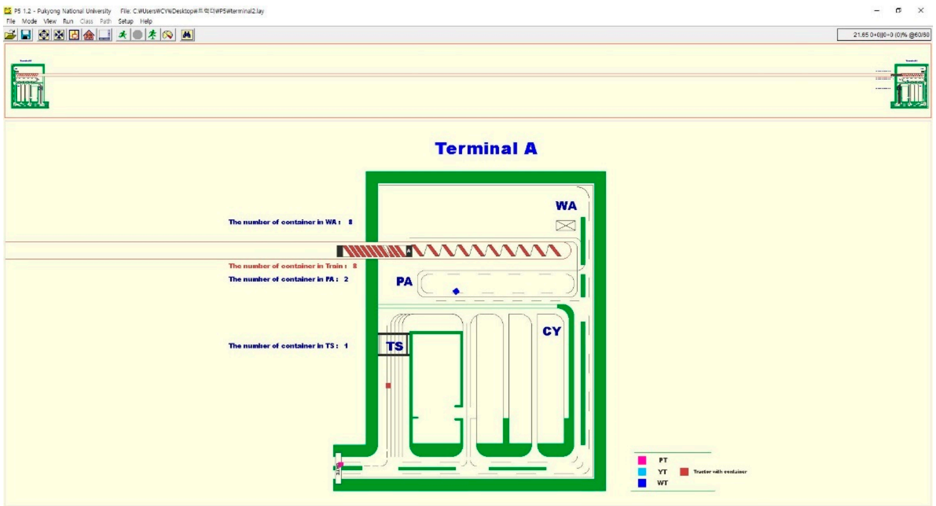


(**d**)

Figure 15. *Cont.*



(**e**)

Figure 15. Visualization of the simulation results through animation: (**a**) outline of overall system; (**b**) private tractor ACT; (**c**) yard tractor ACT 1; (**d**) yard tractor ACT 2; (**e**) yard tractor ACT in the waiting area.

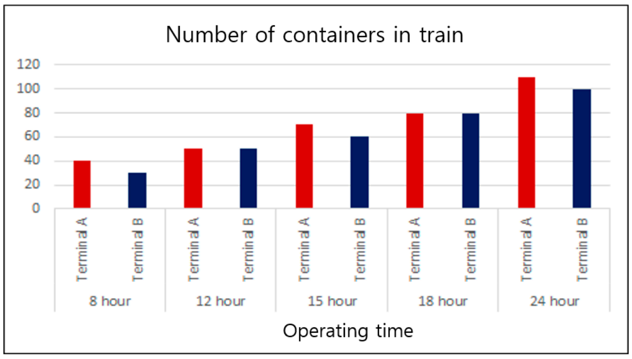
4. Discussion

The freight car operation system was simulated using the developed simulation program and the set parameters. The results varied according to the type of rail, number of freight cars dispatched, travel time between terminals, and daily operation time of the freight car and are summarized below.

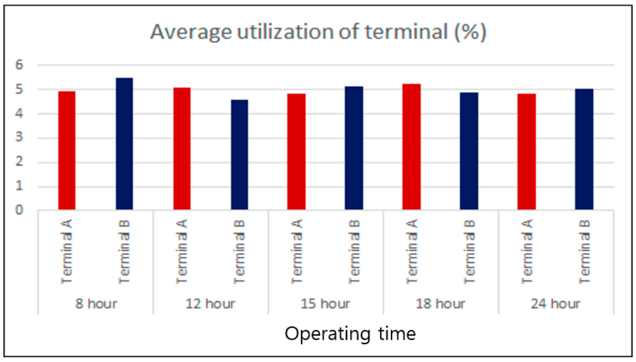
As shown in Figure 16, a freight car was dispatched in virtual terminal A. The simulation results obtained while the freight car's daily operation time was changed with the travel time between terminals set as 1 h are shown in the figure. The number of containers transported increased as the daily operation time increased, but there was no significant difference between the utilization of the terminal equipment and the utilization of the yard tractors in the terminal. This was owing to the short travel time between terminals. Therefore, another simulation was conducted in which the travel time between terminals was varied according to a daily operation time of 18 h, with high utilization and many containers transported (Figure 17). However, when the travel time between terminals was >1 h, the utilization of terminal equipment was significantly reduced. This was due to the travel speed and short loading and unloading times of the tractors operating in the terminal.

The travel time between terminals should be >1 h to justify the use of a freight car. Therefore, the simulation was performed according to a freight-car daily operation time of 18 h, with a 1 h travel time between the terminals. The rail type and the number of freight cars dispatched to each terminal were varied. In the case of a rail type of one-direction and avoidance, when a freight car traveling from terminal A to terminal B and a freight car traveling from B to A meet, the freight car dispatched in terminal A avoids the other and waits. As the number of freight cars in each terminal increases, the number of containers transported increases, and the utilization of the terminal facility and yard tractors in the waiting area also increases. However, the waiting time for freight cars dispatched in terminal A also increases rapidly (Figure 18). In the case of a two-direction rail, as the number of freight cars dispatched in the terminal increases, the number of containers transported increases, and the utilization of the terminal facility and the yard tractors in the waiting area also increases (Figure 19). In the case of two rails, on average, considering the indices, it was most advantageous to dispatch five freight cars in terminal A and four in terminal B.

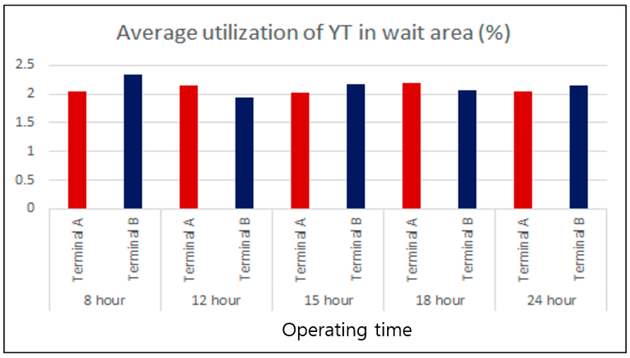
The simulation was based on the factors set in this study; more accurate results can be obtained if the actual parameters are reflected.



(**a**)

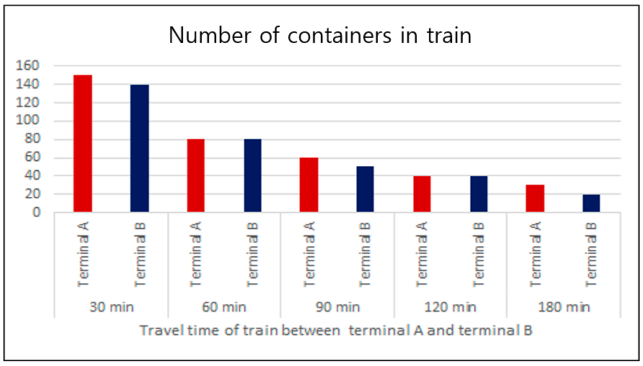


(**b**)

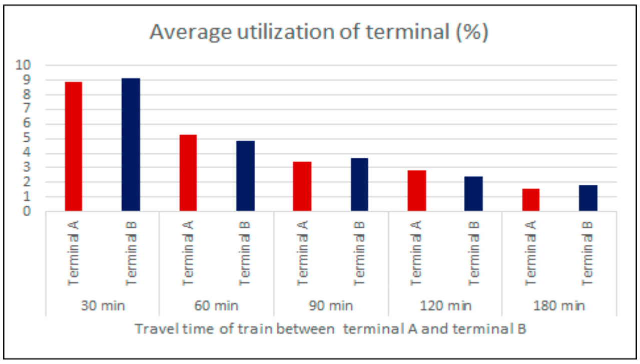


(**c**)

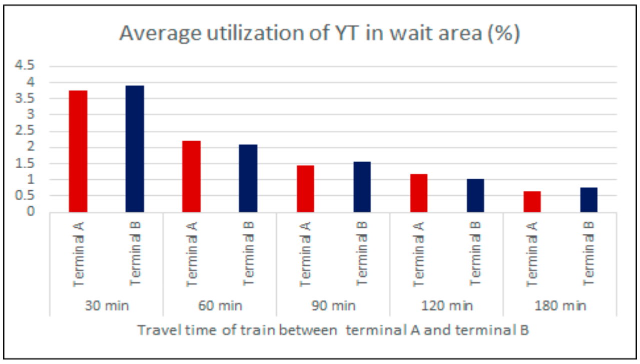
Figure 16. Simulation results for operating time in one direction with a single train, with a travel time of 1 h between terminals A and B: (**a**) number of containers on the train; (**b**) average utilization of terminal; (**c**) average utilization of yard tractor in waiting area.



(**a**)



(**b**)



(**c**)

Figure 17. Simulation results for the travel time for a one-directional rail between terminals A and B for a single train. The operating time of the train was 18 h. (**a**) Number of containers on the train; (**b**) average utilization of a terminal; (**c**) average utilization of a yard tractor in the waiting area.

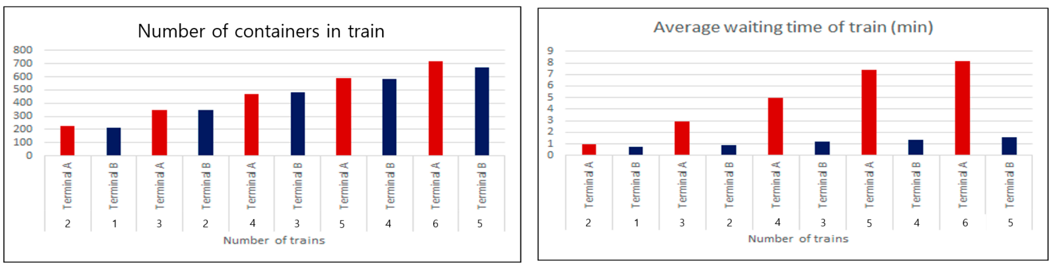
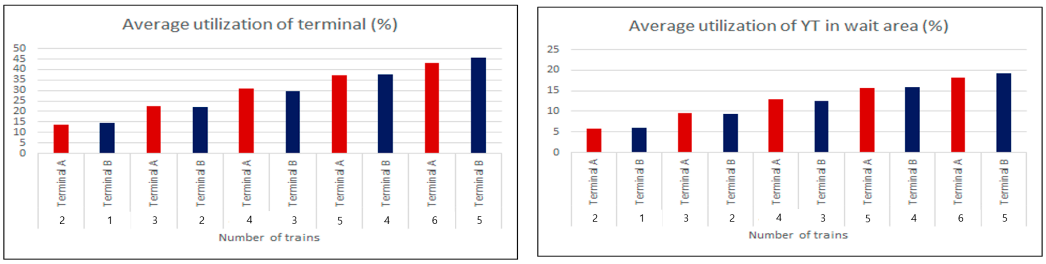


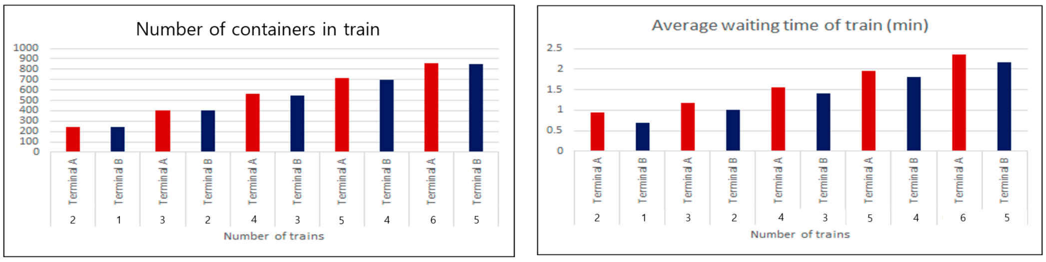
Figure 18. *Cont.*

(**a**) (**b**)

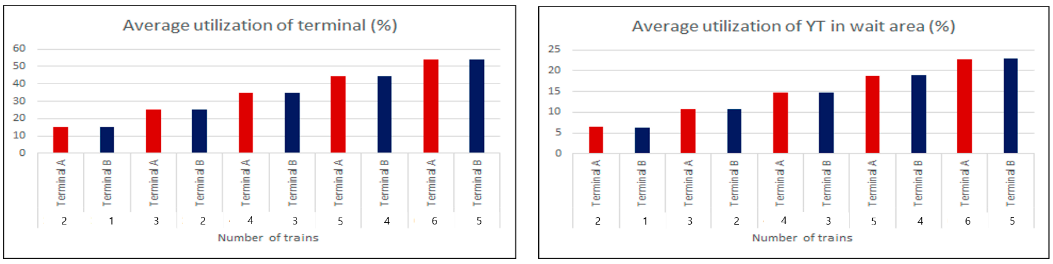


(**c**) (**d**)

Figure 18. Simulation results for number of one-directional routes and avoidances by trains, as well as the travel times between terminals A and B, with a train operating time of 18 h: (**a**) number of containers on the train; (**b**) average waiting time of the train; (**c**) average utilization of the terminal; (**d**) average utilization of a yard tractor in the waiting area.



(**a**) (**b**)



(**c**) (**d**)

Figure 19. Simulation results for number of two-directional routes with trains, as well as the travel times between terminals A and B, with a train operating time of 18 h: (**a**) number of containers on the train; (**b**) average waiting time of the train; (**c**) average utilization of the terminal; (**d**) average utilization of a yard tractor in the waiting area.

5. Conclusions

We developed a simulation program using GPSS/H to examine the system capacity and efficiency in the planning stage of the new ACTS currently under development and verified the results. This simulation program yielded numerical results indicating how the processing capacity and equipment utilization of the system changed depending on the input equipment or the operation method of private tractors. The simulation program provides numerical values of the main outcome indices, and it allows users to visually verify the algorithm and to intuitively check the events occurring in the terminal over time via an animation based on the PROOF5 program.

The simulation program that we developed models a new, unprecedented type of RO/RO rail system, and it can be used to directly connect and operate logistics hubs, such as ports and hinterland logistics complexes or ports and industrial complexes, indicating the significance of this study. As this system is still in the development stage, a limitation exists in that the actual area for implementation has not been determined. Additionally, the analysis was performed in a virtual environment based on the standard layout. At the stage of actual implementation in a specific region, the efficiency of the existing road transport-based port terminals and hinterland complex operating systems can be analyzed and compared with that of the proposed system, which can be further developed in future research.

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Conflicts of Interest: The authors declare no conflict of interest.

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