DEVELOPMENT OF OPERATION STRATEGY TO IMPROVE EFFICIENCY FOR TWIN AUTOMATED TRANSFER CRANE IN AN AUTOMATED CONTAINER TERMINAL

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Abstract

In order to become a mega hub port, major ports all over the world are making every effort to enhance their productivity through efficiency of internal operation. Accordingly, in order to enhance the competitiveness of a container terminal, an automated container terminal is considered as the best alternative. An automated container terminal is using such automated handling equipment as AGV (Automated Guided Vehicles) and ATC (Automated Transfer Crane). The efficient equipment operation plays a critical role in enhancing the productivity of an automated container terminal.

In an automated container terminal, the most important equipments are AGV and ATC. Each block of containers with a vertical layout is generally operating two ATCs. The two ATCs can be crossed or not at each block. In the case of operating crossover ATC, it has an advantage of high flexibility that ATC work is possible at both TPs (Transfer Point) of each block. But it has also a disadvantage that the yard has to be operated at a low storage level of containers in the terminal yard. Recently, for automated container terminals, which are being prepared for opening in Korea, they plan to use uncrossed twin ATC in order to make the storage level of their yards high at a low cost. Therefore, studies have to be made in order to increase the efficiency of twin ATC system based on the flexibility that the crossover ATC system has. This research aims to suggest an operation strategy to improve efficiency of twin ATC at each storage block in a yard.

Key words: Automated container terminal, Crossover ATC, Twin ATC, Operation strategy

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1. INTRODUCTION

Port logistics volume is steadily increasing along with growing global economy. The container ship companies that are seeking economy of scale are introducing ultra large containerships, letting them call at only hub ports, and using feeders for the other small ports. Because of these environmental changes in major ports and in shipping business, many large container terminals all over the world are making all efforts to attract ultra large container ships, trying to secure more container cargoes, and investing much money in their ports in an effort to be a hub port. In particular, in order to satisfy diverse customers (including shipping companies, shippers, forwarding companies, and transporters), these container terminals have to increase productivity. For enhancement of productivity, instead of paying attention to manpower-centered work, they are focusing on automation that can bring high efficiency. An automated container terminal refers to the one that makes use of automated transportation equipment such as AGV (Automated Guided Vehicle) and ATC (Automated Transfer Crane). For this reason, the careful selection and efficient operation of transportation equipment plays a critical role for enhancement of the productivity of an automated container terminal.

Meanwhile, the yard of a container terminal is a place where numerous containers for import and export move in and out for loading and unloading, and also are to be kept for a while before being delivered to the shippers. A yard has a limited space and is not easy to expand or change its capacity. As mentioned above, logistics volume is steadily increasing, and the yard space is not easy to expand. In this case, therefore, in order to enhance the productivity of the container terminal by making efficient use of its yard, how to operate the yard has to be carefully designed from the planning stage. It is very important in the sense that yard organization brings an efficient interface between the work processes in a container terminal (Franke, 2004).

Yard management of a container terminal usually depends on the operating company of a container terminal, operating method, logistics volume of container, and regional circumstances, but its role is to make maximum utilization of facility and space in the yard. And it affects directly productivity of the terminal. Therefore, a reasonable and proper yard operation can bring not only productivity improvement but also cost reduction without causing additional investment. Korea is currently making many efforts for the development of an automated container terminal, and many researches are being made on the proper type of ATC used in the container terminal. Concerning the ATC now being used in many countries, type of their equipment, operating system, the number of ATC in each block, and the layout of the storage block, in which ATC is in operation, are different from each other. Also, their operation methods vary from each other in many ways. It is so because each container terminal has been developed according to their cargo volume, cargo characteristics, and the physical features of their container terminal. For these reason, it is not easy to make a decision on what type of ATC is suitable for a new automated container terminal.

Usually, under the given ATC type, many researches have been made in order to enhance the efficiency of yard operation, including ATC operation method, decision making on container location in block, re-marshaling and re-handling methods. Vis (2002) has developed a heuristic algorithm, which minimizes empty travel distance of handling system in the container stacking yards. Kim and Park (2002) proposed the operational rules for yard crane dispatching and container allocation for the yards with crossover RMGCs (Rail Mounted Gantry Crane) in automated container terminals. And Ng (2005) examined the scheduling problem of multiple yard cranes to perform a given set of jobs with different ready times in a yard. He used integer programming and a dynamic programming-based heuristic to solve the scheduling problem. There are also studies on integrated scheduling for handling equipment including a yard crane in an automated container terminal (Meersmans and Wagelmans, 2001; Park *et al.* 2006).

Besides, researches on the proper selection of equipment have been made for the sake of efficient yard operation. Fisher *et al.* (1988) suggested the heuristic rules for the selection of proper equipment type in terms of the economical and technical point of view. Welgama and Gibson (1996) suggested a method to simultaneously make a decision on both the layout and equipment selection of a container terminal. Also, Vis (2006) compared the performance of manned straddle carriers and automated stacking cranes by means of simulations. Meanwhile, comparative analyses have been made on the characteristics and efficiency of ATC that are now in operation in the container terminals. Saanan and Valkengoed (2005) compared three different RMGCs – single RMGC, crossover RMGC, and twin RMGC – to check their efficiency in terms of productivity, flexibility, area utilization and cost. Through this comparison, they concluded that the crossover RMGC that have got the highest mark in terms of productivity and flexibility is the best performing one. However, the benefit in terms of them was not big in comparison with the twin RMGC. And the twin RMGC showed better performance than the crossover in terms of storage capacity, system complexity, investment cost and operational cost.

In this study, we try to design an efficient yard layout and yard operation method in order to improve the efficiency of the twin ATC, when considering introduction of the twin ATC which is superior to the crossover ATC in terms of low investment cost, operational simplicity, and higher storage capacity. And we prove superiority of the new twin ATC system through a simulation.

More specifically, the new operation strategy of the twin ATC can make the second ATC of landside perform the work of the seaside TP (Transfer Point) simultaneously, when work load is getting higher at the seaside TP of each block due to loading/unloading containers on a ship. For example, the seaside TP can be moved to the inside of a storage block in order to let the second ATC work without interference of the first ATC at seaside TP, through evacuating the containers in some rows in the storage block. In order to evaluate the new operation strategy, we compared it with the existing twin ATC and the crossover ATC according to following criteria, such as the completion time for handling all the containers allocated to the fixed storage location, the average waiting time of AGV and trucks at the TP, the delay time caused by ATC interference and the total travel distance of ATC. Also, under the different environments in terms of the total amount of container handlings and the number of containers handled at transfer point of seaside and landside in the storage block, the new operation strategy of twin ATC are tested and compared with the general twin ATC and the crossover ATC. To this end, this study develops a simulation model, and tests it under diverse environments. And the same ATC dispatching rule at TP and the strategy for interference avoidance of ATC are used in this simulation.

2. CHARACTERISTICS OF STACKING CRANE SYSTEM IN THE YARD

The stacking yard of a container terminal is usually using the following stacking equipments: straddle carrier, RTGC (Rubber Tired Gantry Crane), and RMGC (Rail Mounted Gantry Crane). The straddle carrier can have a density of 500 – 600 TEU/ha, RTGC can have a density of 900 – 1,100 TEU/ha, and RMGC a density of over 1,200 TEU/ha (Saanen and Valkengoad, 2005). This means that RMGC is possible to stack containers higher and denser without additional land obtainment.

For this reason, many automated container terminals are using an automated RMGC in the yard as handling equipment. In this study, an ATC refers to an automated RMGC. The ATC is an automated crane that moves containers inside the yard, and also transfers containers to AGV or other trucks. AGV is an unmanned vehicle that loads containers from an ATC or a quay crane, and moves automatically between ATC and quay crane. Container handling at seaside can be performed by mutual cooperation between quay crane, ATC, and AGV. The typical layout of a container terminal using ATC is shown in figure 1.

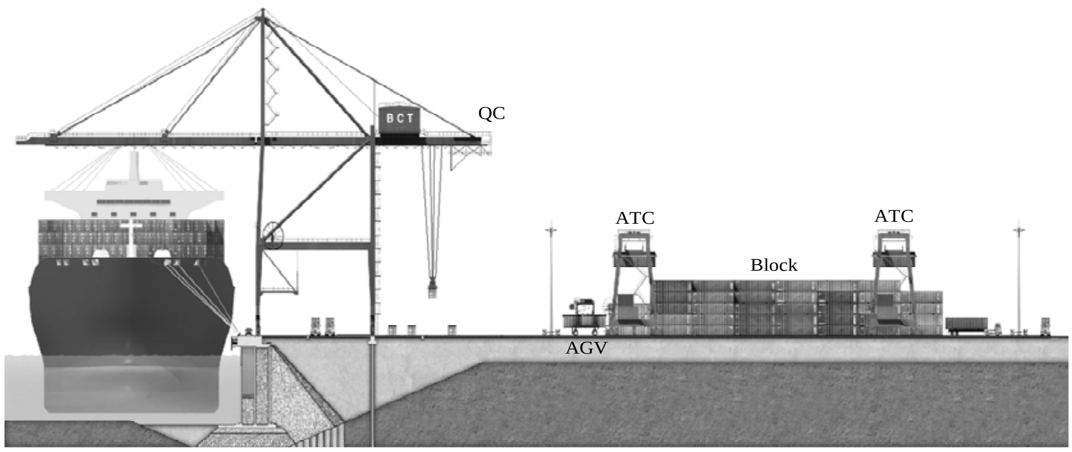


Figure 1. The typical layout of an automated container terminal using ATC

At present, ECT (Europe Combined Terminal) in Rotterdam and CTA (Container Terminal Altenwerder) in Hamburg are using ATC, and Euromax Terminal in Rotterdam is also scheduled to introduce ATC. The Sinsundae Terminal in Busan is using ATC in its blocks of a horizontal layout type. The ATC in ECT is 6 wide and 1 over 2 to 1 over 4 high, and each block has one ATC. In case of CTA, each block has two ATCs that can be crossed. One of them is 10 wide and 1 over 4 high, the other is 14 wide and 1 over 5 high. In case of Euromax under construction, each block is scheduled to have two ATCs that won't be crossed. These two ATCs will have the same size of being 10 wide and 1 over 5 high.

In comparison with CTA type and Euromax type, ECT type can operate much more blocks in a yard and the division of workload can be made easily. But it has a disadvantage that the total productivity becomes low because of one ATC's operation per each block. This type is a proper stacking system for the container terminals that have many transshipment containers. In case of most automated container terminals recently being in construction, each block is of vertical layout and two ATCs. In line with this trend, the typical stacking systems in an automated container terminal are the crossover ATC of CTA and the twin ATC of Euromax.

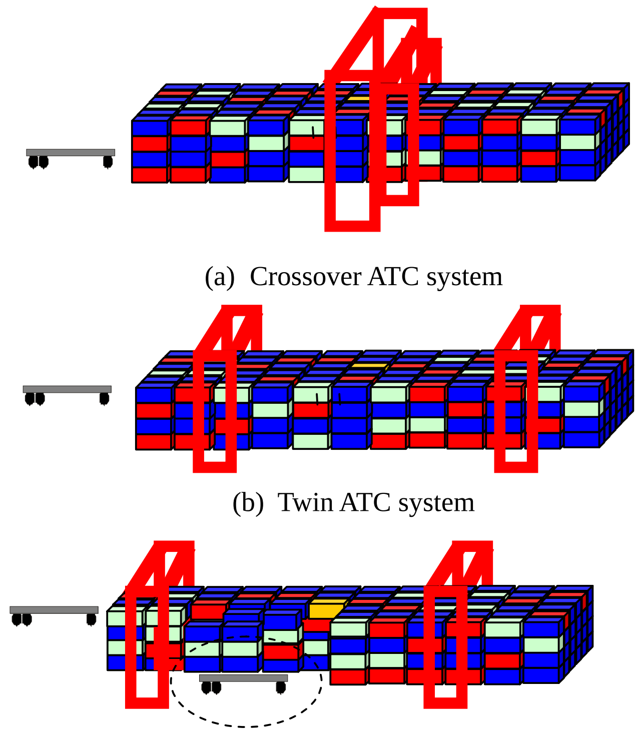
As the crossover ATC can use two units of cranes simultaneously, when both seaside and landside are busy with cargoes, it has a high flexibility, thus enhancing productivity. However, as the size of two ATC is different, the stacking height can be decided by the small size of ATC. This means that the stacking height of the crossover ATC is lower than twin ATC, consequently leading to lower storage capacity. To keep its stacking height as high as the twin ATC, the crossover ATC system needs a bigger ATC, which requires additional investment. Also it needs additional rails which cause high investment cost and low storage capacity. Moreover, the crossover ATC demands a highly delicate control system for two ATCs that are in cross operation.

That is, in terms of productivity and flexibility, the crossover ATC has an advantage, but it also has a disadvantage from the aspect of storage capacity, system complexity, investment cost and operational cost. However, compared with the crossover ATC, the twin ATC is better in terms of storage capacity, system complexity, investment cost and operational cost. In addition, as the twin ATC can have a more number of blocks in a limited area than the crossover ATC, it makes it possible to split the workload of yard cranes. In fact, in terms of productivity, the crossover ATC and the twin ATC show no much difference. Therefore, if the twin ATC can raise its flexibility, its strong points will be doubled. This study focuses on finding out a solution for this problem.

3. SIMULATION MODEL FOR STACKING CRANE SYSTEM

In order to improve the flexibility of a twin ATC system, which is a key alternative for the stacking system of an automated container terminal, this study suggests a new operation strategy of the twin ATC system, compares it with the existing twin ATC and the crossover ATC system, and consequently prove the efficiency of the new operation strategy through simulation with some criteria.

The newly suggested twin ATC system enables the two ATCs to work at the seaside of each block. That is, some containers in the two rows of each block are removed, and one TP at the seaside are to be transferred to the middle bay of each block, so that the second ATC (landside ATC) is able to do the seaside work. The three kinds of stacking systems are illustrated in figure 2.



(a) Crossover ATC system

(b) Twin ATC system

(c) New twin ATC system

Figure 2. Stacking crane system in a yard of container terminal

3.1 Simulation Environment

This study develops a simulation model to evaluate the new operation strategy based on some criteria. The following factors in each block – the size of each block, the number of container moves, the initial condition of each block, the order list at the seaside and at the landside, container location in block pertaining to the order list, and the travel velocity of equipment – are used for the simulation under the same condition in order to make a comparison of three kinds of above-mentioned stacking system. Our simulations are conducted by a program developed through Java 2 JDK 1.6 and MySQL 5.0 on an Eclipse 3.1.2. The simulation environment of three stacking systems can be summarized as follows.

3.1.1 Crossover ATC System

- Number of a block: 1
- Length of a block: 40 TEU

- Number of rows in a block: 10 wide
- Number of TP (seaside and landside): 5
- Speed of ATC: 3.0 m/s (large), 4.0 m/s (small)
- Trolley speed & Hoist speed: 1 m/s
- Positioning time on an AGV: 10 seconds
- Positioning time on a truck: 30 seconds

In the ATC system, a gantry and a trolley can move simultaneously. The container move in the block needs a positioning time of 10 seconds in addition to the travel time of a crane. ATC crossing can be made only when the trolley of a large ATC is placed at the crossing location, and crossing can be made without reducing speed. The waiting time for the crossing of two ATCs is required only when the small ATC tries to cross the large ATC that is at work and the distance between the works of the two ATCs is within three bays. Priority is given to the work of trucks, so that the trucks arrived at the landside can finish their job within 10 minutes after their arrival.

One of the two ATCs works at the landside, the other works at the seaside. But if there are more than two jobs to be done at the other TP while own TP is idle, the other ATC can move to the TP for help. And if job happens at the TP on the opposite side while supporting, the ATC that is the nearest to the TP moves for the job. The jobs at the five TPs are done based on FIFO (First In First Out) rule.

3.1.2 Twin ATC System

- Number of a block: 1
- Length of a block: 40 TEU
- Number of rows in a block: 10 wide
- Number of TP (seaside and landside): 5
- ATC speed: 4.0 m/s
- Trolley speed & Hoist speed: 1 m/s
- Positioning time on an AGV: 10 seconds
- Positioning time on a truck: 30 seconds

The ATC at the landside works at the landside TP, and the ATC at the seaside works at the seaside TP. The two ATCs are fixed on each TP. The two bays in the middle of each block are used as a relay zone for moving in a block. Accordingly, container moves are made between the relay zone and the corresponding TP of each ATC. Also, if the distance between the two ATC is within three bays, one ATC has to wait until the other ATC finishes its work. In the twin ATC system, a gantry and a trolley can move simultaneously. Container move in the block needs a positioning time of 10 seconds in addition to the travel time of a crane. The works at the five TPs are done according to FIFO rule.

3.1.3 New Twin ATC System

- Number of a block: 1
- Length of a block: 40 TEU
- Evacuation part in a block: 20 bays of 2 rows
- Number of rows in a block: 10 wide
- Number of TP (seaside and landside): 5
- ATC speed: 4.0 m/s
- Trolley speed & Hoist speed : 1 m/s
- Positioning time on an AGV: 10 seconds
- Positioning time on a truck: 30 seconds

The operation strategy of the new twin ATC system is, for the most part, the same as that of a twin ATC system. But since one seaside TP is shifted in the block, a new rule for the AGV coming into this TP is needed. In this study, an AGV is allocated to use the TP, when it handles the containers placed or to be placed in the work area of the second (landside) ATC ranging from a relay zone to the landside TP. Up to two AGVs can wait for work in the inside TP. If the number of waiting AGV is two at the inside TP, no more allocation is allowed. In case of two AGVs are waiting at the inside TP, the work is done on LIFO (Last In First Out) rule. The works at other TPs are done according to FIFO rule.

3.2 Test Environment and Simulation Parameter

In order to compare and evaluate three stacking systems, simulation is performed under the same environment. The size of each block is the same, and the initially stored containers' condition of each block is also the same. The arrival interval of works to be done at the seaside and landside TP is randomly occurred between 50 and 100 seconds. The order list of all the works that need to be done is made in advance. The information on containers' location in a block related to the works is given before. All these information is filed in a database for simulation, and so three stacking systems are simulated under the same environment. Re-handling inside a block is not taken into consideration.

And the simulation is performed under various parameters - number of containers and container ratio handled at the seaside and landside TP, so that three stacking systems can be compared and evaluated. The values of parameters used in the tests are as follows:

- The number of containers handled: 100, 300, 500, and 1,000
- The work ratio of the seaside TP and the landside TP within the number of containers handled: 5:5 and 8:2

4. RESULTS OF SIMULATION

In order to compare and evaluate three stacking systems, simulation was performed for the following criteria: completion time for handling all containers, the average waiting time of AGVs and trucks at the seaside TP and landside TP, total travel distance of ATCs, and the delay time caused by ATC's interference. The simulation was iterated 10 times with new initial values under every situation. The final results are mean value which is obtained from 10 runs.

Table 1 shows the completion time of three stacking systems. The completion time of the new twin ATC system is shortest among three systems when seaside is busy (8:2). The completion time of the crossover ATC system is shortest among them when landside is busy (5:5). In this test, the completion time is not significant criterion for evaluating the efficiency of stacking cranes because the completion time depends on the last work of order list. But it shows that the better completion time of the new twin ATC at the iterated tests could be accompanied by improved productivity through its higher flexibility. It can imply the productivity improvement of new twin ATC system although the meaning is not big.

Table 1. The completion time of three stacking systems

# of container	Ratio	Crossover	Twin	New Twin
100	5:5	7571.5 (sec.)	7598.6 (sec.)	7576.7 (sec.)
	8:2	7674.9	7671.1	7664.1
300	5:5	22805.6	22830.4	22818.8
	8:2	22759.4	22755.2	22728.6
500	5:5	37781.3	37805.6	37804.9
	8:2	37808	37791.8	37786.6
1000	5:5	75607.1	75611	75608.8
	8:2	75814.6	75804.6	75755.8

Table 2 and figure 3 show the average waiting time of AGVs and trucks at each TP. The crossover ATC has the lowest values at landside, but the new twin ATC has the lowest values at seaside in all of cases. This is made possible by the increased flexibility of new twin ATC operation. It shows that the seaside TP's movement into the block increases flexibility of twin ATC operation obviously. The new twin ATC system will be able to give higher productivity to a container terminal.

Table 2. The average waiting time of AGVs and trucks at each TP

# of container	Ratio	TP	Crossover	Twin	New Twin
100	5:5	landside	63.02 (sec.)	70.8 (sec.)	68.44 (sec.)
		seaside	53.55	50.95	48.25
	8:2	landside	56.99	68.56	63.87
		seaside	64.71	52.1	44.19
300	5:5	landside	66.12	74.64	70.4
		seaside	56.35	52.6	49.2
	8:2	landside	50.6	62.45	59.05
		seaside	70.2	52.6	42.6
500	5:5	landside	71.8	75.97	75.85
		seaside	55.8	53.40	52.35
	8:2	landside	54.4	68.67	64.82
		seaside	70.2	53.2	43.2
1000	5:5	landside	67.2	74.86	74.61
		seaside	55.2	54.2	51.4
	8:2	landside	54.6	66.8	62.8
		seaside	69.6	54.2	44.35

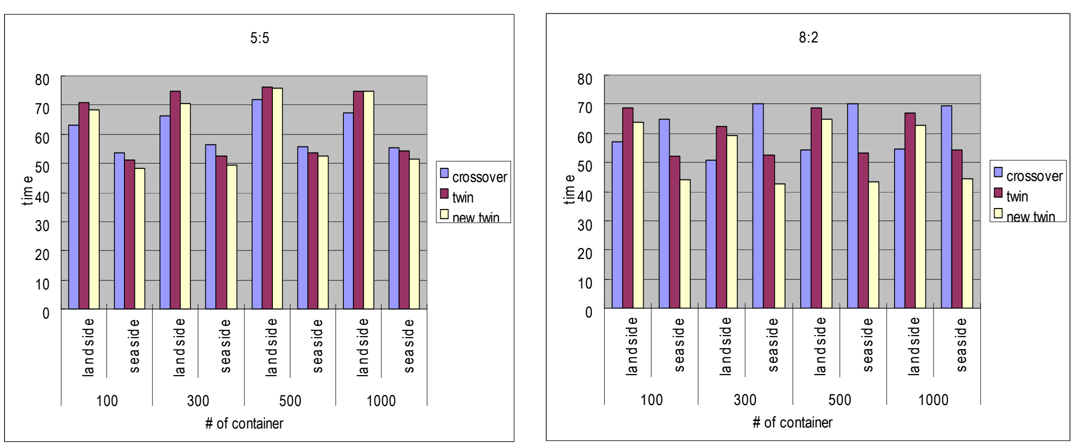


Figure 3. The comparison of average waiting time of AGVs and trucks at each TP

Table 3 shows the total travel distance of three ATC systems. It is confirmed that the new twin ATC system has the shortest travel distance. It was made by movement of seaside TP totally. The shortest travel distance of the new twin ATC system can contribute to improve the productivity of a container terminal. But on the other hand, the twin ATC system has the longest travel distance. The relay zone, which aims to shorten a travel distance, carries little significance. The longest travel distance is believed to have a negative effect on other evaluation criteria.

Table 3. The total travel distance of ATCs (meter)

# of container	Ratio	Crossover	Twin	New Twin
100	5:5	18801.25 m	22491.95 m	16495.7 m
	8:2	20931.3	24437.4	14714.7
300	5:5	58882.2	68614	51212.2
	8:2	62238.8	76913.2	43781.4
500	5:5	99040.5	114558.6	84527.3
	8:2	104962	128655.8	74124.7
1000	5:5	197259.4	229053.5	168727
	8:2	207873.9	253146.4	147264

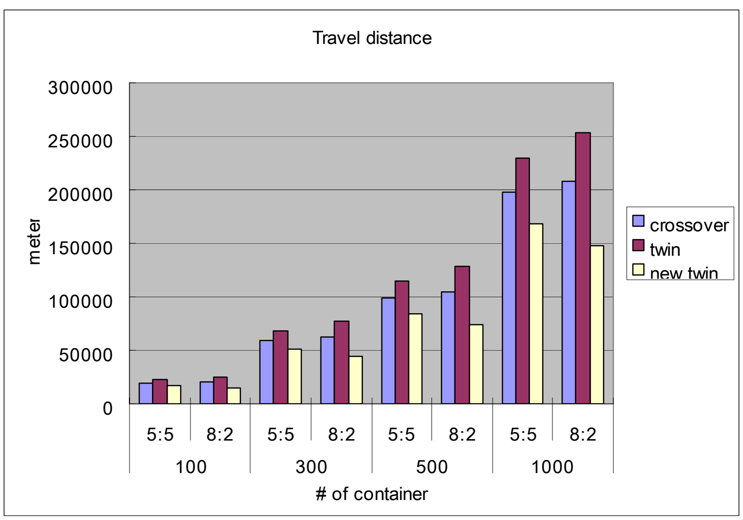


Figure 4. The comparison of total travel distance of ATCs

Table 4 shows the delay time caused by ATC's interfering with each other. The twin ATC has the longest delay time. It is guessed because of many relay tasks. Also, the results show that the flexibility of the new twin system decreases the delay time in comparison with the twin ATC system.

Table 4. The delay time of ATCs

# of container	Ratio	Crossover	Twin	New Twin
100	5:5	49.1 (sec.)	31.8 (sec.)	19.1 (sec.)
	8:2	20.4	57.6	12.9
300	5:5	68.4	182.2	97.2
	8:2	88.6	152.2	19.4
500	5:5	412.4	366.6	187.4
	8:2	102.8	318.2	38.2
1000	5:5	575.4	676.2	347.6
	8:2	215.2	641	113.8
Mean		191.5375	303.225	104.45

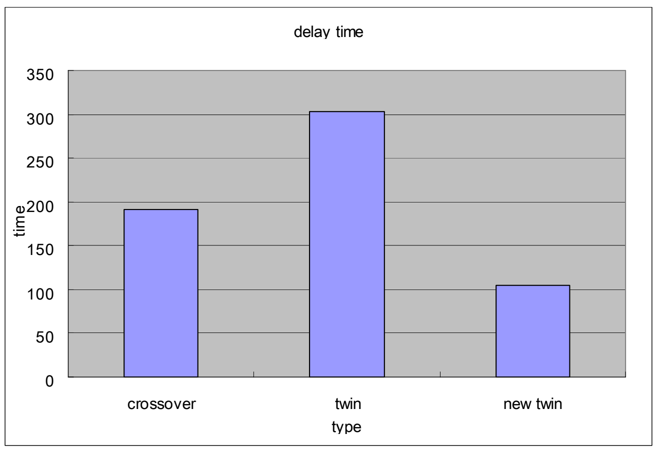


Figure 5. The comparison of delay time of ATCs

The twin ATC has longest travel distance and delay time which is the main cause of the low productivity. Their low productivity comes from low flexibility. The results of overall evaluation reveal that the new twin ATC system has the improved productivity and flexibility. The new twin ATC is superior to the twin ATC in the evaluation criteria and even crossover ATC in some evaluation criteria. This proves the efficiency of the new operation strategy suggested for a twin ATC system.

5. CONCLUSION

This study suggested a new operation strategy for twin ATC that carries important advantages including low investment cost, operational simplicity, and high storage capacity, and proved its efficiency through simulation. The new operation strategy succeeded in improving the flexibility of the work in the seaside, consequently leading to productivity enhancement.

The technical aspect such as the control of an AGV that moves into a block in the new twin ATC system requires further study. But as this task goes beyond the limits of this study, it has not been dealt with in this research. From now on, more studies should be made to consider how the degree of container evacuation in a specific block could affect productivity and storage capacity as well as overall profit. Also, a more concrete operation method such as the priority of work at each TP has to be made to improve operation efficiency of the new twin ATC system.

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