

Article

Simulation Modelling for Automated Guided Vehicle Introduction to the Loading Process of Ro-Ro Ships

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Abstract: This paper aims to introduce the adaptation of automated guided vehicles (AGVs) in the car-loading process of Ro-Ro ships compared with the current loading process. This study analyzed the applicable scenarios for the AGVs' adaptation in a Ro-Ro port, employing Arena simulation to compare the productivity of the loading processes. The results revealed that the adaptation of the AGVs in the car-loading process of the Ro-Ro ships improves productivity and solves several problems of the current loading process. With 21 or more AGVs, the entire processing time is similar to or less than the current loading process, whereas, after 40 AGVs, it stayed the same. Furthermore, as the number of AGVs increases, the transfer time decreases, but the queue becomes longer. Identifying the effect of the AGV adaptation, this study provides valuable insights for developing the various traffic situations in Ro-Ro port operations.

Keywords: automation; automated guided vehicles; Ro-Ro port; vehicle loading process; productivity



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1. Introduction

With an increase in global seaborne trade and the volume in port terminals, cargo loading/unloading operations have become important in reducing vessel turnaround time [1]. To increase the port operational efficiency, automated guided vehicles (AGV) have been employed at a number of terminals, including the Europe Combined Terminal (ECT) in Rotterdam and the Container Terminal Altenwerder in Hamburg, among others [2]. The adaptation of these AGVs is expected to increase in the future because these unmanned vehicles can reduce safety concerns, labor shortages, and operational costs [3]. Therefore, global container terminals strive to expand the scope of the automation system, with machines carrying out their own loadings, and several studies related to AGVs introduction have been conducted. For instance, the effectiveness measure of a container terminal from a number of employed AGVs was simulated and pointed out the importance of the appropriate choice of both numbers of employed AGVs and the AGVs dispatching rule [4]. Although prior studies focused on container cargo handling, few studies have been conducted on car carriers, the Ro-Ro (roll-on and roll-off) system for the loading/unloading process. Generally, the cargo loading/unloading operation at Ro-Ro terminals requires more stevedores than other cargo terminals as the vehicles depend on drivers for loading and unloading. A gang of stevedores is composed of a supervisor (foreman), a hatch boss, a signalman, a key car, a driver, a van driver, and a lasher. The number of total gangs is decided according to the ship capacity. Several groups of drivers drive and park their cars on board while lashers work on the deck. Due to the nature of these tasks, they are challenging to carry out in an unmanned or mechanized form, so the current Ro-Ro system is heavily dependent on human resources.

Scholars have noted two problems with the current loading process: labor shortages and car accidents that could lead to vehicle damage, mainly during the loading/unloading process [5]. These marine accidents happen because of human error (~85%) [6]. Cars falling into the sea accounted for 80% of accidents during loading/unloading operations, and life losses have occurred in 20% of these accidents [7]. These accidents are a severe loss for port operations. In the Ro-Ro terminal, it is the nature of cargo that cannot be stacked to require the terminal to proceed with the operation, with automation, in that way overcoming such problems and improving the operation process, which is needed rapidly.

This paper introduces the potentials of using AGVs in the car loading process of Ro-Ro ports to address these problems and improve productivity. Arena software was chosen to simulate the current loading process and the AGV loading process. Simulated processes were compared through various scenarios to analyze the productivity. Among the simulation module functions, “tnow” was used to measure the processing time within specific sections. After modeling the simulation, more productivity was found with the employment of a specific number of AGVs, along with several improvements. First, in terms of terminal operators, personnel expenses can be reduced. The simulation revealed that approximately 21 AGVs equated to three stevedore gangs’ productivity, increasing the ROI by 34%. Moreover, productivity can be increased as the AGVs are available almost all day, except for its battery-charging time, while the typical work is less than 12 h a day. Lastly, the simulation has demonstrated that the adaptation of AGVs improves productivity and several problems, with significant implications for automating Ro-Ro port operations.

2. Literature Review

2.1. Previous Research on Productivity in the Loading Process in a Port

The service time, mainly about (un)loading time, provided by the terminal is one of the leading quality indicators when evaluating the Ro-Ro port performance and the margin the terminal has left to improve [8]. Generally, a worker’s proficiency in cargo handling and the operational method at the yard area are critical factors for improving the service time, and they could decide port competitiveness [9]. With regard to improving the Ro-Ro terminal operational method, a simulation model is often developed to identify possible bottlenecks for decision support [10,11]. A formulation approach, such as a metaheuristic algorithm, also was experimented with to optimize the yard management problem in a Ro-Ro terminal [12]. However, when it comes to improving workers’ productivity at extreme industry sites, such as the Ro-Ro terminal, several problems must be handled. Extreme environmental conditions, a noisy environment, and lack of resources and facilities are reported to be the leading causes of fatigue, back pain, upper body pain, and headache, resulting in loss of worker productivity and reduced health and safety in the industry [13]. Unless systematically trained, stevedores are continuously recruited, and the ergonomic design of the work systems is established in the terminal, which one can hardly expect from the Ro-Ro port; thus, it is difficult to demand more human resource productivity. Therefore, this study introduces an adaptation of an AGV to a Ro-Ro port that is highly reliant on human resources, to improve its productivity.

2.2. Automated Guided Vehicle Introduction to the Loading Processes of Pure Car Carriers

Ro-Ro ships are cargo ships intended to transport all kinds of rolling vehicles; the two most common types are PCC (Pure Car Carriers) and PCTC (Pure Car and Truck Carriers) [14]. PCC is specially designed to transport only cars capable of 2000–4000 units at a time, and PCTC is optimized for transporting both cars and other heavy units with a payload of 4000–8000 units [15].

As shown in Figure 1, for loading a PCTC, stevedores are usually sent by shuttle van to the yard, from where they drive new cars one by one onto the ship via its stern ramp. Once drivers reach the assigned parking sector, they leave the car, and the van takes them back to the yard to pick up another lot while key cars park the cars on the spot. At the same time, a gang of lashers fastens the cars to the ground in the vessel.

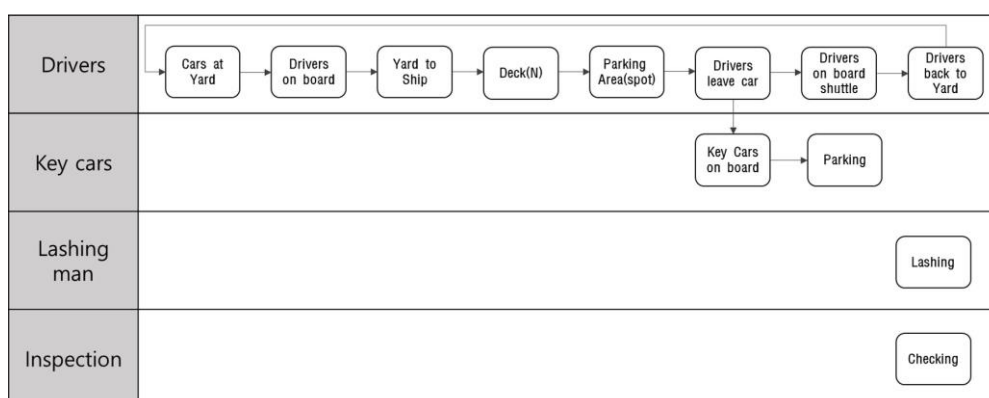


Figure 1. Current loading process (source: the Authors).

To improve productivity, container terminals worldwide have increasingly adapted AGVs. In the case of container terminals, AGVs can be moved in several ways, depending on the technology, and nowadays, many container terminals have chosen AGVs designed to navigate by the line-following principle using technologies from embedded guided wires, paint stripes, magnetic tape, laser guidance, and inertial navigation [16]. However, it is challenging to apply guidance device technologies in Ro-Ro operations since the vessel position on land changes at every port. Thus, in variable environments, such as Ro-Ro ports, the introduction of AGVs that can navigate without the line-following principle must be considered. The development of an unmanned forklift navigating without the line-following principle has been discussed [17,18]. Thus far, French startup Stanley Robotics is the leading company that has developed an AGV capable of moving and parking cars both outside and indoors. This autonomous vehicle uses GNSS, cameras, and LiDAR-based simultaneous localization and mapping (SLAM) to find the path and move cars, with a maximum speed of 10 km/h. At selected airports in Europe, including the Gatwick (UK) and Lyon Saint-Exupéry (France) airports, the robot is operational [19].

The input data for simulation was motivated by an application of the latest car carriable AGV technology. The following section discusses the simulation methodology adapted for this study.

3. Simulation Methodology

Arena is a DES (Discrete Event Simulation) software [20], and several studies have employed it to imitate complex port operations, such as Muravev et al. [11] and Kotachi et al. [21]. Other simulation software, such as Anylogic and Flexsim flow process, also can be used for modeling concerning problems. Subtle differences in the results can be given due to random numbers created by the different mechanisms of the programs. The benefits of these simulations will enable researchers to estimate port performance, overcoming the mathematical limitations of the optimization technique [22], and Rusca et al. [23] have tested a container terminal. The simulation also identifies possible bottlenecks in the process and supports productivity improvement [10,24]. Therefore, this study uses Arena 14.0 for model building, productivity measure, and analysis.

The concept of simulation models was developed based on the existing loading system. The concept of simulation models is to imitate the current loading system and AGV loading system, respectively. The simulation model covers the loading process from the yard to parking areas in the vessel. In Section 3.1, the sample deck with its parking areas and vehicles traveling speed in each section is introduced. Section 3.3 demonstrates the two loading systems developed by Arena software.

3.1. Simulation Model

3.1.1. Parking Area

The nominal vehicle carrying capacity is the largest number of standard-sized vehicles that a ship can load [14], which is generally represented by R/T, so this study was motivated to simulate the vessel's nominal vehicle carrying capacity. R/T originated from RT43, a 1966 Toyota Corolla, the first mass-produced car shipped in car carriers. It is now widely used to represent the largest number of standard-sized vehicles that Ro-Ro ships can load. Each deck's surface was divided into a rectangular shape to represent parking sectors to use a triangular distribution in the simulation. Each parking sector's unit was calculated as $4.125 \text{ m} \times 1.550 \text{ m}$, considering a space between individual RT43 cars when lashed. As shown in Figure 2, Deck 6 presents an example to demonstrate the deck's divisions, as it has the most general structure of the 13 decks.

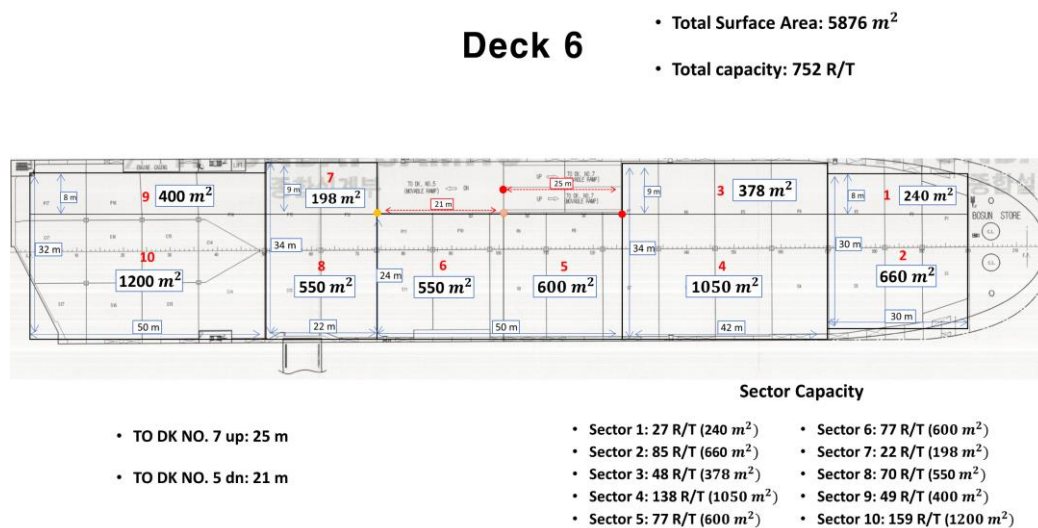


Figure 2. Deck 6 layout (source: the Authors).

3.1.2. Speed Variations and Safe Following Distance

As shown in Table 1, the sectional vehicle speed is set based on the Hyundai Glovis transportation and handling manual. In the conventional approach, it is challenging to expect a constant speed from 7000 cars since speed variations occur among drivers. Nevertheless, robots can attain this.

Table 1. Speed variations and safe following distance.

	Yard	External Ramp	Stern Ramp	Parking Area	Safe Distance
Drivers	21.25–25.0 km	6.8–8.0 km (5 mph)	21.25–25.0 km	5–10 mph	15 m
AGVs	10 km	10 km	10 km	10 km	6 m

3.1.3. Sectional Vehicle Travel Time

Max, mid, and min vehicle travel times to each parking sector are calculated based on travel distance and car speed. Drivers' parking and traveling processes within the ramp area are expressed by a normal distribution. However, a robot's parking and traveling processes are expressed by a constant value. Furthermore, lashing and inspection processes are not involved in the simulation as they are considered as another process conducted simultaneously.

3.2. Assumptions of the Simulation Model

Three different arena simulation models were developed; current loading process, AGV loading process scenario 1, and AGV loading process scenario 2. Some assumptions were made to reduce unnecessary details and compare the models under the same situation.

The model has been constructed based on the following assumptions:

- The loading/unloading place is identical, and the loading cargo is the same as the R/T cars, assuming that all 7352 cars are loaded.
- The surfaces of the deck pillars are not considered, as the space between each pillar is large, and its surface is small.
- The vehicles depart from the yard to the ship at the same time.
- The specific stowage plan considering the balance of the ship is not detailed.

These assumptions were chosen for the following reasons. First, cars and loading places with different sizes and loads can measure the loading time differently. Second, we have focused on testing the vessel loading system in an unconstrained situation in the port environment. Third, we focused on comparing two loading systems in the same stowage plan, so the specific stowage plan was unnecessary.

3.3. Arena Simulation Modeling

This study analyzed three different simulation models, respectively: the current loading process (Figure 3), AGV loading process scenario 1 (Figure 4), and AGV loading process scenario 2 (Figure 5). The entire process is detailed in six steps to aid a better understanding.

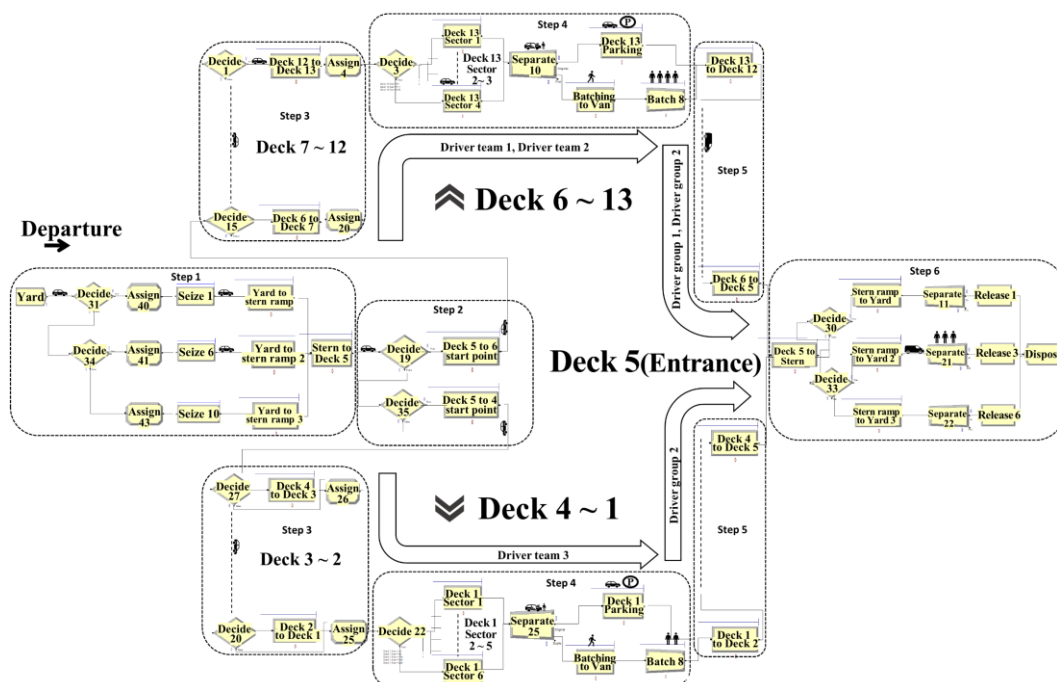


Figure 3. Current loading process model (source: the Authors).

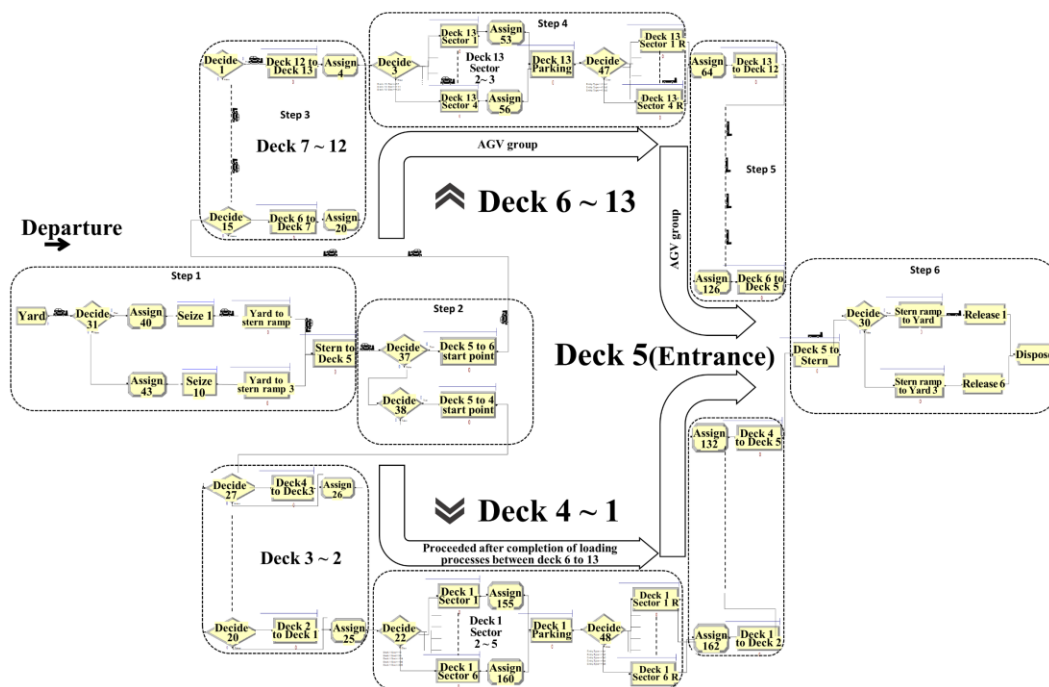


Figure 4. AGV scenario 1 simulation model (source: the Authors).

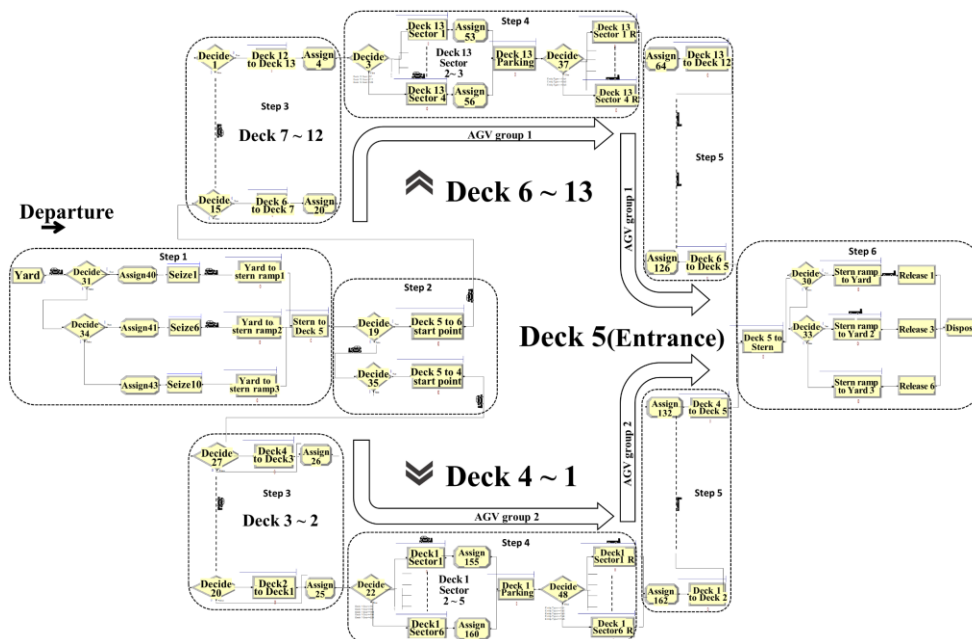


Figure 5. AGV scenario 2 simulation model (source: the Authors).

3.3.1. Current Loading Process

Step 1: The Create module represents the arrival of 7532 cars to the yard. Through the Decide modules, the entire entities are divided into three groups. The first group of entities is limited by the Seize module to allow 16 resources, representing two teams of drivers and going through all the processes between decks 6 and 13. The second group is allowed by eight resources passing through all the processes between decks 4 and 1, and the third group consists of a merge of the other two groups and finishes the work on deck 5. In Step 1, the entity departs from the yard and enters the ship to reach the deck 5 starting point by the “Yard to stern ramp” and “stern to deck 5” processes.

Step 2: After arrival at the deck five starting point, the first and second groups move to the processes “deck 5 to 6 start point” and “deck 5 to 4 start point”, respectively.

Step 3: From “deck 5 to 6 start point”, the first group passes through the internal ramp process “deck U-1 to U”. Simultaneously, from “deck 5 to 4 start point”, the second group goes through the internal ramp process “deck D+1 to D”.

* U: 6,7,8,9,10,11,12,13

* D: 1,2,3,4

Step 4: When the entity reaches deck N, it moves to the assigned parking sector through the process “deck N sector X”. At the parking sector, the entity is duplicated by a separate module and goes through the “deck N Parking” and “batch” processes, one each, to simulate the situation key car’s parking and driver’s grouping to the shuttle van.

* N: 1~13

Step 5: After a batch is made with eight entities, a temporary batch goes through the internal ramp process “deck U to U-1” or “deck D to D+1”, which is the opposite process of Step 3.

* U: 6,7,8,9,10,11,12,13

* D: 1,2,3,4

Step 6: Once the batch arrives at the yard, it is separated into a single entity again through the Separate module, and the entity passes through the Release module to depart the next driver teams.

3.3.2. AGV Loading Process, Scenario 1

Step 1: The AGV loading process scenario 1 is divided into two groups through the Decide module. The first group of entities is limited by the Seize module to allow resources by a specific number, representing the number of AGVs. Another group is limited by the Seize module to allow resources with the same number of resources as Group 1, to simulate the deck 5 loading process. In Step 1, the entity departs from the yard and enters the ship to reach the deck 5 starting point through the “yard to stern ramp” and “stern to deck 5” processes.

Step 2: After arrival at the deck 5 starting point, the group first moves to process “deck 5 to 6 start point”, and when all the loading processes between decks 6 to 13 are completed, the group moves to the process “deck 5 to 4 start point”.

Step 3: Upon arrival at the starting point, the AGV passes through the internal ramp process “deck U-1 to U” and later passes through “deck D+1 to D”.

* U: 6,7,8,9,10,11,12,13

* D: 1,2,3,4

Step 4: When the entity reaches deck N, it moves to the assigned parking sector through the process “deck N sector X.” Each AGV then discharges the car through the parking process “deck N parking” and returns to the front of the inner ramp through the process “deck N sector X R.”

* N: 1~13

Step 5: AGVs go to the process “deck U to U-1” or “deck D to D+1” to return to the yard.

Step 6: Finally, the AGV returns to the yard and then passes through the “release” module to send the next AGV.

3.3.3. AGV Loading Process, Scenario 2

Step 1: As shown in Figure 5, in scenario 2, the entities are divided into three groups through the Decide modules. The first group is limited by the Seize module to allow resources for a specific number of AGVs and goes through all the processes between decks 6 and 13, while the second group goes through all the processes between decks 1 and 4, and the third group consists of a merge of the other groups to work on deck 5 at the end. In Step 1, the entity departs from the yard and enters the ship to reach the deck 5 starting point by the “yard to stern ramp” and “stern to deck 5” processes.

Step 2: After the arrival at the deck 5 starting point, the first and second groups move to the processes “deck 5 to 6 start point” and “deck 5 to 4 start point”, respectively.

Step 3: Upon arrival to the “deck 5 to 6 start point”, the first group passes through the internal ramp process “deck U-1 to U”. Simultaneously, the second group goes through the internal ramp process “deck D to D-1”.

* U: 6,7,8,9,10,11,12,13

* D: 2,3,4

Step 4: When the entity reaches deck N, it moves to the assigned parking sector through the process “deck N sector X”. Each AGV then discharges the car through the parking process “deck N parking” and returns to the front of the inner ramp through the process “deck N sector X R”.

* N: 1~13

Step 5: Once the AGV arrives at “deck N sector X R”, it goes through the process “deck U to U-1” or “deck D to D+1” to return to the yard.

Step 6: The AGV returns to the yard through the opposite process of Step 1, and the entity passes through the Release module to send the next AGVs.

4. Simulation Results

4.1. Current Loading Process Simulation Results

Figure 6 shows the simulation results of the current loading process. The simulation was conducted with five replications. The entire processing time was defined as “E idle time measure”, decks 6 to 13 as “idle time measure”, decks 1 to 4 as “idle time measure 2”, and work on deck 5 as “deck 5 idle time measurement”. Since “idle time measure”, which is the upside processing time, and “idle time measure 2”, which is the downside processing time, were conducted simultaneously, the one that took 127,598 s longer affected the entire processing time. Then, the entire processing time was 137,598 s after the final processing time on deck 5 was added.

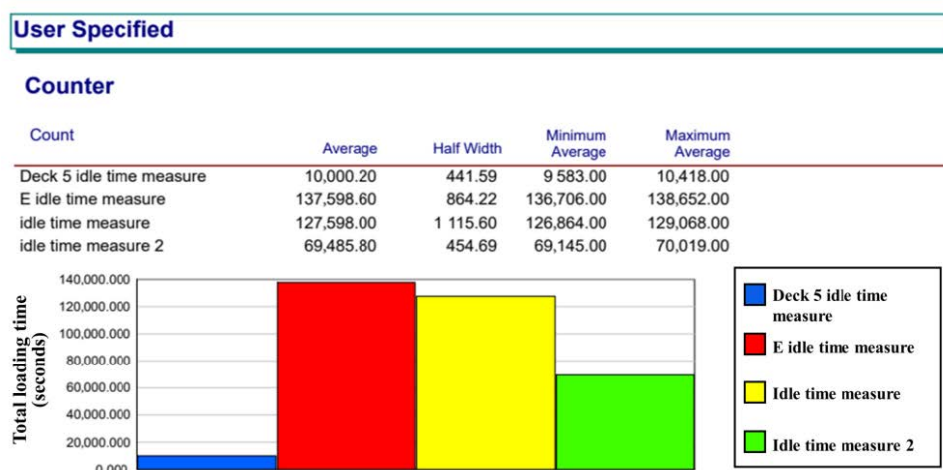


Figure 6. Current loading process simulation result (source: the Authors).

4.2. Simulation Validation

Before we used the simulation model to test the AGV loading system, we confirmed the validation against the real data from the actual loading process. First, we modeled the current loading system based on the actual loading process. Then we ran the simulation using the values (vehicle speeds, sources limit) from the Hyundai Glovis transportation and handling manual and the same number of drivers participating in the actual loading process. The simulation took 1,338,652 s to complete the loading process, equal to 96 vehicles load per 90 min. According to a survey from the Pyeongtaek Port, the average vehicle load recorded 115 vehicles per 90 min. The comparison with real data shows that the simulation’s current loading system takes more time for loads. The discrepancy between

the simulation result and the real data was attributed to running the simulation based on terminal transportation and handling manual. The actual loading process is carried out with acceleration beyond the speed limit as drivers are put under pressure to complete tasks quickly, so we used our simulation model to measure the standard loading time as the manual. To ensure results validity, we reported the output of the simulation's confidence interval at the 95% ($\alpha = 0.05$) confidence level.

4.3. AGV Loading Process, Scenario 1, Simulation Results

The simulation was run with 8–40 AGVs. Table 2 shows the simulated AGVs' loading processing time and diminishing rate. In scenario 1, all the AGVs are dispatched for loading vehicles from upside to downside collectively, so the downside processing is followed after the upside processing. Their loading times are shown on the table, respectively. When more than 22 AGVs were employed, the entire processing time was lower than the current loading process. As presented in the simulation results of 38–40 AGVs, once reaching the highest value, increasing the number of AGVs decreased productivity or maintained the same level with increased queueing time on a ramp. To resolve the queue, the operation was separated into two parts by separating the AGVs into two groups in scenario 2.

Table 2. AGV loading process scenario 1 simulation results.

Total AGVs	Upside Processing Time (s)	Downside Processing Time (s)	Entire Processing Time (s)	Diminishing Rate (%)
8	268,320	59,140	351,604.00	
9	238,589	52,697	312,880.00	−11.01
10	215,141	47,532	281,963.00	−9.88
11	195,882	43,326	257,026.00	−8.84
12	180,435	39,640	236,340.00	−8.05
13	166,358	36,746	218,204.00	−7.67
14	155,110	34,068	203,093.00	−6.93
15	145,133	31,924	190,098.00	−6.40
16	136,211	29,896	178,535.00	−6.08
17	128,661	28,360	168,641.00	−5.54
18	122,084	26,858	160,105.00	−5.06
19	116,115	25,551	152,229.00	−4.92
20	110,702	24,411	145,265.33	−4.57
21	105,924	23,371	138,889.33	−4.39
22	101,942	22,459	133,789.00	−3.67
23	97,901	21,691	128,719.00	−3.79
24	94,618	20,926	124,489.00	−3.29
25	91,852	20,390	120,983.00	−2.82
26	89,290	19,911	117,781.00	−2.65
27	87,394	19,390	115,240.00	−2.16
28	86,020	19,206	113,620.00	−1.41
29	84,910	19,014	112,294.00	−1.17
30	83,890	18,867	111,085.00	−1.08
31	83,287	18,851	110,438.00	−0.58
32	82,736	18,921	110,006.00	−0.39
33	82,295	18,910	109,513.00	−0.45
34	81,874	18,852	109,041.00	−0.43
35	81,769	18,920	108,997.00	−0.04
36	81,469	18,863	108,679.33	−0.29
37	81,428	18,882	108,645.00	−0.03
38	81,314	18,866	108,506.00	−0.13
39	81,411	18,824	108,506.00	0.00
40	81,333	18,913	108,560.00	0.05

4.4. AGV Loading Process, Scenario 2, Simulation Results

Table 3 shows the results of scenario 2. A total of 21 AGVs equated to the productivity of the current loading process. Queueing time on a ramp was reduced significantly.

Moreover, the overall productivity of scenario 2 was higher than scenario 1. However, raising the number of AGVs in the upside or downside, beyond a certain level, decreased productivity, so it was essential to balance the number of AGVs between the two parts. As shown in the simulation results of 39–42 AGVs, upon reaching the lowest time value, more AGVs did not decrease the time spent in the process because of the maximum capacity of the stern ramp.

Table 3. AGV loading process scenario 2 simulation results.

Total AGVs	AGVs (Upside)	AGVs (Downside)	Upside Processing Time (s)	Downside Processing Time (s)	Entire Processing Time (s)	Diminishing Rate (%)
8	6	2	327,041.33	236,749.67	350,821.00	
9	7	2	290,852.67	236,634.00	312,006.33	−11.06
10	8	2	262,208.33	237,603.33	281,278.00	−9.85
11	9	2	238,292.67	236,166.00	255,694.67	−9.10
12	9	3	218,935.67	158,367.33	234,860.00	−8.15
13	10	3	202,296.00	157,852.00	217,084.33	−7.57
14	11	3	188,178.33	158,389.67	201,906.00	−6.99
15	12	3	176,167.00	158,476.00	189,083.00	−6.35
16	13	3	165,282.00	158,691.33	177,424.00	−6.17
17	13	4	156,143.00	119,141.00	167,635.00	−5.52
18	14	4	147,691.00	119,484.00	158,610.00	−5.38
19	15	4	140,284.00	119,861.00	150,695.00	−4.99
20	16	4	133,788.00	120,084.00	143,779.00	−4.59
21	17	4	127,758.00	120,283.00	137,361.00	−4.46
22	17	5	122,303.67	96,386.33	131,604.33	−4.19
23	18	5	117,629.33	96,698.00	126,654.00	−3.76
24	19	5	113,248.00	97,187.67	122,076.00	−3.61
25	20	5	109,384.00	97,694.33	118,052.67	−3.30
26	21	5	105,717.67	98,064.00	114,253.67	−3.22
27	21	6	102,380.00	81,852.00	110,847.00	−2.98
28	22	6	99,578.33	82,506.00	107,942.33	−2.62
29	22	7	97,063.00	71,270.00	105,388.00	−2.37
30	22	8	94,666.00	62,894.00	102,990.00	−2.28
31	22	9	92,839.00	56,447.00	101,140.00	−1.80
32	22	10	91,044.00	51,348.00	99,339.00	−1.78
33	23	10	89,658.00	52,295.00	97,909.00	−1.44
34	24	10	88,635.00	53,079.00	96,908.00	−1.02
35	24	11	87,582.00	48,946.00	95,879.00	−1.06
36	25	11	86,885.00	50,259.00	95,189.00	−0.72
37	26	11	86,817.00	51,722.00	95,163.00	−0.03
38	26	12	86,174.00	48,307.00	94,512.00	−0.68
39	27	12	86,203.00	50,312.00	94,498.00	−0.01
40	27	13	86,372.00	47,675.00	94,690.00	0.20
41	28	13	86,217.00	49,287.00	94,535.00	−0.16
42	28	14	86,397.00	47,174.00	94,660.00	0.13

5. Discussion and Conclusions

The results of the simulation revealed many advantages of adapting AGVs in the loading process. First, in terms of port operators, the driver-related personnel costs can be cut. To date, the cost of a single AGV remains unclear, but experts presume it to cost about \$233,939 [25]. Despite the expensive vehicle capital, the AGV loading system has the potential to reduce 60% of the total operating cost in 10 years.

Furthermore, 21 AGVs equate to 35 stevedores, including drivers, key cars, signalers, and van drivers, so the ROI of employing AGVs can be calculated at 34%. Moreover, average repairs cost around \$250 per car damaged [5]. As physical damages during the loading/unloading process happen because of human failure, the employment of AGVs is expected to reduce hidden costs. Second, possible operating hours can be increased.

The working hours of the Ro-Ro port stevedore team are $1.5 \text{ h} \times 6$, less than 12 h. In the simulation, the entire processing time of the current loading process was 136,522.00 s, but the actual work time charge can be three days. However, AGVs can operate for almost 24 h. Therefore, even if the productivity of the two types of loading processes is equal in the simulation, AGVs can provide more productivity due to the available operating hours. The simulation results suggest the employment of AGVs can improve productivity and solve several problems, which has significant implications for automating the operations of the Ro-Ro ports.

Several limitations were noted during this study. These limitations provide directions for future studies. First, this simulation was constructed under the assumption that the vessel's nominal vehicle capacity is fully loaded with the actual number of stevedores participating. However, because the actual size of the cars to be loaded differs from the standard, the total number of vehicles that can be loaded probably differ from the nominal vehicle capacity. Therefore, the study must be developed to be applied to more varying vehicles. Second, the departure of the initial AGVs is simultaneous, potentially increasing waiting times at the external ramp. Further studies must be conducted by considering departure schedules, giving priority to specified groups in the yard. Lastly, the AGV loading process results revealed that as the number of AGVs increased, queuing times on a ramp increased, affecting the entire processing time. In order to resolve the queue, scenario 2 was implemented with a plan to separate the queue in a ramp, and it has proven to improve productivity and reduced queueing time. However, as the final queueing time arises from the stern ramp, the maximum number of AGVs was determined by the capacity of the stern ramp. Therefore, a bidirectional movement plan for AGVs within the stern ramp must be considered to improve final productivity.

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