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Sensor Application: Introducing Autonomous Vehicle Technology in Loading Vehicles to a Pure Car and Truck Carrier

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More than 2 million motor vehicles are exported from the Republic of Korea annually and most of them are transported by pure car and truck carriers (PCTCs), vessels designed for the transport of motor vehicles. These vessels are equipped with multiple decks and ramps, enabling efficient loading and unloading of motor vehicles. However, loading and unloading of motor vehicles poses a particular challenge, as each motor vehicle has to be loaded and unloaded individually. In current practice, a team of drivers brings a vehicle on or off board leading to significant operational inefficiencies and increased costs. With the development of sensor and autonomous vehicle technology, vehicles are sensing their environment and performing some portions of driving tasks without human involvement. This new technology is expected to improve the current transportation and logistics system. For example, a fully automated vehicle system can replace human drivers in the loading and unloading of motor vehicles, improving the operational efficiency of PCTCs. In this study, we investigate the operational improvement when the conventional loading task is switched to autonomous driving. A microscopic traffic simulation program is utilized to represent the loading of vehicles on a PCTC with autonomous vehicle technology. The total time required to load one deck of the PCTC is compared among loading methods used to investigate the operational improvement when the autonomous vehicle technology is introduced under different operating conditions including vehicle speed and vehicle headway.

1. Introduction

The automobile industry is one of the strategic industries that has a considerable influence on the overall global economy. In particular, the domestic automobile industry is one of Korea's major industries, and more than 4 million automobiles are produced domestically annually, of which more than 2 million are exported.(1) Given that most of the exported automobiles are transported through ports, the automobile import and

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export system through ships can be considered important.[2] One of the characteristics of the import and export system of automobiles on ships is that the loading operation is highly dependent on manpower, and vehicles are loaded into a pure car and truck carrier (PCTC) only by direct driving by workers.[3] This is due to the characteristics of automobile cargo, which is the target of shipment. Unlike container cargos, where the loading work is mechanized and automated through standardization, automobile cargos, which show the characteristics of bulk cargos, are difficult to standardize and apply automation, so only human-based work is possible during shipping.[4] However, it is expected that for this type of car shipping, loading methods can be changed through the application of autonomous vehicle technology, which is currently being researched and developed around the world.[5–8] With autonomous vehicle technology, it appears that it will be possible for a vehicle to enter into a PCTC by itself. In addition, with mobile communication technology, it seems possible for a vehicle to move along the optimal route from the yard to the parking location within the ship and then to be loaded using autonomous parking technology. If an infrastructure system that supports autonomous vehicles in ports and PCTCs is developed, it is expected that the shipping work of motor vehicles can be automated.[9,10] Accordingly, Korea has recently begun the development of an "automated ship loading and discharging support system for exported and imported autonomous vehicles (AVAS)" to automate the loading operations of autonomous vehicles at ports and ships.[11,12] This research refers to a system that supports autonomous vehicles to receive shipping commands from the system and move on their own to perform shipping tasks. This technology is of high importance as it is directly mentioned in the "Digital Strategy of Korea" announced by the government.[13] The development of an AVAS is expected to considerably improve the efficiency of loading operations within a PCTC. This is because constraints such as working hours and the number of workers due to the high dependence on manpower in the existing work system can be overcome by introducing an AVAS. In addition, it is expected that work methods that are difficult to use with human resources can be used through autonomous vehicle technology. These forecasts should be confirmed in detail through simulation analysis in which AVAS is implemented.

The aims of this study are as follows. First, we aim to check the differences in traffic indicators (such as loading time and delay) according to the vehicle loading method within a PCTC. Second, we aim to compare changes in shipping efficiency and derive implications when autonomous vehicle technology is applied to car loading operations within the PCTC.

2. Sensor Data and Methods

This study was conducted according to the flow shown in Fig. 1. First, a research methodology was set up to analyze the shipping efficiency of PCTCs. A Hyundai Glovis SPIRIT ship and Pyeongtaek International Terminal were used in the analysis, and data related to the targets were collected. The research assumptions were established using the collected data.

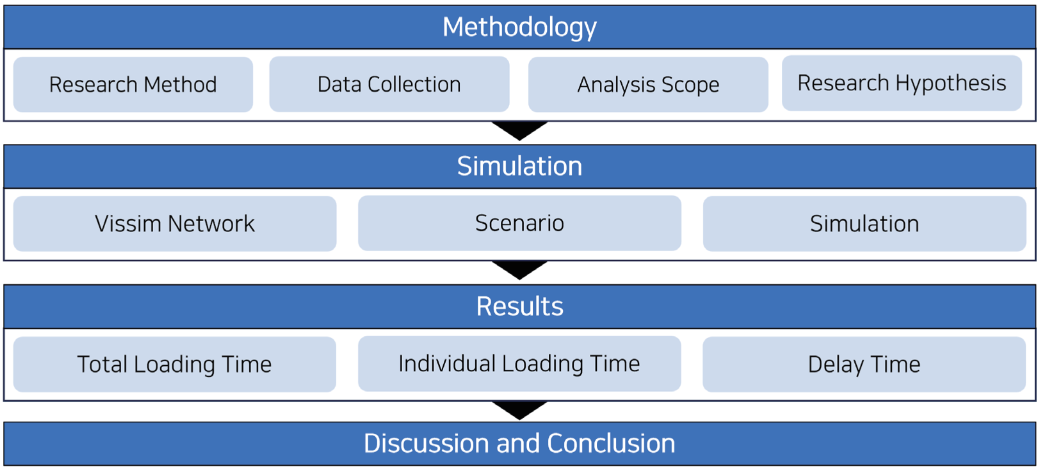

Fig. 1. (Color online) Research flow.

On the basis of the collected data and scenarios, the operational difference between the autonomous vehicle technology for loading vehicles onto a PCTC and conventional loading methods needs to be analyzed. There are multiple ways of estimating the traffic operational difference among different loading methods. Field experiments with actual autonomous vehicles would be unrealistic since it will require permission from related government agencies and approval from companies involved in this process. For these reasons, traffic simulation was utilized to measure the differences in this study. A traffic simulation program can regenerate the traffic conditions with good precision and is considered an alternative method with significantly low cost and time.

A network was built using a commercial microscopic traffic simulation program, Vissim. Vissim is a discrete, stochastic, time-step-based microscopic simulation model. This multipurpose traffic simulation program has been developed to model a wide range of traffic conditions including freeway, arterial, and public transit operations. In the simulation, scenarios were set up with different loading methods, loading orders, and speed limits. Afterward, analysis was performed for each scenario and the results were compared. The total loading time, average loading time per vehicle, and average delay per vehicle were analyzed. Finally, discussions were made and conclusions were drawn from the analysis results.

2.1 Data collection

PCTCs are vessels designed exclusively for loading automobiles and are capable of transporting bulk cargo, including automobiles and heavy equipment, to loaded trailers. In this study, we selected Glovis SPIRIT shown in Fig. 2, which belongs to Hyundai Glovis, as a PCTC capable of loading 6500 passenger cars, which is used as a standard for the PCTC market in the international shipping industry.[14] A drawing of the internal structure of the ship was obtained and the network of the ship was established.[15,16] Table 1 shows the specifications of the Glovis SPIRIT.

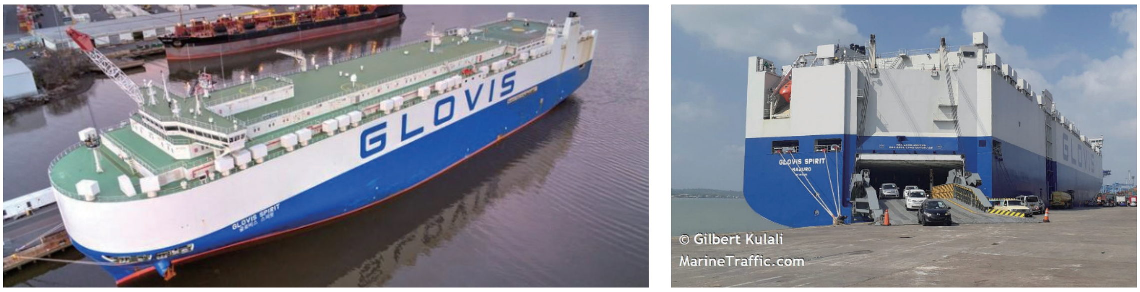

Fig. 2. (Color online) Hyundai Glovis SPIRIT.[15]

Table 1
Hyundai Glovis SPIRIT Specifications.[16]

Description	
Year built	2013
Length overall (m)	199.97
Breadth extreme (m)	35
Gross tonnage (t)	64650
Summer deadweight (t)	20138
Capacity (AEU)	6641

An automobile-only port specializes in handling automobiles as cargo and is equipped with equipment for loading and unloading finished automobile products such as passenger cars and trucks. In this study, Hyundai Glovis Pyeongtaek International Terminal was selected as the analysis site[17] because it is a major port that has ranked first in the country for 13 consecutive years, handling the import and export of more than 1 million automobiles annually.[18] Data were collected by visiting the terminal, conducting interviews with officials, and checking the actual work process.

The workforce composition and daily work schedule were confirmed when loading cars at Hyundai Glovis Pyeongtaek International Terminal, and the details are shown in Table 2. First, at Pyeongtaek International Terminal, a team is used as the minimum unit of personnel involved in car loading. One team consists of a total of 16 people, including 1 foreman, 1 signalman, 1 guide, 2 shuttle drivers who drive the shuttle back to the yard, 3 kickers (parkers), and 8 automobile drivers. Therefore, during loading operations, personnel travel back and forth between the ship and the yard, transporting eight vehicles per team at a time. The number of teams deployed varies depending on the size of the ship, and it was confirmed that three teams were deployed on the ship in this study. The daily work schedule at Hyundai Glovis Pyeongtaek International Terminal is divided into a total of 6 sessions.

2.2 Simulation network

Vissim is a microscopic traffic simulation software program developed by PTV, Germany, in 1992 to model various means of transportation.[19–25] Vissim provides various functions to implement transportation facilities that exist in reality, such as highways, city streets,

Table 2
Hyundai Glovis Pyeongtaek International Terminal Daily Work Schedule.

Description	Time	Minutes in working
Session 1	07:40–09:20 (including 10 min break)	90 min
Break	09:20–09:40	
Session 2	09:40–11:10 (including 10 min break)	80 min
Lunch	11:10–12:40	
Session 3	12:40–14:10 (including 10 min break)	80 min
Break	14:10–14:40	
Session 4	14:40–16:10 (including 10 min break)	80 min
Dinner	16:10–17:10	
Session 5	17:10–18:40 (including 10 min break)	80 min
Break	18:40–19:10	
Session 6	19:10–20:40 (including 10 min break)	80 min
Total		8 h 10 min

roundabouts, and bus lanes. Moreover, it simulates traffic flows that appear through interactions between vehicles on the basis of a car-following model. In this study, Vissim was used as an analysis tool using the Car Park Creator function that supports a parking lot model. This function provides input variables to describe the vehicle's parking behavior. Also, various behaviors can be implemented by adjusting the parking direction, parking space entry speed, and parking order.

A Vissim network was modeled on the basis of the Car Loading Plan, which indicates the vehicle arrangement sections given by the ship's drawing data. Because there is a limitation that it takes a considerable amount of time to implement all layers, one of the 12 floors was selected to build the network. In this study, the 6th floor (Deck 6) of the Glovis SPIRIT was selected because the number of loading units per floor was close to the median among all 12 floors. The Car Loading Plan image of the 6th floor is shown in Fig. 3. The image shows that the left side is the front part of the ship (bow), and the right side is the rear part (stern) of the ship.

The ramps connected to the 6th floor include two inner ramps connecting the 5th and 6th floors and the 6th and 7th floors, and one side ramp directly connecting the 6th floor and the pier. Therefore, there are a total of 3 ramps on the 6th floor. Since the two inner ramps are movable (foldable), more vehicles can be accommodated by storing the ramps. The total number of vehicles that can be loaded on the 6th floor is 733. However, the car loading plan presented in Fig. 4 represents the arrangement plan in a situation where the loading vehicle enters the 6th floor directly through the side ramp and parks forward on the entire 6th floor, that is, the maximum number of loaded vehicles.

However, this plan is premised on the use of a side ramp directly connected to the 6th floor, and actual vehicle loading operations mainly use the ramp located at the stern of the 5th floor of the ship. Therefore, in this study, it was assumed that all vehicles entered through the ramp on the 5th floor of the ship, and the vehicle placement space was determined excluding the inner ramp between the 5th and 6th floors. As a result, the total number of units shipped was set at 681.

On the basis of the above assumptions, a network of the 6th floor was modeled, and the process is as follows. As shown in Fig. 5, parking paths were constructed along the outside of the

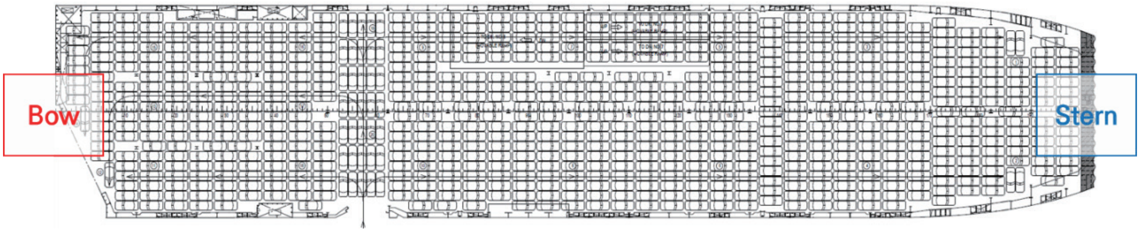

Fig. 3. (Color online) Simulation layout.

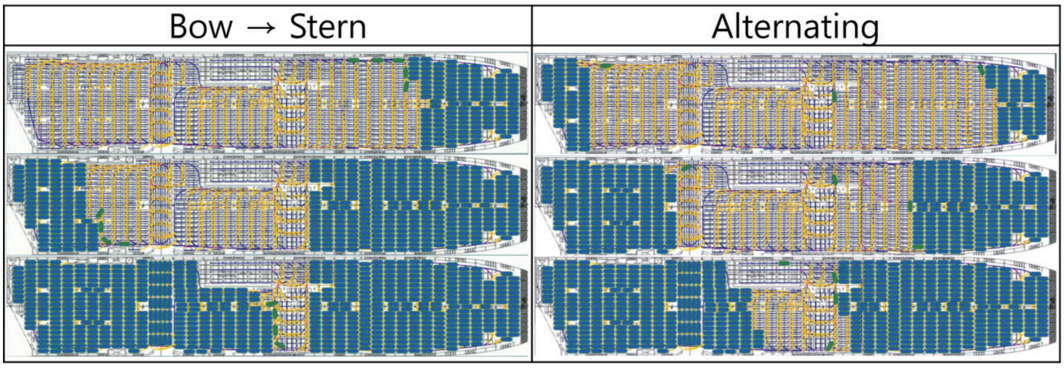

Fig. 4. (Color online) Processes of loading orders.

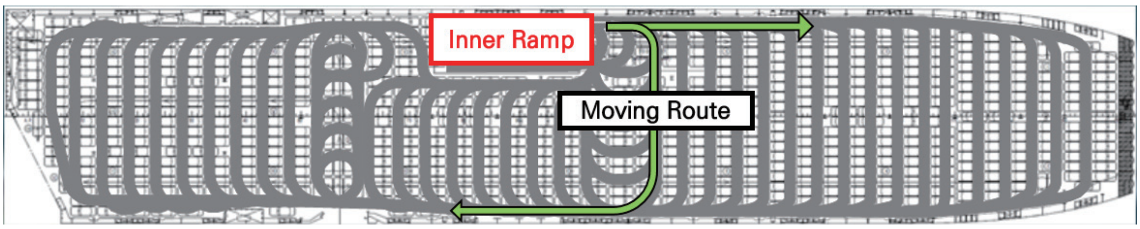

Fig. 5. (Color online) Parking paths.

6th floor to allow overall movement from the inner ramp. In addition, a grid-like network was built to allow movement to individual parking spaces without disturbing the loaded vehicles.

After building the network, parameters related to the driving behavior and parking behavior of the autonomous vehicle were set. Vissim implements the driving behavior of individual vehicles according to the parameters of the car-following model based on the Wiedemann model.(26) The Wiedemann model includes the Wiedemann 74 and 99 models, which are used to implement the driving behavior of each vehicle on freeway traffic and urban traffic, respectively. CoEXist, which presented values for each parameter of autonomous vehicles, recommended the use of the Wiedmann 99 model, which has more types of driving parameter than the other model.(27) Moreover, CoEXist divided autonomous driving behaviors into four levels and presented parameters for each level. In this study, the 'All-Knowing' values were applied. Each parameter and description applied in this study are shown in Table 3.(28)

Table 3
Car-following model parameters.

Parameters	Description	Vissim default	All-knowing
CC0	Standstill distance (m)	1.5	1.0
CC1	Gap time distribution (s)	0.9	0.6
CC2	‘Following’ distance oscillation (m)	4	0
CC3	Threshold for entering ‘Following’	−8.0	−6.0
CC4	Negative speed difference	−0.35	−0.1
CC5	Positive speed difference	0.35	0.1
CC6	Distance dependency of oscillation	11.44	0
CC7	Oscillation acceleration (m/s^2)	0.25	0.1
CC8	Acceleration from standstill (m/s^2)	3.5	4.0
CC9	Acceleration at 80 km/h (m/s^2)	1.5	2.0

Also, the vehicle’s loading work schedule set was different between manual loading and automatic loading. In the case of manual loading, the driver in the team manually drives and loads the vehicle. To implement this in simulation, the ‘Time Interval of Vehicle Input’ was adjusted and set by referring to the daily work schedule collected at Pyeongtaek International Terminal.

In the case of automatic loading, the vehicle is loaded by moving the vehicle without a driver through autonomous vehicle technology. Therefore, it is necessary to implement a situation where individual vehicles continuously enter the network at regular intervals, rather than an actual daily work schedule. In this study, analysis was performed by fixing the vehicle entry interval to 5 s using the component Object Model Application Programming Interface (COM API) function provided by Vissim.

2.3 Scenarios

To confirm changes in shipping operations due to the introduction of autonomous vehicle technology, a total of seven scenarios were constructed according to the loading method, loading order, and travel speed, as shown in Table 4.

The loading method refers to whether autonomous vehicle technology was introduced or not. Manual loading is the current method of loading vehicles by group using the working schedule from Hyundai Glovis Pyeongtaek International Terminal. In contrast, automatic loading continuously loads individual autonomous vehicles.

The loading order was set to make different parking sequences inside the vessel according to the loading method. For example, in the ‘Bow → Stern’ loading order as in Table 4, vehicles were parked near the bow and then loaded near the stern. In the ‘Alternating’ loading order, vehicles were parked on both sides of the ship one by one. The processes of both loading orders are shown in Fig. 4.

Travel speed was set at the speed limit of Pyeongtaek International Terminal for the manual loading scenario. For the automatic loading scenario, the travel speed limits were set at 20, 30, and 40 km/h to confirm the effect of travel speed.

Table 4
Scenarios.

Scenario	Loading method	Loading order	Speed limit
1	Manual	Bow → Stern	30 km/h
2	Automatic	Bow → Stern	20 km/h
3	Automatic	Bow → Stern	30 km/h
4	Automatic	Bow → Stern	40 km/h
5	Automatic	Alternating	20 km/h
6	Automatic	Alternating	30 km/h
7	Automatic	Alternating	40 km/h

In this study, three simulation indicators were used to compare simulation results. The total loading time means the time required to load vehicles on one deck of PCTC to complete the loading operation. It was calculated by measuring the time from the entry of the first vehicle to the completion of parking of the last vehicle. The average loading time per vehicle means the average time spent in the network until the loading work of each vehicle is completed. The average delay per vehicle was measured by the "Vehicle In Network" function in Vissim during the simulation.

3. Results

Before confirming the simulation results for each scenario, the simulation model was verified to confirm the validity of the simulation results. The accuracy of the simulation was evaluated on the basis of the average number of loading units per hour of an actual team.

The actual average number of loading units per hour of the team working at Pyeongtaek International Terminal is 76.66. In this study, the total loading time of scenario 1, which was applied to the manual loading method was 3 h, 31 min, and 40 s. The break time during the total loading time was 40 min. The number of loading units per hour was 238.02 units based on only the working time excluding the break time. In this model, it was assumed that three teams were put in, so the average number of loading units per hour of a team in the simulation was 79.34 units. Therefore, the error rate of the simulation model was about 3.5%, showing quite high accuracy.

Table 5 shows the total loading time for each scenario. In the case of the automatic loading method, it was confirmed that the total loading time was significantly reduced compared with the manual loading method. Scenarios 2, 3, and 4 using the 'Bow-Stern' loading order showed that their total loading time was reduced by about 48% compared with scenario 1. Scenarios 5, 6, and 7 using the 'Alternating' loading order showed their total loading time reduced by about 69% compared with scenario 1. From these results, the estimated time saving for uploading would be approximately 30 h (12 floors times 2 h and 30 min). Considering that conventional loading with human drivers cannot be conducted during night time, the theoretical time saving would be two days. It is still not clear when fully autonomous vehicle technology will be introduced in loading vehicles. There might be an in-between state, for example, autonomous vehicle technology with human drivers partially involved. Also, regulations and companies would require additional safety measures, and their loading process might involve using a

Table 5
Total loading time.

Scenario	Loading method	Loading order	Speed limit	Total loading time	Reduction rate
1	Manual	Bow → Stern	30 km/h	3 h 31 min 40 s	—
2	Automatic	Bow → Stern	20 km/h	1 h 49 min 38 s	48.2%
3	Automatic	Bow → Stern	30 km/h	1 h 48 min 44 s	48.6%
4	Automatic	Bow → Stern	40 km/h	1 h 48 min 18 s	48.8%
5	Automatic	Alternating	20 km/h	1 h 5 min 39 s	69.0%
6	Automatic	Alternating	30 km/h	1 h 4 mins51 s	69.4%
7	Automatic	Alternating	40 km/h	1 h 4 min 30 s	69.5%

Table 6
Total loading time.

Scenario	Loading method	Loading order	Speed limit	Average loading time per vehicle	Increased average loading time per vehicle
1	Manual	Bow → Stern	30 km/h	2 min 10 s	—
2	Automatic	Bow → Stern	20 km/h	26 min 44 s	24 min 34 s
3	Automatic	Bow → Stern	30 km/h	25 min 52 s	23 min 42 s
4	Automatic	Bow → Stern	40 km/h	25 min 26 s	23 min 16 s
5	Automatic	Alternating	20 km/h	3 min 26 s	1 min 16 s
6	Automatic	Alternating	30 km/h	2 min 39 s	29 s
7	Automatic	Alternating	40 km/h	2 min 17 s	7 s

Table 7
Average delay.

Scenario	Loading method	Loading order	Speed limit	Average delay per vehicle	Increased delay per vehicle
1	Manual	Bow → Stern	30 km/h	25 s	—
2	Automatic	Bow → Stern	20 km/h	24 min 11 s	23 min 46 s
3	Automatic	Bow → Stern	30 km/h	24 min 7 s	23 min 42 s
4	Automatic	Bow → Stern	40 km/h	24 min 6 s	23 min 41 s
5	Automatic	Alternating	20 km/h	53 s	28 s
6	Automatic	Alternating	30 km/h	55 s	30 s
7	Automatic	Alternating	40 km/h	57 s	32 s

combination of autonomous vehicles and human drivers. Therefore, the time-saving estimates would vary depending on future operating conditions. However, it can be concluded that autonomous vehicle technology has the potential to significantly reduce time and workforce in loading vehicles.

Table 6 shows the average loading time per vehicle for each scenario. In the case of the automatic loading method, it was confirmed that the average loading time per vehicle was significantly increased compared with the manual loading method. Scenarios 2, 3, and 4 using the 'Bow-Stern' loading order showed that their average loading time per vehicle was increased by about 23 min compared with scenario 1. Scenarios 5, 6, and 7 using the 'Alternating' loading order showed that their average loading time per vehicle increased by at least 7 up to 1 min compared with scenario 1.

Table 7 shows the average delay per vehicle for each scenario. In the case of the automatic loading method, it was confirmed that the delay was significantly increased compared with the manual loading method.

Scenarios 2, 3, and 4 using the 'Bow-Stern' loading order showed that their average delay was increased by about 23 min compared with scenario 1. Scenarios 5, 6, and 7 using the 'Alternating' loading order showed an increased delay by about 28 s compared with scenario 1.

4. Conclusion

According to the simulation analysis, it was confirmed that the change of the loading method from manual to automatic decreased the total loading time by more than 48% compared with manual loading. In addition, the change in the loading order also decreases the total loading time by more than 69% compared with the currently used loading order. However, the change in travel speed showed relatively insignificant differences in total loading time. The average loading time per vehicle and delay per vehicle were considerably affected by the headway of vehicles and the time required for parking. The loading method would have impacts since the conventional method requires human drivers' turnaround time and break time, whereas autonomous driving technology would eliminate these times. Also, the loading order would make a significant difference since parking in the front and back of the ship would reduce the vehicles' waiting time at the parking spot. However, the speed limit does not significantly increase the efficiency of loading, since a significant portion of time is dedicated to the parking process, not the moving process from the yard to the parking spot.

In this study, we investigated the operational improvement of loading vehicles on PCTCs when autonomous vehicle technology is introduced. Since the introduction of autonomous vehicle technology reduced the total loading time, it has been demonstrated that the technology can improve the loading operation of vehicles into PCTCs. Autonomous vehicle technology also has the great potential to additionally improve loading efficiency by applying new operation methods such as changing the loading order. Therefore, operational improvement of loading vehicles onto PCTC requires not only technological development but also the study of a proper operation plan.

As limitations of this study, the simulation was conducted at only one deck. It is necessary to analyze all decks of a ship. In this study, we unified the size of the loading vehicle unit. It is necessary to use various vehicles for practical research. In addition, in this study, we focused only on loading vehicles onto the PCTC, but loaded vehicles must be unloaded. Thus, it is necessary to study the effect of autonomous vehicle technology on unloading vehicles.

In this study, the conventional loading process and the loading process with autonomous vehicle technology were analyzed. These processes are based on simple assumptions of the loading process. Understandably, this assumption is one of the limitations of this analysis. For the conventional loading process, human driver behavior was assumed to follow the default values provided in Vissim. However, the drivers in this process may have different driving characteristics. It is anticipated that the different driving characteristics of drivers will not make a significant difference in this analysis since the main point of this study was to investigate the operational improvement of loading vehicles into the PCTC when autonomous vehicle technology is introduced. However, it will require a precise calibration of driving parameters for more detailed analysis.

It is anticipated that other factors will also impact the operation of loading vehicles into PCTCs when autonomous vehicle technology is introduced. It is still not clear when fully autonomous vehicle technology will be introduced in loading vehicles. There might be an in-between state, for example, autonomous vehicle technology with human drivers partially involved. Also, regulations and companies would require additional safety measures, and their loading process might be using a combination of autonomous vehicles and human drivers. These factors will be investigated as future research topics.

Acknowledgments

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