AGV APPLICATIONS FOR SHORT SEA CONTAINER TERMINALS

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Abstract – *Container terminal authorities have been forced to find more efficient techniques to improve the performance in order to deal with huge amounts of containers processing by the dramatic growth in the freight volumes. Advanced technologies like automated guided vehicles (AGV) and automated lifting vehicles (ALV) have been recently used in container terminals to improve efficiency owing to their abilities on the repetitive nature of the terminal operations. Contrary to deep sea container terminals, short sea container terminals like in Turkey are built as artificially filled near the coasts because of their low berth deepness. The most common layouts in the short sea container terminals are* Π, *L, Ψ or π berth typed. In this paper, an object oriented simulation model is developed for* berth type Π *and used to demonstrate the impact of automation on the performance of the short sea container terminals. Indeed, we concentrate on the effects of AGV dispatching rules on the determined performance criterion of total container handling in quay cranes. The results of the simulation show that AGV dispatching rules and terminal layouts have significant effects on the performance of the terminals and the number of the AGVs used.*

Key Words – *AGV dispatching rules, object oriented simulation, short sea container terminals*

INTRODUCTION

Today, almost all overseas shipping of furniture, toys, footwear, clothing, auto parts, electronics components, and computers is done via standardized 20", 40", and 45" long steel containers aboard deep-sea container vessels. In addition, the amount of fruit, vegetables, fish, meat, and general foodstuffs shipped in refrigerated containers is increasing. In today's just-in-time global supply chain, improving the efficiency of container shipping processes is more important than ever.

In seaports, container terminals are the places where container vessels are loaded and unloaded, and where the containerized cargo is temporarily stored while awaiting a future transportation.

These facilities can be classified as automated and non-automated considering the equipment technologies used. In automated container terminals, container info and automatic control technologies are used. These kinds of terminals have been established in Western Europe countries where work force is expensive. So, these terminals are more efficient than the others and also, the operation costs of these terminals are less than others. Moreover, in non-automated container terminals, the operations are carried out under the human control. In contrary, this kind of terminals has been established in South-East Asia countries where work force is cheaper (Steenken et. al., 2004).

In container terminals, three types of services such as import, export and transit are executed according to container trade types. One of these services is for import during which containers come by vessel and exit from gate; the other one is for export during which containers come by external transporters (XTs) and exit from berth by vessel; the last one is for transit during which containers come by vessel and exit by another vessel.

Different equipments are used while these services are being executed. In Fig. 1, services executed in a container terminal, transportation and handling operations and the equipments used during the operations are shown. Basically, three types of equipments are used in terminals. These equipments are; firstly quay cranes used for unloading/loading the container from/to vessel, secondly yard cranes used for stacking containers at yards for unloading/loading the container from/to transporter vehicle, and lastly the transporter vehicles used for transportation operations between berth and yard.

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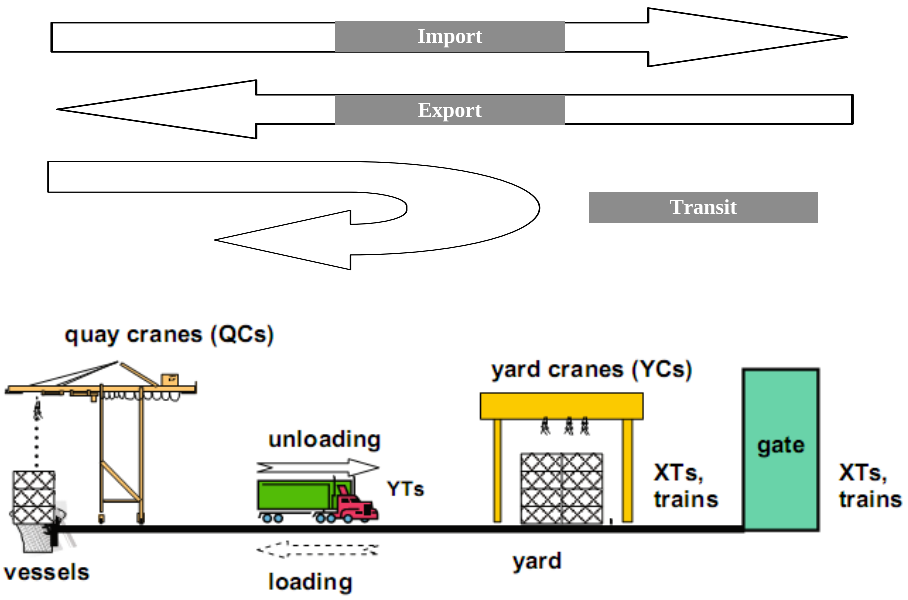

FIGURE. 1
Terminal Services and Equipments (Petering and Murty, 2009)

In automated container terminals, AGVs are similar to conventional trucks, but they operate driverless on a pre-defined guide path. ALVs are vehicles which move over a container, lift it up and transport it to the designated storage location. Contrary to ALVs, AGVs need to interact with a crane. In recent years, Lift AGVs are the systems which can leave and take containers to the buffer areas without lifting them. In non-automated terminals, straddle carriers or conventional yard trucks (YTs) are used for moving containers inside the terminal. On the landside, many European container terminals have railway links which are not so common in most Asian countries (Kulak et. al., 2011).

In the literature, AGV dispatching rules were tested firstly by Egbelu and Tanchoco (1984). Additionally, Durrant-Whyte (1996) and Evers and Koppers (1996) are the first academic studies about AGV applications at container terminals. The design of AGV systems in container terminals is still a common problem. For comprehensive reviews of AGV systems in container terminal literature, we would like to refer to the surveys by Vis (2006) and Roodbergen and Vis (2009).

Qiu et. al. (2002), Kim and Bae (2004), Bish et. al. (2005), Grunow et. al. (2006), Vis and Bakker (2008), Nguyen and Kim (2009) and Angeloudis and Bell (2010) are significant studies about AGV dispatching rules in automated container terminals

In this study, AGV dispatching rules are tested for a Π berth type container terminal layout using simulation by the help of the performance criterion of the total container handling in quay cranes. Hence, a object-oriented simulation model has been developed by using Arena 10.0. Some information about artificially filled type container terminals is given in the second part of the study. AGV dispatching rules are mentioned in the part 3 and some information about the designed container terminal is given in the part 4. In part 5, the simulation model which has been developed for testing is mentioned and the results of the simulation experiments are discussed with their statistically analysis. Finally, in the last part, the results of the study are presented.

ARTIFICIALLY FILLED TYPE CONTAINER TERMINALS

It is obvious in the scientific literature that AGV applications in automated container terminals are for the terminals in huge seaports. All of these huge seaports are built in deep coasts named as natural ports. Usually, container terminals in natural ports have just one major berth extending in parallel to the coast. However, in these terminals, yards are built perpendicularly or in parallel to the major berth.

Contrary to the natural ports, there may be several berths in the artificially filled ports where there are shallow seas. The most common ones above these types are; Π, L, π or Ψ berth typed. Berth and yard layout types of the artificially filled container terminals are described below:

Π berth type: The entire terminal is placed in the port which is artificially filled as peninsula. Yard area is placed in the middle of three berths which surround the peninsula. The terminals in Haydarpasa and Izmir ports are the examples for this type.

L berth type: While the yard area and one berth of the terminal are placed in the port, the other berth is built by filling the sea. Sometimes, this filled berth can be used as partial yard area. The container terminal which is placed in Mersin port is an example of this type.

Ψ berth type: While the yard area of the terminal is placed in the port, berths are placed in the long peninsulas which are filled perpendicularly to the sea. Sometimes, the berth which is artificially filled can be also used as partial yard area. Kumport container terminal in Ambarlı port is an example of this type.

π berth type: While the yard area of the terminal is placed in the port, berths are placed in the long peninsulas which are filled horizontally to the sea. Sometimes, the berth which is artificially filled can be also used as partial yard area. Shangai ports in Yellow Sea are examples of this type.

That container terminals in these kinds of ports have several berths may result in several yard areas in the terminal or horizontally or perpendicularly location of common yard area to the berths. As mentioned in Vis and Anholt (2010), Polat et al. (2010) and Kulak et al. (2011), the layout types of berths have a significant effect on terminal performance. This effect may lead AGV applications and dispatching rules in automated filled typed container terminals to differentiate according to the studies in the literature.

AGV DISPATCHING RULES

In the frame of this study, AGV dispatching rules are analyzed using two different ways. These are: transporter request rules and intersection rules. Transporter request rules are used when a transporter is requested from the berth, yards, and gate. On the other hand, intersection rules used in order not to come across traffic jam or have an accident during AGVs' travel on the designed paths are shown in Fig. 2.

a) Transporter Request Rules:

Smallest Distance: It is for selecting the available transporter nearest the requesting point.
Largest Distance: It is for selecting the available transporter farthest the requesting point.
Random: It is for selecting transporters randomly from the available transporter units.
Cyclical: It is for selecting the first available transporter unit beginning with the successor of the last unit selected.

b) Intersection Rules:

FCFS – First Come First Served: The vehicle that arrived first at the end of its incoming link is given control of the intersection first.
LCFS – Last Come First Served: The vehicle that arrived last at the end of its incoming link is given control of the intersection first.
Closest: Giving the intersection to the vehicle closest to its travel destination.
HVF – High Value First: Giving the intersection to the vehicle whose controlling entity has the highest value of Attribute ID. The highest value means that the transporter is loaded with export container.
LVF – Low Value First: Giving the intersection to the vehicle whose controlling entity has the lowest value of Attribute ID. The lowest value means that the transporter is loaded with import container.

DESIGNED CONTAINER TERMINAL

In the frame of the study, a large scaled Π berth typed and an artificially filled container terminal which can be built in a shallow coast area have been designed. Layout of this terminal which is designed as an automated container terminal is shown in Fig. 2.

In each berth of this terminal, there are two dual automated quay cranes. Also, in the yard area there are 18 blocks (9 blocks near to the gate for import containers, 9 blocks near to berths for export containers). In each block, twin automated stacking cranes, which have telescopic design, are assigned. For export containers, each block length is 270 m. (44 TEU), width is 40 m. (10 TEU) and height is 13 m. (5 TEU). Additionally, for import containers, each block length is 305 m. (50 TEU), width is 40m. (10 TEU) and height is 13 m. (5 TEU). In this condition, simultaneous stack capacity of the terminal is 42.300 TEU.

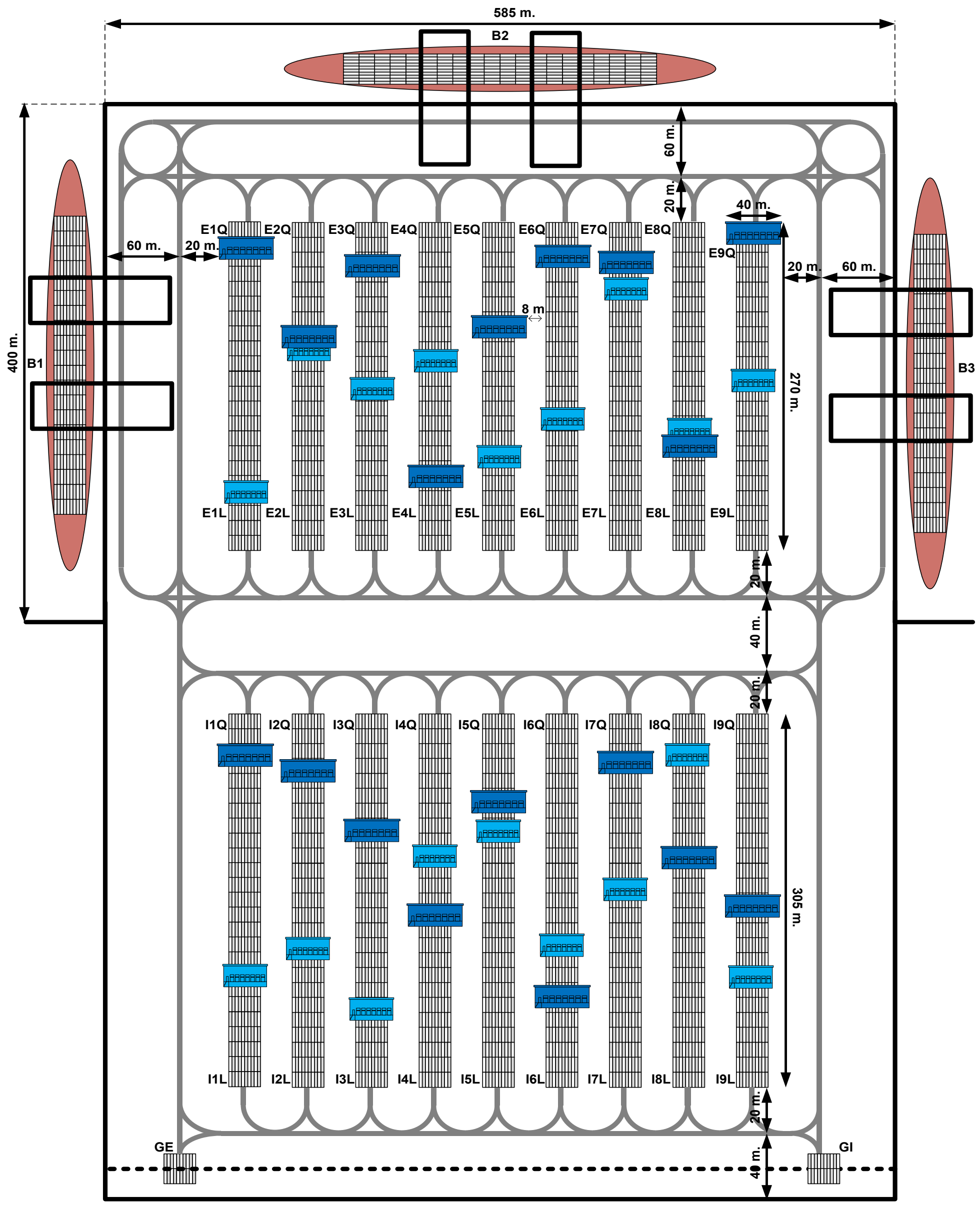

FIGURE. 2
Designed Terminal layout

The simple presentation of AGV paths in the terminal are also shown in Fig. 2. AGV load/unload zones in blocks are located at the endpoints of each block. For export containers, container loading zone is located at the berth side and container unloading zone is located at the landside of block. For import containers, container unloading zone is located at the berth side and container loading zone is located at the landside.

In this container terminal, there are buffer areas which have the capacity of 20 containers at each block and 10 containers at each berth because of lift AGVs. Owing to these buffer areas, yard cranes and AGVs can run loading/unloading operations independently. Hence, it is possible to decrease waiting times of terminal equipments considerably. Optimum number of AGVs used in terminal has been obtained separately for each simulation scenario because of the differentiating number of AGVs according to the tested rules.

SIMULATION TESTS

Simulation Model

In the simulation model which was developed by using Arena 10.0, vessels are the entities. In the first part of the model, features of the vessels (loading/unloading amounts, vessel types – large, medium and small) are assigned and these vessels are allocated to berths. In the second part, there are the operations executed at berths. Loading/unloading processes of the containers in these vessels, and assignment of the containers unloaded from the vessel to the yards and AGV assignments are carried out. In the last part, yard area operations are mimicked.

For the simulation tests, collected data are; inter arrival times of vessels, load to be charged onto a vessel, load to be discharged from a vessel, handling time of quay cranes, handling time of yard cranes, travel time of AGVs, average storage time in yard blocks (Import & Export), Import/Export ratio, equipment availability of quay cranes, equipment availability of yard cranes, equipment availability of AGVs. These data were analyzed using Arena Input Analyzer 10.0 and SPSS 16 following the concept of trace-driven simulation. Distributions with their parameters were determined with respect to minimum squared errors based on the Chi Square Test of the Arena Input Analyzer.

In the model, we assume that YTs and AGVs can carry only one container and operating conditions of the terminal are not affected by weather conditions and do not differ between the working shifts. We also assume that vessel arrivals at berths are unscheduled and thus considered as random events and the collected data may differ. So, the simulation tests are implemented under 3.000.000 TEU demand with 5 replications and one-year simulation time, and total container handling at QCs per year is used as performance criterion.

Numerical Results

In the first experiment set, the simulation model is used for analyzing transporter request rules in designed terminal. For this purpose, 4 different transporter request rules for AGVs and only cyclical transporter request rule for YTs are tested. In the scenarios where AGVs are used, closest is used as intersection rule. These scenarios are also tested with different transporter numbers in order to obtain the optimum transporter number. The effect of transporter request rules using different transporter numbers on total container handling at QCs per year is presented in Fig. 3.

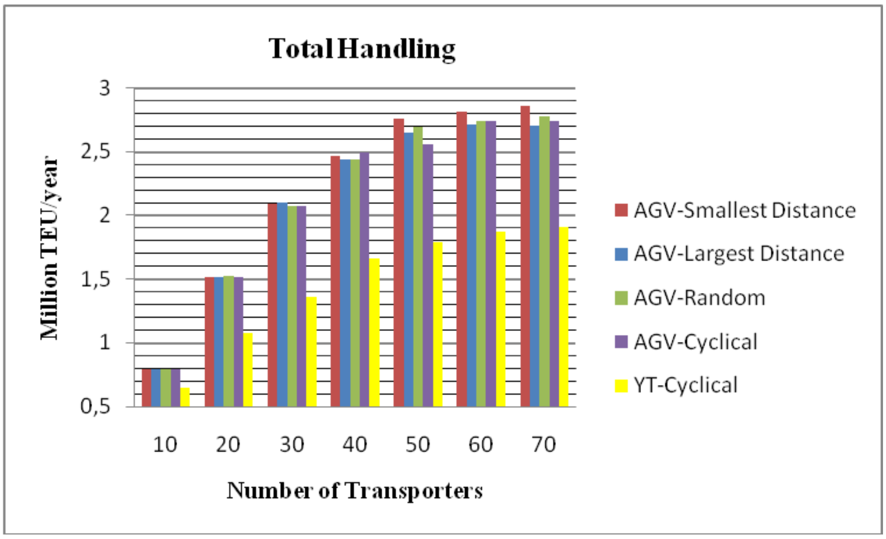

FIGURE. 3
The Effect of Request Rules Under Different Transporter Types and Numbers

As mentioned in Fig. 3, there is a significant difference between using lift AGVs and YTs. The main reasons for this are the low speed of YTs, the equipment failure and accident resulting from the human-controlled system.

In order to analyze the effect of the transporter number and AGV dispatching rules on the total container handling amount, Analysis of Variance (ANOVA) test is implemented with SPSS 16.0. In Table 1, the results of ANOVA test according to 140 simulation data for the effect of transporter number and AGV dispatching rules are presented.

TABLE 1
ANOVA Results For the Effect of Transporter Number and AGV Dispatching Rules*

Source	SS	df	Mean Square	F	Sig.
Transporter Number	$6{,}781 \times 10^{13}$	6	$1{,}130 \times 10^{13}$	$4{,}044 \times 10^{7}$	0,009
Transporter Request Rule	$5{,}921 \times 10^{10}$	3	$1{,}974 \times 10^{10}$	70622,824	0,000
Interaction*	$8{,}611 \times 10^{10}$	18	$4{,}784 \times 10^{9}$	17120,137	0,000
Error	$3{,}130 \times 10^{7}$	112	279444,178		
Total	$7{,}166 \times 10^{14}$	140			
Corrected Total	$6{,}795 \times 10^{13}$	139			

*Dual interaction of intersection and transporter request rules

In Table 1, transporter numbers have a significant difference at %95 confidence level. In other words, the increasing in transporter numbers leads to a notable increasing in total handling amount. In Table 2, the results of Tukey HSD test which are carried out to obtain the differences above are in favor of which transporter request rule are presented. Simulation results which are related to 7 different transporter numbers are used in tests for transporter request rules.

TABLE 2
Tukey HSD Test for Transporter Request Rules

		Homogeneous subgroups (Alfa = 0,05)			
Transporter Request Rules	N	1	2	3	4
Largest Distance	35	2131039,7			
Cyclical	35		2143968,2		
Random	35			2148402,8	
Smallest Distance	35				2186285,9

According to Table 2, it is obvious that the transporter request rule which has the highest handling amount is the smallest distance. So, assigning AGVs to containers with smallest distance rule will provide higher handling amount as it provides time-saving and decreasing in waiting times. In Table 3, the results of Tukey HSD test which is used for obtaining the most appropriate transporter number under smallest distance rule are presented.

TABLE 3
Tukey HSD Test for Transporter Numbers

		Homogeneous subgroups (Alfa = 0,05)					
Transporter Numbers	N	1	2	3	4	5	6
10	5	789789,7					
20	5		1518227,3				
30	5			2089242,3			
40	5				2463485		
50	5					2762870,5	
60	5					2814570,9	
70	5						2863610,5

As mentioned in Table 3, it is clear that there is no notable difference between the numbers of 50 and 60 transporters. So, for 51-54-57-60 numbered transporters, Tukey HSD test is again carried out to find out the optimum number of transporters between the ranges of 50-60. In table 4, Tukey HSD test results are shown.

In Table 4, there is a significant difference between the numbers of 51 and 54, 57, 60 transporters. However, there is no significant difference between the numbers of 54, 57 and 60 transporters. In this paper, although there is no feasibility study related to lift AGVs, the optimum number for these transporters are determined as 54 because of high purchase and installation.

TABLE 4
Tukey Hsd Test for Transporter Numbers

		Homogeneous subgroups (Alfa = 0,05)	
Transporter Numbers	N	1	2
51	5	2745641,6	
54	5		2789305,6
57	5		2800128,0
60	5		2814569,6

In the second experiment set, the simulation model is used for evaluating the scenarios with designed intersection rules in terminals. For this reason, 5 different intersection ruled scenarios for the transporter number 54 and 4 different transporter request ruled scenarios are tested. In Fig. 4, the effect of intersection rules on the performance criterion under different transporter request rules is shown.

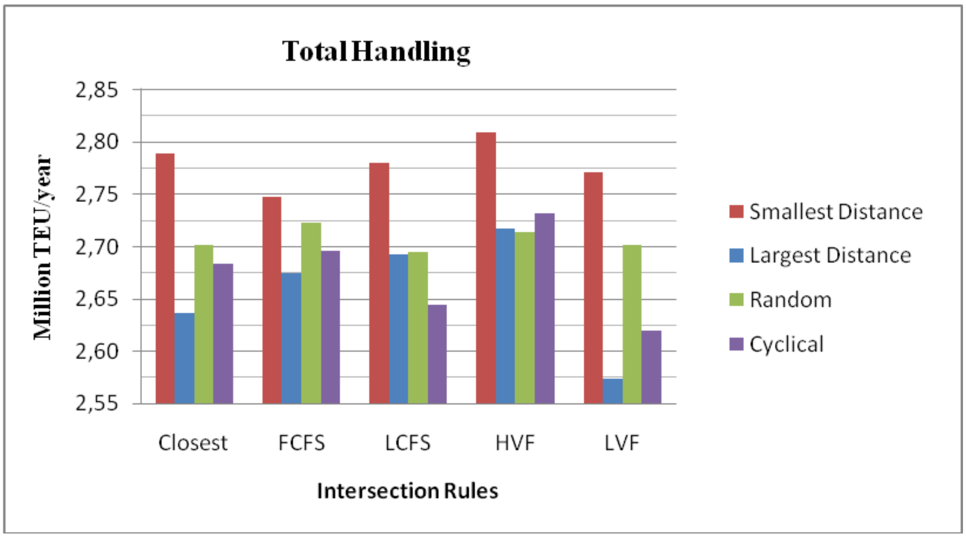

FIGURE. 4
The Effect of Intersection Rules Under Different Transporter Request Rules

As mentioned in Fig. 4, related effect is not stable. For this reason, by using SPSS 16.0, ANOVA test is carried out for simulation results which are to observe the effect of transporter request and intersection rules on the total container handling amount. In Table 5, the results of ANNOVA tests which are executed according to 100 simulation results are presented for the effect of transporter request and intersection rules.

TABLE 5
ANOVA Test Results for Transporter Request and Intersection Rules

Source	SS	df	Mean Square	F	Sig.
Transporter Request Rules	$2{,}678 \times 10^{11}$	3	$8{,}927 \times 10^{10}$	90358,617	0,000
Intersection Rules	$3{,}206 \times 10^{10}$	4	$8{,}015 \times 10^{9}$	8112,358	0,002
Interaction*	$4{,}227 \times 10^{10}$	12	$3{,}522 \times 10^{9}$	3565,043	0,000
Error	$7{,}904 \times 10^{7}$	80	987960,97		
Total	$7{,}256 \times 10^{14}$	100			
Corrected Total	$3{,}422 \times 10^{11}$	99			

*Dual interaction of intersection and transporter request rules

According to the results obtained from Table 5, the transporter request rules have a %5 difference in handling amounts. Similarly, intersection and transporter request rules have a %5 difference in terms of interaction. This interaction shows that transporter request and intersection rules are interdependent. In Table 6, the results of Tukey HSD test, which is executed for determining that previously mentioned differences, are in favor of which dispatching rule is shown. In tests which are for transporter requests, for the number of 54 transporters, the simulation results repeated 5 times are used related to 5 different intersection rules.

TABLE 6
Tukey HSD Test for Transporter Request Rules

Transporter Request Rules	N	Homogeneous subgroups (Alfa = 0,05) 1	2	3	4
Largest Distance	25	2642109,68			
Cyclical	25		2657807,97		
Random	25			2696700,26	
Smallest Distance	25				2779308,80

According to Table 6, in the results which are obtained from the simulation carried out for 54 transporters, in terms of handling amounts, the best one is "smallest distance rule" among the dispatching rules applied in 4 different ways. Smallest distance rule, is different from the other transporter request rules in terms of being at %95 confidence level. In Table 7, the results of Tukey HSD, which is executed with smallest distance rule, and the 5 times repeated simulation results are presented.

TABLE 7
Tukey HSD Test for Intersection Rules

Intersection Rules	N	Homogeneous subgroups (Alfa = 0,05) 1	2	3	4
FCFS	5	2747114			
LVF	5		2770685		
LCFS	5			2780275	
Closest	5			2789305	
HVF	5				2809165

In Table 7, it is shown that HVF is the best rule at % 95 confidence levels among the other intersection rules.

CONCLUSION

In this paper, a simulation model is developed to analyze transporter number, transporter request rules and intersection rules in a Π berth typed designed container terminal. Implemented tests show that the best scenario for the designed terminal configuration is the scenario with using 54 lift-AGVs, "smallest distance rule" as request rule, "HVF" as intersection rule. When the results are compared with Vis and Bakker (2006), smallest distance rule is familiar for transporter request rule in each study. However, in related study FCFS is proposed as intersection rule but, HVF is proposed in this study. The reason for this difference can be the different terminal berth types.

With the help of this study, we have identified that the transporter request and the intersection rules can behave differently according to terminal berth types. Consequently, the effect of these rules will be researched for the other artificial and natural berth types of container terminals. Furthermore, the effect of different transporter types on performance criterion could be another research topic in this type of container terminals.

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