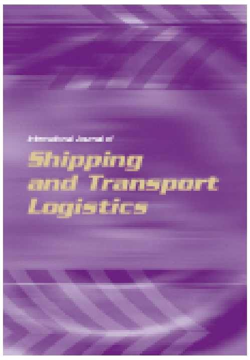

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The impacts of relocating screening scanners on efficiency of transshipment container ports: policy implications for the maritime industry

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The impacts of relocating screening scanners on efficiency of transshipment container ports: policy implications for the maritime industry

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Abstract: With the recent rise in the importance of logistics security around the world, it is worth considering relocating container inspection systems (CISs) to make port operations more efficient. This study aims to investigate changes in the terminal process when container screening equipment is additionally introduced in an automated container terminal. This research conducts a series of simulation experiments to compare two location alternatives of container scanners regarding terminal efficiency. When container screening is hardened, it is found that relocating the CIS to the TP on the waterside of the yard block to perform container screening effectively improves terminal efficiency. Although the expenses in screening containers to the USA and the time required to handle the containers may increase because of complete container inspection regulations, our research suggests this may not be an insurmountable issue.

Keywords: container screening; container scanner relocation; port efficiency; transshipment; simulation; Korean ports; container inspection systems; CISs.

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1 Introduction

Recent events such as the Russian-Ukrainian war and the Lebanese pager bombing have increased the importance of logistics security worldwide. In response, changes to the 'Homeland Security Act of 2002' may require complete cargo screening for all shipments by sea and air before departure from exporting countries. The 'Security and Accountability For Every Port Act of 2006 (SAFE Port Act)', which mandates comprehensive scanning of all shipping containers bound for the United States, was put into effect by order of the US Congress in 2007. According to the SAFE Port Act, prohibited goods must be checked on cargo ships when they enter maritime ports in the USA (Lim et al., 2021).

When container screening at seaports is hardened, costs involved would be exorbitant while time constraints would severely impact the speed of the supply chain and the ability to deliver products on time (Concho and Ramirez-Marquez, 2012). Accordingly, to deter the movement of illegal cargo through ports, many countries have adopted and improved alternative systems and methods to secure information on the movement of containers and to verify cargo in the containers (Zhang and Li, 2021). Since most ports have container scanners around their gates, there is widespread concern that adopting more scanners at all ports would cause traffic congestion and significantly impede trade (Wang et al., 2016). Moreover, the journey of transshipment cargo in terminals is more complex compared to import and export cargo since such cargo needs to move to container inspection areas near gates for screening and then return to yards for placement. Although numerous factors cause congestion and bottlenecks in terminals, one causal factor is operational incompetence, such as lack of handling equipment and low productivity in external trucks (ETs) in such areas (Iyoob and van Niekerk, 2021).

Under this situation, no research has been conducted on increasing the efficiency of terminal operations by relocating some container scanners closer to waterside transfer points (TP) of yard blocks. To fill this gap, it may be worth considering relocating CISs to make port operations more efficient. In 2021, Busan Port in South Korea was the seventh busiest global container port, handling approximately 23 million TEU. Furthermore, in 2022, South Korea boasted the tenth largest fleet in terms of commercial value with leading container shipping lines such as Hyundai Merchant Marine (Lloyd's List, 2023). In addition, because Busan port is one of the world's largest transshipment container ports, and the transshipment rate of Korean ports is over 50%, if total container cargo screening is conducted in the future, the port is expected to be affected by it (Busan Port Authority, 2023). Therefore, Korean ports could likely see significant improvements in terminal efficiency by repositioning CISs in preparation for the stricter container inspections.

This study aims to examine changes in the terminal process, (i.e., container flows) when container inspection equipment is additionally introduced in automated container terminals in preparation for cases where the stricter inspections of container cargo are performed. To this end, simulation experiments compare the difference in terminal performance between cases where container scanners are additionally installed in existing locations and cases where they are installed on waterside TP of yard blocks. To address these gaps, this study investigates the following research questions:

1. What are the key factors affecting container inspection systems (CIS) and port competitiveness?
2. How do relocating CISs impact port efficiency, including dwell time and container handling performance?

The following objectives have been framed subject to the above-mentioned research questions:

1. to identify and validate various factors such as dwell time, port operation efficiency affecting port competitiveness
2. to select alternative locations for container inspection scanners at the transshipment ports to maintain high levels of port efficiency despite strengthened container screening requirements

3 to compare the impact of adding scanners to their original locations versus installing them in new locations on port efficiency and transshipment operations through simulation

4 to enhance enabling the use of CISs by presenting managerial and political implications in the study.

The results of this study may help terminal operators make decisions on utilising additional scanners and provide implications for the Korean government and port authorities facing large volumes of transshipment cargo. A thorough literature review and interviews with Korean terminal operators were used to determine ports' performance.

The remainder of the paper has been organised as follows: Section 2 focuses on the literature supporting factors of container screening, port safety and security, and port competitiveness. Section 3 uncovers and analyses location alternatives of container screening in terminals. Section 4 presents and analyses simulation results, and finally, Section 5 includes concluding remarks, along with limitations and future research directions.

2 Literature review

2.1 Determinants of port efficiency and competitiveness

Although a wealth of literature indicates that there are many common determinants of port selection such as throughput (Munim and Saeed, 2019), dwell time (Aminatou et al., 2018), and port efficiency (Kumar et al., 2020), efficiencies are directly related to port performance. Therefore, port competitiveness and port selection based on port efficiency are among the most common themes regarding port research. Port selection on customer choice is part of customer behavioural research and includes shipping companies, shippers, freight forwarders, and carriers (Wang et al., 2016). Previous studies on port selection models have focused on port selection by shippers. However, a recent study examines port selection regarding liners and shippers (Kim et al., 2021). Moreover, there is a rich literature on terminal operators' perspective, focusing on ETs' waiting time for landside yard cranes (YCs), the number of automated guided vehicles (AGVs)/yard tractors (YTs) utilised, the average distance travelled per container by YCs, AGVs, ETs, and YTs (Nguyen et al., 2016). Especially, literature on port selection has predominantly been approached from a behavioural background (Rezaei et al., 2019). Other studies that examined and described different factors in liner or carrier selection used different methods such as analytic hierarchy process (AHP), decision-making trial and evaluation laboratory (DEMATEL), and analytic network process (ANP), called multi-criteria decision-making (Ha and Yang, 2017).

Dwell time, on the other hand, represents the total time a cargo or ship spends in port, and it indicates how efficiently the port is operated, how quickly cargo moves through the terminal, and how long the vessel is occupied in the port (Sunardi and Somakila, 2020). Ports are improving their intermodal facilities to minimise cargo dwell time and making more storage space available to terminal operators so carriers can focus on their operations (Malchow and Kanafani, 2001). Aminatou et al. (2018) claim that operational, transactional, and storage stay periods are combined to create average dwell time. Because there is so much free storage time, storage dwell time appears to contribute more than other factors. Operational dwell time refers to the duration it takes to unload cargo from ships and the period the cargo is stored in the yard. The effectiveness of the port, the equipment's accessibility, and the degree of storage facility occupancy all play a significant role in dwell time. Most of the transactional dwell time is spent in interactions between importers, port services, and customs processes. Additionally, dwell duration is highly related to port effectiveness. Numerous factors, including quay and gantry crane equipment, container ship berth time and delays, dwell time, container cargo and truck turnaround time, customs clearance, storage capacity, multi-modal connections to the hinterland, and infrastructure, have been linked to the efficiency of container terminals (Xu et al., 2021). For the overall effectiveness of logistics expenses, dwell time at the loading and unloading port is essential (Sunardi and Somakila, 2020). Serebrisky et al. (2016) shows that technological efficiency might depend more on port-specific difficulties than on geographical or institutional context, demonstrating that efficiency is a key component in port competitiveness.

Additionally, one of the elements crucial to the port logistic process is the logistics, (i.e., container flows) process in the terminal (Sunardi and Somakila, 2020). In general, the process dictates how quickly other processes go forward, including trucking containers, screening containers, and storing containers (Lajjam et al., 2014). Most of the academic research on the container terminal process has been devoted to examining the effects of layout-related factors including block size, block count, and the type of material handling equipment on container terminal performance (Gharehgozli et al., 2020).

2.2 Optimising port operations through CIS

Prior studies have explored port operation optimisation (Elsayed et al., 2009; El Noshokaty, 2013) and the economic efficacy of estimating the amount of port security screening equipment necessary at terminal inspection stations. Significant time delays and congestion are caused by inspection procedures for freight traffic in the transportation system. As a result, given the literature review on security in container terminals, container inspection operations may be a bottleneck in this highly complex logistic system (Longo, 2010). In this context, Elsayed et al. (2009) proposed several optimisation techniques for determining the best sensor threshold values under budgetary restrictions, misclassification errors, and inspection costs. These experiments aimed to suggest a screening method that would reduce inspection costs overall while maintaining a user-specified detection rate for questionable containers (Ramirez-Marquez, 2008). Contrarily, several studies have emphasised the importance of humans in container screening. This is because X-ray image interpretation skills of human operators and their ability to identify and detect banned elements in X-ray images are crucial (Michel et al., 2014). Additionally, Kuo and Tang (2011) noted that lower stage inspection rate strongly influences inspection stations' average extra delay time. Because fewer trucks can be examined due to increased weighted screening times based on rising security levels, there will be significant wait times at inspection stations. Thus, to attain and sustain high levels of CIS performance, research on appropriate training techniques and improvements to the human component is crucial (Michel et al., 2014).

Another pattern involves extensive literature-based efforts to create simulation analyses of port systems' container inspections to increase the effectiveness of screening (Khoshons et al., 2006; Yıldırım and Gokkuş, 2023). Operations at container terminals, particularly cargo transport in terminals, are significantly impacted by inspection area structure. The typical outcome of random site selection for inspection areas is increased truck traversal distance and traffic volumes, which places an unnecessary burden on terminal roadways (Zhou et al., 2020). To better control the flow of screening-required containers and determine its effects on terminal efficiency of integrating inspection activities, Longo (2010) created a simulation model for container terminals. Harris et al. (2009) used a simulation approach to determine the inspection resources needed at intermodal terminals to minimise disruptions caused by increased inspection activities, and results showed that a general resource allocation could eliminate or minimise delays caused by screening. Lewis et al. (2003) proposed a method to balance the proportion of containers that need examination and the delays faced by departing vessels. They utilised a problem-modelling approach to understand the relationship between the percentage of containers that need to be inspected and departure delays in terms of container throughput, vessel and vehicle turn-around time, and unproductive time.

3 Inspection system location alternatives

3.1 Container inspection

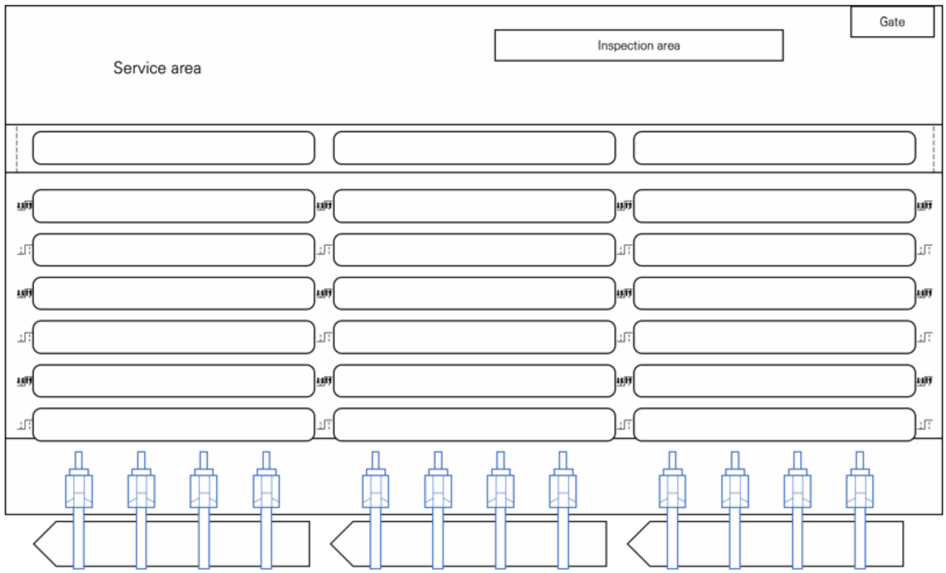
The flow of containers refers to the physical movement of containers being processed in the terminal at port, and such movement is influenced by the layout of terminal facilities such as container inspection areas. Such layout is typically distinguished according to the layout of container yard blocks. If yard blocks are parallel to the quay wall, they are called horizontal yard blocks, and if arranged vertically, they are called vertical yard blocks (Figure 1). The former can be seen as the layout of a traditional container terminal. In contrast, the latter can be seen as the layout adopted in advanced ports such as the Port of Rotterdam in the Netherlands, the Port of Hamburg in Germany, and Long Beach container terminal in the United States. In vertical yard blocks, automated vehicles can be introduced to transport containers between the berth and the yard, and with the advance of technology, numerous terminals are attempting to adopt this layout (Gharehgozli et al., 2020). Busan New Container Terminal in South Korea, which opened in the 2010s, has adopted this layout although it did not introduce automated transport vehicles. In 2030, terminals at Busan New Port in Korea are scheduled to use vertical yard blocks and automated transportation equipment is expected to be used.

Additionally, the process of container handling can be differentiated subject to the types of trade – imports, exports, and transshipments. Transshipments are further classified into intra-terminal transshipments, where imports and exports occur at the same terminal, and inter-terminal transshipments, where imports and exports occur at different terminals at the same port. Since imports and exports also partially occur in transshipments, the typical imports and exports are referred to as local imports and local exports, respectively, and those in transshipments are distinguished as transshipment imports and transshipment exports.

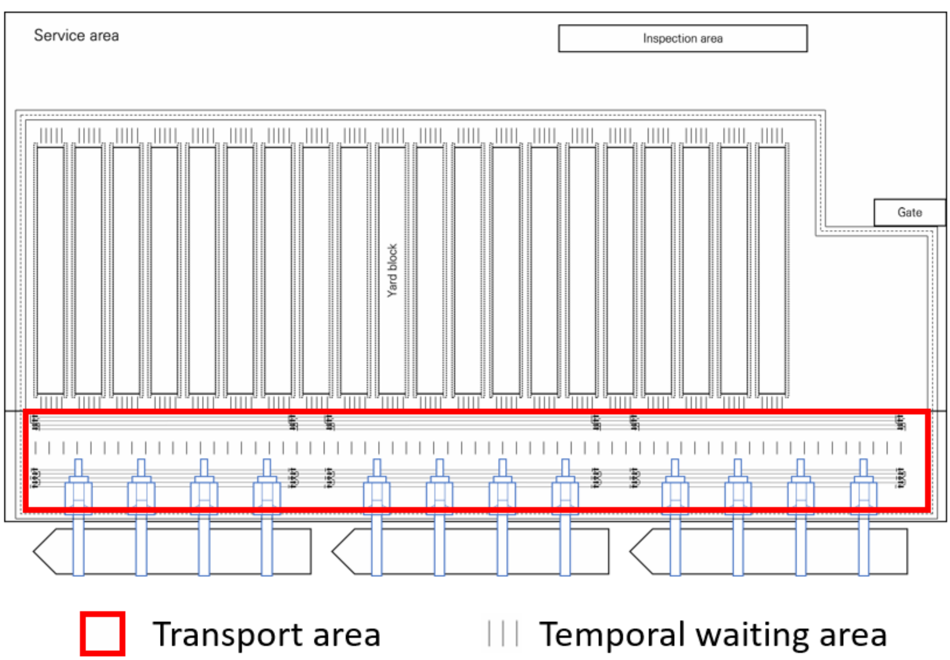
Table 1 Container handling and transport sequences and equipment used (see online version for colours)

Index	*Operation*	*Direction*	*Equipment*	*Import*	*Import (screening)*	*Export*	*Export (screening)*	*Intra-terminal transfer*	*Intra-terminal transfer*
A	Discharging	Inbound	Quay crane	1	1	-	-	1	1
a	Transport		AGV	2	2	-	-	2	2
B	Transfer (Scanning)		YC (Scanner)	3	3	-	-	3	3
b	Transport		YC	4	4	-	-	4	4
C	Placing		YC	5	5	-	-	5	5
c	Transport		YC	6	6	-	-	6	-
D	Transfer		YC	7	7	-	-	7	-
d	Transport		RT	8	8	-	-	8	-
E	Scanning		Scanner		9	-	-	9	-
e	Transport		RT	9	10	-	-	-	-
f	Transport	Outbound	RT	-	-	1	1	-	-
E	Scanning		Scanner	-	-		2	-	-
g	Transport		RT	-	-		3	10	-
F	Transfer		YC	-	-	2	4	11	-
h	Transport		YC	-	-	3	5	12	-
G	Placing		YC	-	-	4	6	13	-
i	Transport		YC	-	-	5	7	14	6
H	Transfer		YC	-	-	6	8	15	7
j	Transport		AGV	-	-	7	9	16	8
I	Loading		Quay crane	-	-	8	10	17	9

Figure 1 Container terminal layouts, (a) container terminal with horizontally-arranged yard blocks, (b) container terminal with vertically-arranged yard blocks (see online version for colours)



(a)



(b)

This study focuses on automated container terminals, which are increasingly being considered for implementation in new ports. The reason is that AGVs can move in and out of container inspection areas, (i.e., waterside TP of yard blocks), minimising direct human involvement in terminals with a perpendicular layout. In contrast, crewed trucks would be used in a parallel layout, requiring drivers to exit their vehicles whenever containers undergo screening and inspection in the yard. This would reduce the productivity of screening operations and pose serious safety risks. Drivers would need to remain outside their vehicles near yard blocks where yard cranes operate, exposing them to potential accidents.

Figure 2 shows container flows according to the type of trade, differentiated and represented as arrows, considering the vertical layout and container handling operations, including container screening. A detailed examination of such flows reveals differences in the sequence of equipment visited by the containers in the terminal and the operations, summarised in Table 1.

Figure 2 Container flows and operations (see online version for colours)

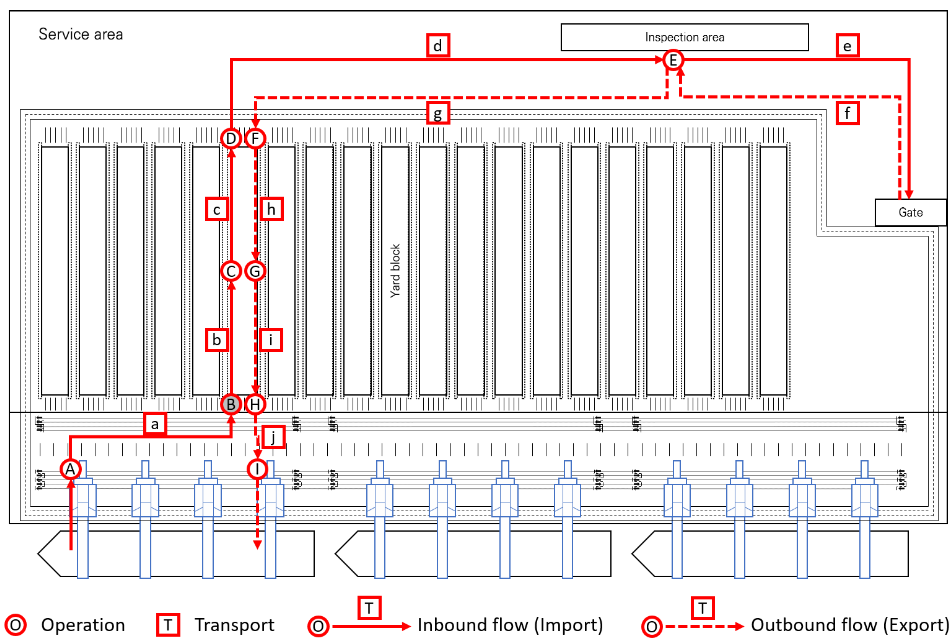


Table 1 presents six different operational scenarios:

1 import

2 import with container screening

3 export

4 export with container screening

5 intra-terminal transshipment with screening conducted at the service area

6 intra-terminal transshipment with screening conducted at the waterside TP in the yard block.

These scenarios are structured subject to a series of operations, container movement directions and associated equipment. The first column of the table contains indices that identify specific operations and container movements. Operations performed at a particular location are represented by uppercase letters, while container movements between two locations are indicated by lowercase letters. This distinction is visually illustrated in Figure 2. The numerical values in the table denote the sequential order of operations in each scenario. For instance, the screening operation labelled as index E represents a scanning process for inbound containers. In the second scenario, (i.e., import with screening) and the fifth scenario, (i.e., intra-terminal transshipment with screening in the service area), the screening operation corresponds to the ninth step in the scenarios. Therefore, the numerical values represent the actual procedural sequence. For scenarios of the same type as the fifth and the sixth scenarios, additional process steps indicate an increased number of operations and, consequently, longer processing time, as reflected in the final two columns.

The structure of Table 1 is designed to help interpret the sequential flow of operations within each scenario, ensuring a comprehensive understanding of the procedural steps involved. For instance, for imports, a container unloaded from the quay is loaded onto an internal transport vehicle and moved to a designated yard block. It is unloaded by the waterside YC and stacked in the yard block. After that, it is loaded onto an ET by the landside YC, and it leaves the terminal through the gate after undergoing a series of screening if necessary. On the other hand, in the case of intra-terminal transshipment, the process is the same up to the point where the container is stacked in the yard block. However, instead of being handled by the landside YC, it is loaded onto an internal transport vehicle again via the waterside YC and moved to the quay. From there, it is loaded onto a designated ship and leaves the terminal.

As explained in the introduction, environmental changes in trade mean that if container screening is conducted at transshipment ports, it would be rational to do so at transshipment import ports rather than transshipment export ports. This is to ensure that information about hazardous materials can be confirmed as quickly as possible to avoid any issue of liability. In the case of inter-terminal transshipments, containers pass through service areas where the inspection equipment is located and exit through the gate. However, in the case of intra-terminal transshipments, although containers do not leave terminals through the gate, they still need to be moved to service areas for container screening (intra-terminal transfer[a] in Table 1), which may involve handling operations related to screening. If such an inspection is performed before containers are loaded on the yard, several container handling operations are not necessarily implemented while potentially improving container flows in the terminal (intra-terminal transfer[b] in Table 1).

3.2 *Location alternative*

In the previous sub-sections, it is identified that if container scanning operations are performed at transshipment ports, keeping the scanners only in service areas as is currently done will result in unnecessary routes and additional handling or transportation operations for intra-terminal transshipments. Thus, it is worth considering changing scanner installation locations from a logistics efficiency perspective. Based on the summarised Table 1, installing scanners in transportation areas or at yard blocks' waterside TP would be alternatives to removing unnecessary travel to and from the landside. Placing such scanners in transportation areas is not a realistic alternative. The biggest problem is that it disrupts the traffic of container transport vehicles. Vertical terminals have a space in the middle of the transportation area where automated vehicles can temporarily wait (Jeon et al., 2011). Consequently, scanners also need to be installed in this location to minimise traffic congestion. Automated vehicles transporting containers that do not require screening must avoid scanners, which are recognised as an obstacle, preventing them from moving in the shortest distance and minimum time. As a result, more vehicles would need to be deployed, leading to traffic congestion in the system. In addition, scanners periodically require maintenance and repair (M&R). Still, the transportation areas where automated transport vehicles are deployed are secured to prevent the entry of workers and human-crewed vehicles. This means that it is difficult for human workers to access scanners in the middle of transportation areas. In extreme situations, transportation systems could be temporarily halted for M&R operations, which is unrealistic. On the other hand, waterside TP areas of each yard block are spaces where vehicles can wait and receive loading and discharging services, so it cannot be seen as significantly disrupting traffic. Also, TP areas correspond to the boundaries of secured areas, making it relatively easier for human workers to enter and perform maintenance and repair. Therefore, waterside TP areas would be realistic alternatives for scanner locations.

4 Simulation and experimental results

4.1 Simulation scenarios

The study selects two installation alternatives as scenarios: The as-is (Scan-SA) scenario, which installs container scanners in service areas to perform screening services, and the to-be (Scan-TP) scenario, which installs scanners not only in service areas but also in waterside TP areas of yard blocks. Each scenario is detailed according to the inspection rate of screening target containers and the inspection rate of all containers. Containers for local exports, transshipment exports, or transshipment imports would become screening targets if enhanced screening were adopted. The inspection rate is converted into the inspection rate of all containers, which adds local imports, transshipment imports, and transshipment exports to the aforementioned three types of cargo flow; in other words, the proportion of containers to be inspected out of the total cargo. An increase in screening target containers implies an increase in the number of ports requiring container inspection completion under import conditions. The inspection rate of target containers is set to increase by 10% points from 0 to 100%, and the other rate also increases accordingly.

This study established an experimental environment on the actual layout of a terminal in Busan Port, South Korea. This approach facilitates the identification of realistic inter-facility distances and other crucial operational aspects. Additionally, data on import, export and transshipment container flows and patterns were collected from five terminals in Busan Port, processed, and refined to generate input data for the simulation experiments. Using real-world data enhances the validity and significance of the experimental results. The specific dataset used in the experiments is summarised in Appendix.

4.2 Performance indicators

As detailed in Table 2, this study selects five performance indicators related to the movement of containers and cargo handling equipment and the number of vehicles required. The first performance indicator (PI1) is ETs' waiting time (minutes) for landside YCs. Transshipment import containers that need to move to service areas for cargo screening in the Scan-SA scenario can be scanned at the waterside TP in the Scan-TP scenario without moving to service areas. Therefore, using the landside cranes will be lower in the latter scenario. As a result, the time that ETs wait for landside YCs is affected, making it a meaningful performance indicator. The second performance indicator (PI2) is the number of AGVs utilised, which refers to the fleet size of vehicles deployed in the transportation area for waterside operations. In the Scan-TP scenario, the efficiency of the AGVs' operations might be partially reduced due to screening at waterside TPs of the yard blocks. As a result, additional AGVs may need to be deployed to perform normal waterside operations. The third performance indicator (PI3) is the number of YTs utilised, which refers to the fleet size of YTs deployed for landside operations. They travel between the yard and storage areas for empty containers and transport containers subject to screening between laden container yards and CIF areas. In the Scan-TP scenario, there is no need for transshipment import containers to be transported by YT in landside operations for inspection. Therefore, this indicator would be appropriate for comparing the two scenarios. The fourth performance indicator (PI4) is the average distance travelled per container (in metres) by YCs, AGVs, ETs, and YTs. In the Scan-TP scenario, the handling of containers by landside YCs and YTs decreases. Therefore, this performance indicator can be used to compare the two scenarios. The fifth performance indicator (PI5) is the time (in minutes) taken to complete an intra-terminal transshipment screening. This refers to the elapsed time from the point that the container is loaded onto an AGV at the apron until it is inspected and placed in the yard. This is calculated differently in the two scenarios. In the Scan-SA scenario, this time refers to the duration it takes to travel from the apron to the container yard, through the CIS for container screening, and back to the yard. In contrast, in the Scan-TP scenario, it refers to the duration it takes to be inspected at the waterside TP of the yard block from the apron and then place the container in the container yard.

Table 2 Description of performance indicators

Performance indicators	*Description*	*Units*
ETs' waiting time (PI1)	ETs' waiting time for landside YCs	Minutes
The number of AGVs used (PI2)	The fleet size of AGVs for waterside operations	Units
The number of YTs used (PI3)	The fleet size of YTs for landside operations	Units
The average distance travelled per container (PI4)	The average distance travelled per container by YCs, AGVs, ETs, and YTs	Metres
Transshipment screening time (PI5)	The time taken to complete an intra-terminal transshipment inspection	Minutes

4.3 Key assumptions

The key assumptions for simulation are as follows: first, it is assumed that the terminal has sufficient AGVs and YTs. It helps to understand the number of AGVs and YT utilised in each scenario. Second, it is assumed there are enough scanners in service areas to avoid bottleneck situations. In the Scan-TP scenario, each yard block has a scanner, assuming scanning services can be provided when necessary. Next, for the experiment, the port terminal applied was the standard size of terminals in South Korea, 1,100 m in width and 600 m in length, and the facilities in the terminal were arranged concerning a vertical terminal, including the New Port of Busan Terminal 5. The port throughput applied was the throughput of the New Port of Busan Terminal 5. The process time of the scanner was set to 120 seconds. It is the process time of the container scanners, which were developed from 2020 to 2024 in the 'development of automatic screening and hybrid detection system for hazardous material detecting in port container' R&D project commissioned by the Korea Institute of Marine Science and Technology Promotion under the Ministry of Oceans and Fisheries. Finally, the warm-up period for system stabilisation was set to 60 days, and the experiment time was 30 days. More detailed input parameters for the simulation can be found in Appendix.

4.4 Experimental results

This study utilised ExtendSim to model the container handling process in a vertical terminal and performed a series of simulation experiments subject to various experimental scenarios. ExtendSim is a specialised tool for process analysis, and the developed model incorporates all types of container handling operations within the port, except for gate operations, thereby maximising its fidelity. The conditions outlined in Sub-sections 4.1, 4.2, 4.3 and Appendix was applied in the experiments, and the results are summarised in Table 3 and the subsequent figures. To clarify the difference between

1 the inspection rate of screening target containers

2 the inspection rate of all containers in Table 3, Section 4.1 provides the relevant explanation.

Additionally, details on different performance indicators in Table 3 can be found in Table 2.

Regarding PI1, the results in Table 3 and Figure 3 show that the Scan-SA scenario was inferior to the Scan-TP scenario as the screening target rate increased. This is because screening target transhipment containers in the Scan-SA scenario also occupy the YCs to move between the yard and the service area. When the screening target rate was 10%, it was confirmed that the ETs waited for 18.3 minutes on average in the Scan-SA scenario and 14.5 minutes in the Scan-TP scenario to be served. The difference of 3.8 minutes may not seem significant in terms of time, but in terms of ratio, the latter can be favourable as it is about 79% of the former. When the screening target rate is 50%, the average waiting time in the Scan-TP scenario is 15.3 minutes, and it only becomes 39% of that in the other scenario. When the inspection rate exceeds 90%, the waiting time of the ETs in the Scan-SA scenario exceeds two hours, which means that the system is not operating normally.

From the perspective of PI2, as recorded in Table 3 and Figure 4, the Scan-SA scenario has a slight advantage over the Scan-TP scenario, but no significant difference was observed. This seems to be because most terminals adopt a system that tolerates the waiting of container transport vehicles by deploying more to increase the utilisation of the more expensive cranes. In the Scan-TP scenario, transshipment screening target containers are scanned before being placed in the yard after unloading in the quay. This increases the working time of the AGVs. Therefore, more AGVs may be required. However, since terminal operators adopt a system that tolerates vehicle waiting, as mentioned, the system performs inspections for AGVs instead of making them wait, so the results do not show a significant difference in the actual number of AGVs used. Regardless of the screening target rate, about 47~49 vehicles were used in the Scan-SA scenario and 48~50 vehicles in the Scan-TP scenario.

Figure 3 ET's waiting time for YCs (see online version for colours)

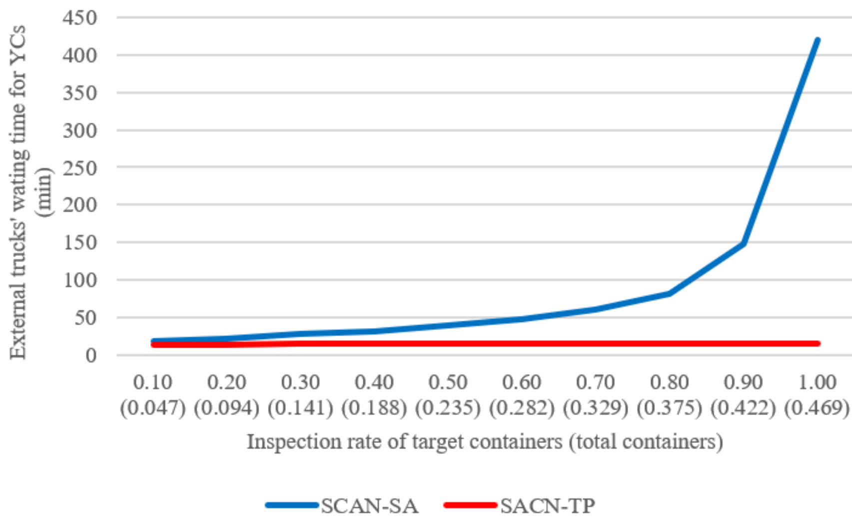


Figure 4 The number of AGVs used (see online version for colours)

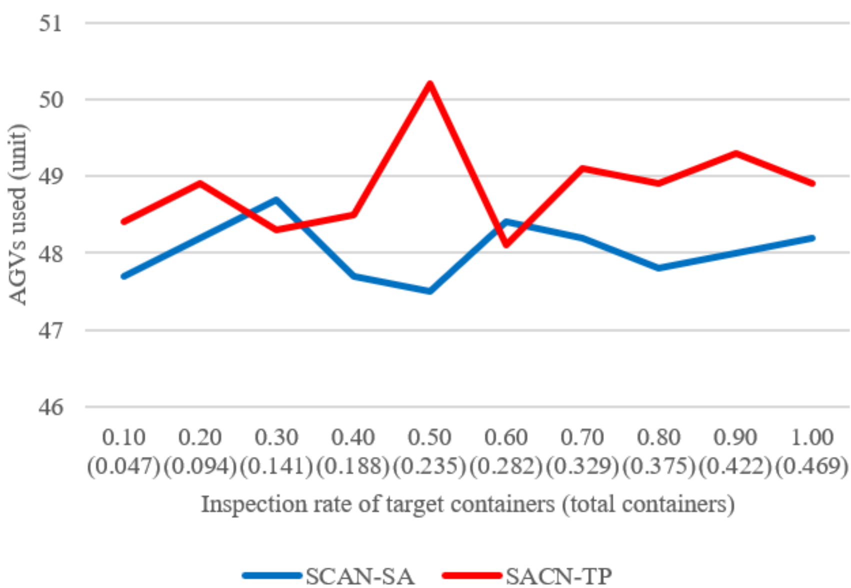
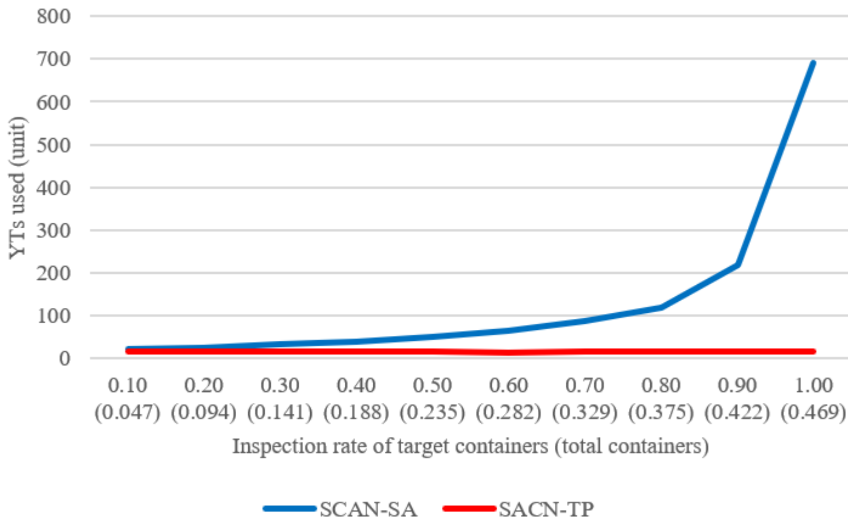


Table 3 Summary of simulation results

Scenario			*Inspection rate of screening target containers (Inspection rate of all containers) (%)*										
			0.0 (0.0)	*10.0 (4.7)*	*20.0 (9.4)*	*30.0 (14.1)*	*40.0 (18.8)*	*50.0 (23.5)*	*60.0 (28.2)*	*70.0 (32.9)*	*80.0 (37.5)*	*90.0 (42.2)*	*100.0 (46.9)*
Scan-SA	PI1	Avg.	14.9	18.3	22.3	27.9	31.2	39.4	47.3	61.1	81.4	148.4	420.3
	(Min)	Max	173.1	187.9	238.6	231.4	261.4	273.5	378.5	537.9	528.2	864.8	1,893.8
	PI2	Avg.	48.2	47.7	48.2	48.7	47.7	47.5	48.4	48.2	47.8	48.0	48.2
	(Unit)	Max	92	87	92	95	87	86	91	90	90	82	90
	PI3	Avg.	15.9	20.4	25.7	32.7	38.5	49.9	64.6	86.4	118.0	219.2	690.1
	(Unit)	Max	44	62	66	86	99	128	147	189	219	359	924
	PI4	YC	379.8	388.0	396.5	405.2	413.4	421.4	429.6	438.5	446.9	454.8	463.3
	(m)	AGV	873.4	873.8	872.4	875.4	875.9	873.7	873.9	875.6	871.9	875.3	872.8
		ET	512.1	530.0	545.0	558.6	571.1	588.1	608.8	618.7	637.3	652.2	669.2
		YT	267.8	289.1	310.9	338.0	357.7	377.8	406.3	427.7	449.7	471.0	495.2
	PI5	Avg.	-	72.0	78.7	88.7	95.0	112.7	126.6	151.8	196.4	327.3	827.0
	(Min)	Max	-	350.6	485.0	425.1	501.1	545.0	699.4	784.8	994.8	1,605.4	3,375.2
Scan-TP	PI1	Avg.	-	14.5	14.5	14.7	15.0	15.3	14.6	15.0	14.9	15.0	14.8
	(Min)	Max	-	169.6	182.6	166.0	196.6	181.6	183.5	251.4	184.9	246.1	174.0
	PI2	Avg.	-	48.4	48.9	48.3	48.5	50.2	48.1	49.1	48.9	49.3	48.9
	(Unit)	Max	-	91	90	89	88	87	93	91	88	86	85
	PI3	Avg.	-	16.2	16.0	16.0	16.1	16.3	15.7	16.2	16.0	16.3	16.1
	(Unit)	Max	-	41	49	43	45	49	44	49	45	47	42
	PI4	YC	-	380.1	379.9	379.8	379.7	379.7	380.0	380.0	379.9	380.1	379.9
	(m)	AGV	-	874.1	874.3	874.3	870.2	877.3	873.8	873.3	873.0	875.6	876.0
		ET	-	528.9	544.5	561.3	575.8	588.0	604.9	621.8	637.7	651.9	665.2
		YT	-	269.8	270.4	269.0	269.1	267.1	267.2	269.6	268.6	269.3	268.1
	PI5	Avg.	-	19.0	19.3	19.3	19.3	19.6	19.1	19.5	19.3	19.4	19.2
	(Min)	Max	-	76.6	104.3	95.2	94.7	102.2	122.0	123.8	86.5	110.8	91.7

Concerning PI3 shown in Table 3 and Figure 5, the Scan-SA scenario was inferior to the Scan-TP scenario. This is because, similarly to the comparison in the first performance indicator, in the Scan-TP scenario, transshipment screening target containers do not need to be moved to the inspection site in the service area by YTs, reducing YT use. When the screening target rate is 10%, an average of 20.4 vehicles are used in the Scan-SA scenario and 16.2 vehicles in the Scan-TP scenario, which appears to be a significant but not huge difference. However, when the screening target rate reaches 70%, the use in the Scan-SA scenario is 86.4 vehicles, and if it exceeds 80%, it exceeds 100 vehicles, indicating that system improvements may be necessary.

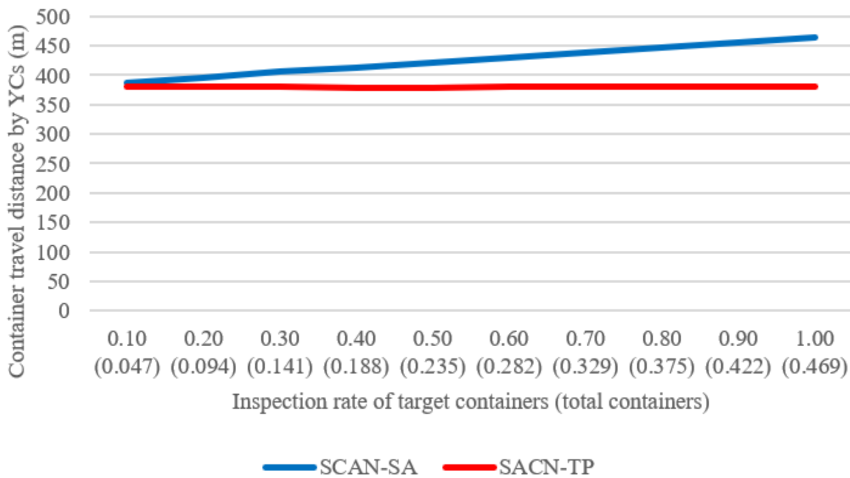
Figure 5 The number of YTs used (see online version for colours)



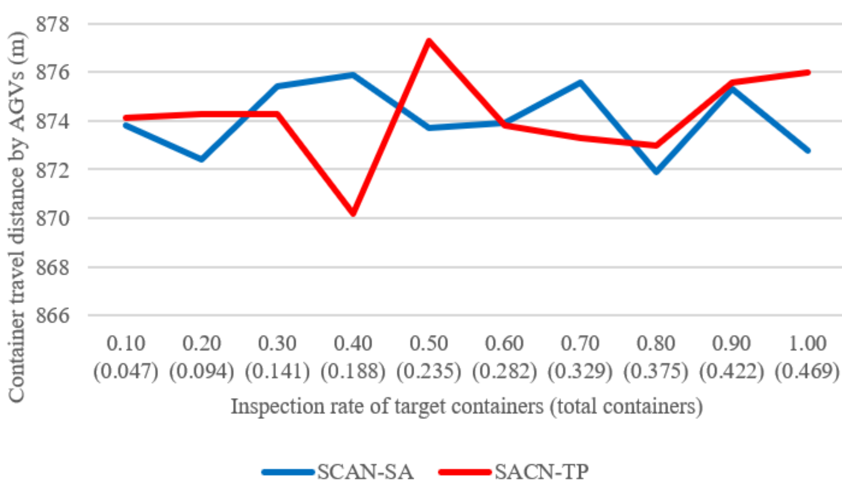
Referring to Table 3 and Figure 6 regarding PI4, the Scan-TP scenario was found to be superior in terms of the distance travelled by YCs and YTs compared to the Scan-SA scenario. This is because the additional work caused by the transshipment screening in the Scan-SA scenario does not occur in the Scan-TP scenario. When the inspection rate is 10%, the travel distance of the YCs is 388 metres on average in the Scan-SA scenario and 380 metres in the Scan-TP scenario, which did not show a significant difference. However, when the inspection rate was 50%, it was 421.4 metres and 379.7 metres, respectively, and when it reached 100%, it was 463.3 metres and 379.9 metres, showing a significant difference. Similarly, the travel distances of the YTs were not significantly different when the screening target rate was 10%, at 289.1 metres and 269.8 metres in each scenario. However, when the inspection rate reached 100%, it was 495.2 metres and 268.1 metres, respectively, showing a remarkable difference. In contrast to the two detailed performance indicators explained above, it was confirmed that there was no difference in the travel distance of AGVs and ETs.

Regarding PI5 (see Table 3 and Figure 7), the Scan-TP scenario overwhelmingly surpassed the Scan-SA scenario. Unlike in the Scan-TP, where screening is performed on transshipment containers while they are being transported to the yard, such containers in the Scan-SA scenario have to move to the service area via YCs and YTs for inspection and then return to the yard. In other words, although there is a certain amount of screening time when first entering the yard, the operation time and waiting time by the YCs and YTs are significantly greater, making the Scan-TP scenario appear superior to this performance indicator.

Figure 6 Travel distances by terminal resources, (a) travel distance of containers by YCs, (b) travel distance of containers by AGVs, (c) travel distance of containers by ETs, (d) travel distance of containers by YTs (see online version for colours)

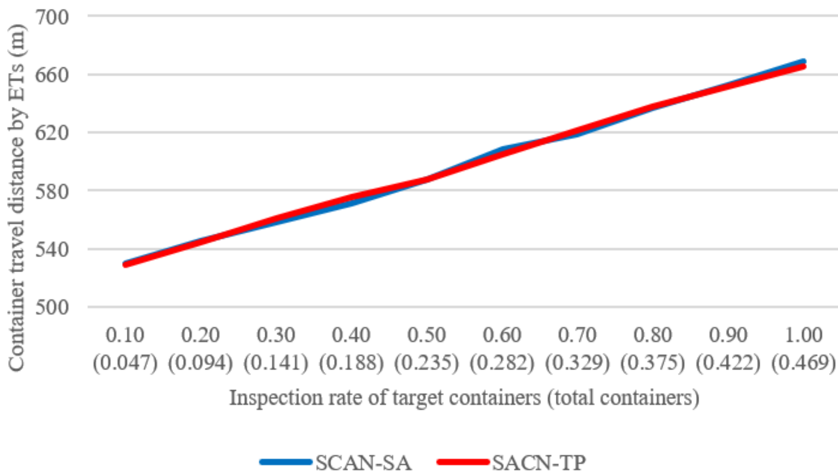


(a)

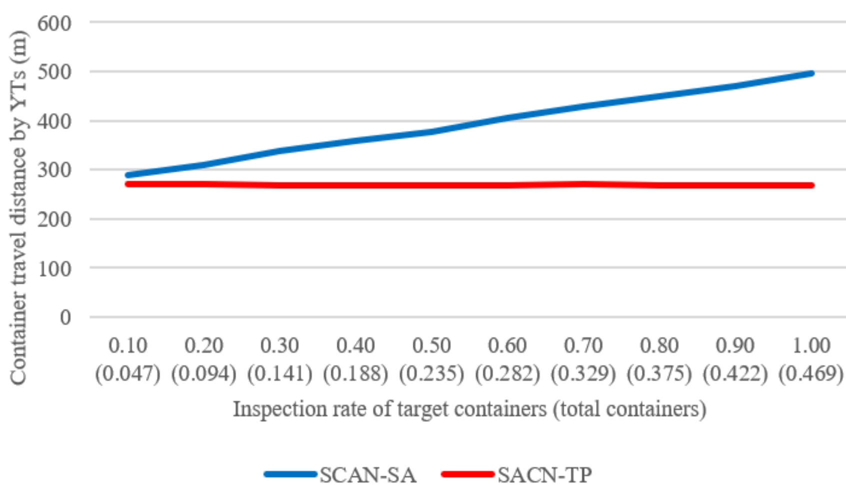


(b)

Figure 6 Travel distances by terminal resources, (a) travel distance of containers by YCs, (b) travel distance of containers by AGVs, (c) travel distance of containers by ETs, (d) travel distance of containers by YTs (continued) (see online version for colours)



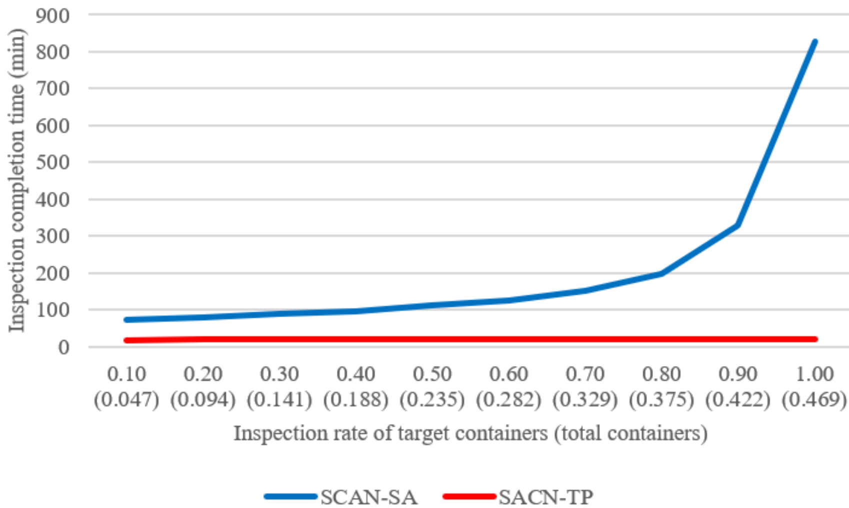
(c)



(d)

To summarise, the Scan-TP alternative proved superior in terms of PI1, PI3, PI4, and PI5. Although the Scan-SA alternative was slightly superior in PI2, the difference was only about one vehicle, which is hard to consider significant. Thus, from a logistics process perspective, it appears more advantageous to perform container scanning in the yard block TP as well as the service area.

Figure 7 Screening completion time for containers in intra-terminal transport (see online version for colours)



5 Concluding remarks

When strengthened container screening comes to port logistics, the cost of physical inspection becomes exorbitant. This significantly impacts the speed of the supply chain and the ability to deliver products on time. Yet such a theme of relocating CISs within the port for port efficiency in research is rare. Especially, maritime ports with high transshipment rates, such as Korean ports, are expected to be more directly affected. To this end, the authors compared the efficiency gains of cases where some of the container scanners are relocated near waterside TP of yard blocks, (i.e., to-be) in preparation for strengthened container screening in automated container terminals where they are installed in service areas of the port, (i.e., as-is) through a simulation approach. The benefits of this research include improved competitiveness through shorter service times and minimised operating costs due to decreased usage of port facilities. This study has several policy implications for governments, port authorities, and terminal operators by presenting a new port process for responding to the coming stricter container screening. The findings provide a clearer understanding of the process for transshipment cargo inspection, determine alternatives, and make immediate modifications to achieve response policies.

This research conducts a series of simulation experiments to compare two location alternatives of container scanners regarding terminal efficiency. The results of the study show that the Scan-TP alternative is superior in most performance indicators (including PI2, PI3, PI4, and PI5). In other words, when strengthened container screening is introduced, relocating the CISs to the TPs on the waterside of the yard blocks to perform container screening effectively improves terminal efficiencies. Terminal managers must deal with various interrelated logistical problems, and the effectiveness and productivity of the terminal depends on their solutions (Castilla-Rodriguez et al., 2020). Furthermore, short ship turnaround times contribute to lower operating costs (Kim et al., 2021).

According to Tan and Hilmola (2012), measures should be taken to improve the ease, quality, efficiency, and lead time of logistics flows to the transshipment port to maintain its position as a transshipment hub port while also competing on cost. Particularly, due to challenging processes, several of Korea's neighbouring ports are unsuitable for transshipment. Additionally, nations like China which export a lot of their goods may ship directly to the U.S. without using the transshipment ports in South Korea. However, the need for container screening for transshipment goods will rise if container inspection is put into place (Congressional Budget Office, 2016). To encourage more frequent visits from shipping lines to transhipment ports, ports need to consider repositioning the location of container scanners. By doing so, containers not inspected at their point of origin can be subjected to screening upon arrival at transshipment ports. This might open new opportunities for transshipment commodities to be shipped with less lead time and lower freight rates.

New management practices are widely acknowledged as necessary to improve effectiveness, boost productivity, and lower operational costs (Castilla-Rodriguez et al., 2020). There are several studies that have been done to shorten the time spent handling containers (Maknoon et al., 2016). Furthermore, several studies can be used to execute a container search fast and correctly (Zhou et al., 2020). Although the expenses in scanning containers bound for the USA and the time required to handle containers may increase because of complete container inspection regulations, our research suggests this may not be an insurmountable issue. Zhou et al. (2020) have stated that the traffic volume on terminal road networks increases when the inspection areas are far from the gate. Similarly, if the inspection area is distant from the berth, it is likely to result in unnecessary traffic within the terminal, leading to an increase in transshipment container handling time. Therefore, it is recommended that the inspection area for transshipment cargo should be situated closer to the berth, considering the traffic operations and management within the terminal. This will minimise work disruptions due to increased inspection activities and ensure that the allocation of resources is optimised to eliminate or reduce delays caused by screening (Harris et al., 2009). In conclusion, the Korean government and the PAs should evaluate the relevant legal framework in anticipation of the stricter screening of containers in the future, and devise policy measures to support the reorganisation of CISs.

In this research, five performance indicators were employed to enhance the efficiency of the terminal by revamping the container scrutiny system at a transshipment port in anticipation of stricter container screening. By presenting a new system for inspecting containers at transshipment ports, this inquiry is anticipated to significantly contribute to the advancement of novel knowledge in this domain and inspire comparable research efforts in other regions. Nevertheless, there are still queries about the factors that determine logistical performance. To supplement the results of this investigation, it will be crucial to recognise other internal and external performance dimensions in the port industry. It is projected that the diversification and segmentation of performance indicators will lead to a more precise and reliable evaluation of CISs in forthcoming research. Additionally, investigating the impact of container scanner relocation on key decision-making problems, such as vehicle scheduling and trajectory planning, could be a meaningful avenue for future research. Moreover, analysing the optimal number of scanners required at TP on the waterside of yard blocks, as well as determining specific yard blocks to be assigned to scanners, could provide further insights into terminal operations. The integration of such decision-making problems with the scanner relocation issue is expected to offer valuable perspectives for the future management and operation of automated container terminals.

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Declarations

All authors declare that they have no conflicts of interest.

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Appendix

Table A1 Average number of container generation per hour

Time interval (hour)	*In type*	
	Gate in	*Apron in*
00~01	147.955	52.515
01~02	162.857	52.263
02~03	165.234	52.389
03~04	175.481	55.314
04~05	168.934	53.156
05~06	155.049	51.279
06~07	126.464	50.566
07~08	119.773	63.354
08~09	48.892	48.756
09~10	34.299	50.216
10~11	29.864	48.647
11~12	30.264	50.801
12~13	41.921	52.263
13~14	33.290	53.416
14~15	29.630	53.679
15~16	27.539	51.400
16~17	28.985	50.566
17~18	39.924	49.757
18~19	56.032	65.251
19~20	54.811	51.400
20~21	56.877	49.986
21~22	68.806	51.159
22~23	87.741	50.683
23~24	108.312	52.389
Day total	1,590.310	1,651.850

Table A2 Probability of container type

Container type	*In type*	
	Gate in	*Apron in*
Full	0.725	0.851
Empty	0.275	0.149
Total	1.000	1.000

Table A3 Probability of container flow type

In type	*Flow type*	*Container type*	
		Full	*Empty*
Gate in	Export	0.730	0.770
	Inter-terminal transshipment	0.270	0.230
	Total	1.000	1.000
Apron in	Import	0.270	0.840
	Intra-terminal transshipment	0.510	0.100
	Inter-terminal transshipment	0.220	0.060
	Total	1.000	1.000

Table A4 Average dwell time of containers (unit: day)

Accumulative probability	*Flow type, container type*							
	Import		*Export*		*Intra-terminal transshipment*		*Inter-terminal transshipment*	
	Full	*Empty*	*Full*	*Empty*	*Full*	*Empty*	*Full*	*Empty*
0.05	0.30	0.16	1.50	1.70	0.81	1.43	0.19	0.76
0.10	0.72	0.33	2.37	2.93	1.49	2.86	0.52	1.25
0.15	1.06	0.48	2.87	3.98	2.00	3.56	0.76	1.62
0.20	1.52	0.68	3.40	4.99	2.64	4.01	1.05	1.95
0.25	1.99	0.91	3.87	6.06	3.24	5.19	1.31	2.51
0.30	2.48	1.18	4.31	7.00	3.84	6.11	1.55	3.18
0.35	2.98	1.54	4.74	7.89	4.48	6.82	1.79	3.96
0.40	3.54	1.90	5.17	8.74	5.06	8.69	2.05	4.46
0.45	4.13	2.39	5.60	9.85	5.59	10.81	2.36	5.02
0.50	4.77	2.85	6.05	11.00	6.09	12.50	2.69	5.86
0.55	5.48	3.49	6.53	12.58	6.60	14.12	3.05	7.20
0.60	6.26	4.20	7.03	13.97	7.10	14.61	3.46	8.32
0.65	7.10	5.11	7.55	16.14	7.67	15.38	3.93	9.61
0.70	8.21	6.62	8.26	19.28	8.41	16.83	4.57	11.64
0.75	9.21	8.06	8.95	23.06	9.17	18.65	5.17	12.89
0.80	10.50	9.83	9.85	27.30	10.26	20.55	5.94	15.88
0.85	13.04	12.44	10.95	30.67	11.50	21.41	6.89	17.78
0.90	16.85	16.22	12.36	34.97	12.98	23.44	8.15	20.06
0.95	21.89	23.04	14.63	40.07	15.50	27.75	10.37	23.31
1.00	31.29	37.10	21.43	54.09	21.67	43.86	16.20	37.21

Figure A1 ExtendSim simulation model (see online version for colours)

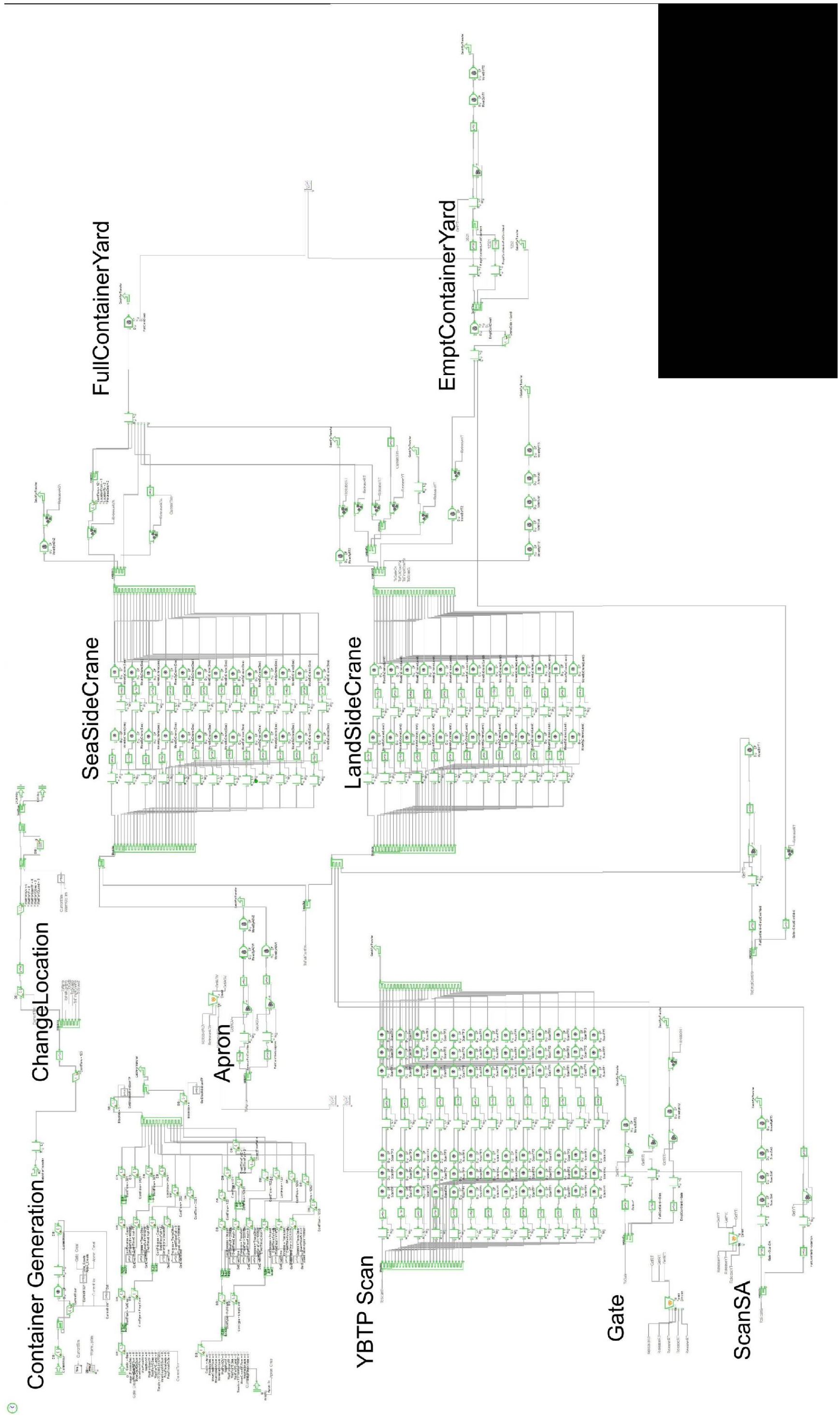

Table A5 Location (layout) of port facilities

Unit: metre	*Port facility*				
	Apron	*Full container yard*	*Service area (ScanSA)*	*Empty container yard*	*ScanTP*
Centre of X coordinate	700	819	811	581	165
Centre of Y coordinate	544	298	55	70	258
Width	1,400	975	0	0	331
Height	0	377	0	0	457

Table A6 Process time of equipment

Equipment		*Process time (seconds)*
Scanner	ScanSA	120
	ScanTP	120
Yard crane	Waterside	382
	Landside	559

Table A7 Container flow process

In type	*Container type*	*Flow type*	*Container flow process*
Gate in	Full	Export	Gate – Full container yard – Apron
			(when scanning is required)
			Gate –ScanSA – Full container yard – Apron
			(when scanning is not required)
		Inter-terminal transshipment	Gate – Full container yard – Apron
			(when scanning is required)
			Gate – ScanSA – Full container yard – Apron
			(when scanning is not required)
	Empty	Export	Gate – Empty container yard – Full container yard – Apron
		Inter-terminal transshipment	Gate – Empty container yard – Full container yard – Apron
Apron in	Full	Import	Apron – Full container yard – Gate
		Intra-terminal transshipment	Apron – Full container yard – Apron
			(when scanning is not required)
			Apron – Full container yard – ScanSA – Full container yard – Apron
			(when scanning is required within ScanSA scenario)
			Apron – ScanTP – Full container yard – Apron
			(when scanning is required within ScanTP scenario)

Table A7 Container flow process (continued)

In type	*Container type*	*Flow type*	*Container flow process*
Apron in	Full	Inter-terminal transshipment	Apron – Full container yard – Gate
	Empty	Import	Apron – Full container yard – Empty container yard – Gate
		Intra-terminal transshipment	Apron – Full container yard – Empty container yard – Full container yard – Apron
		Inter-terminal transshipment	Apron – Full container yard – Empty container yard – Gate