

# Highly Efficient AGV Transportation System Management Using Agent Cooperation and Container Storage Planning

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**Abstract**—The development of a highly efficient management methodology for an Automated Container Terminal (ACT) poses a problem for port authorities. The focus here is on a transportation system for an Automated Guided Vehicle (AGV) for an ACT. In this paper, we design the detailed management models, i.e., agent cooperation and container storage planning for the transportation system. Then, we optimally design systems that are constructed with the use of the designed management models. Comparisons of the systems are made to evaluate cost effectiveness based on the total construction cost and validity of the management models. Finally, a proposal is made for the most efficient management system.

**Index Terms**—AGV transportation system, system management, agent cooperation, container storage planning.

## I. INTRODUCTION

The increasing number of container shipments has caused higher demands on seaport container terminals, container logistics, and management, as well as on technical equipment. In this regard, concern is increasing regarding Automated Container Terminals (ACTs) in harbors [1] [2]. In this study, we construct an automated transportation system with the use of an Automated Guided Vehicle (AGV) as a transportation agent. For the construction of the AGV transportation system, there are three problems that need to be overcome. They are presented in the following.

- (I) Optimal design of the transportation system
- (II) Comparison, evaluation, and analysis of the transportation systems
- (III) Highly efficient management methodology for the transportation system

Problem (I) represents a design methodology that is related to the challenge: deriving the combinatorial optimal design parameters, i.e., the minimum number of agents that satisfy a demand. For this problem, we have proposed a hybrid design methodology with the use of queuing network theory and a simulation model [3]. On the other hand, we need to carefully identify the most efficient system when several systems, such as vertical and horizontal transportation systems, are being considered (problem II). For this problem, some studies have compared, evaluated, and analyzed the cost effectiveness based on the transportation time and total construction cost [4] [5] [6].

From the results of conventional studies, it is clear that the horizontal AGV transportation system is more cost-effective than the well-known vertical AGV transportation system under a cost model [5]. Therefore, in this paper, we deal

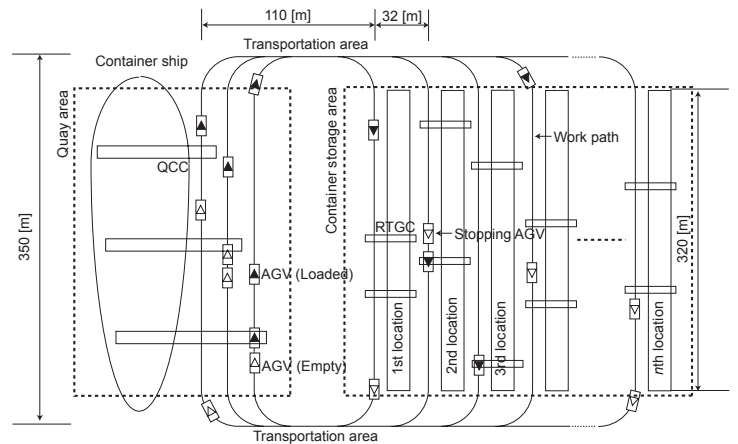


Fig. 1. Horizontal AGV transportation system (top view)

with the specific horizontal AGV transportation system, as shown in Fig.1. However, since a Rubber-Tired Gantry Crane (RTGC) that operates in the container storage area is also an important and flexible agent in addition to the AGV in the horizontal transportation system, a methodology for the management of such a complex system is required.

For this paper, we construct an AGV transportation system while considering this problem (III). In this regard, since there are various types of agents, i.e., heterogeneous multi-agent operating in a transportation system, we first design the detailed system management models that would tackle this problem (III). For the modeling, we need to take into consideration: when, where to, and how the containers should be transported and stored by the agents. Therefore, two challenging points are important for a highly efficient system management: agent cooperation and container storage planning. For the modeled system, we derive the combinatorial optimal design parameters using the proposed design methodology [3]. After that, we compare the cost effectiveness of the designed systems based on the total construction costs, and we evaluate the validity of the management models. Finally, we overcome the problem (III) and are now proposing the most highly efficient problem management model.

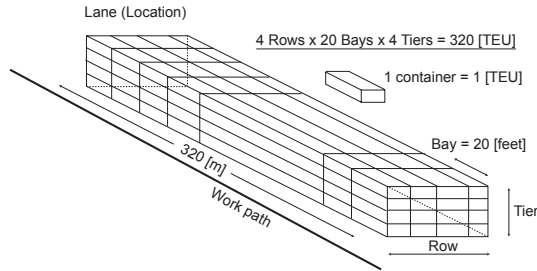


Fig. 2. Container storage location

## II. AGV TRANSPORTATION SYSTEM IN AN ACT

### A. Transportation Procedure

We focus on the container operation by the agents within an ACT. Hence, we consider the container movement from a container ship to a storage destination. In the system shown in Fig.1, the AGVs continue to circulate until they successfully complete all of the container transportation tasks while cooperating with the RTGCs by following the procedures described below:

- step 1. A Quay Container Crane (QCC) that operates in the quay area loads a container to an AGV from a container ship.
- step 2. A container storage location in the container storage area is randomly assigned as the destination location of the container.
- step 3. The AGV transports the container from the quay area to the assigned location in the container storage area through the transportation area.
- step 4. The AGV goes into the work path and then arrives at a container transfer and storage point adjacent to the assigned location.
- step 5. The AGV begins to transfer the container to an RTGC.
- step 6. The RTGC to which the container has been transferred stores it at the storage point and then waits for the next order from the next AGV.
- step 7. The AGV that has already transferred the container to the RTGC goes back to a QCC in the quay area through the transportation area. Back to step 1.

### B. Container Storage Location

Fig.2 shows the location where the containers are stored. In this study, there are 320 (4 Rows  $\times$  20 Bays  $\times$  4 Tiers) [TEU] container storage spaces in one location. Here, TEU represents Twenty-foot Equivalent Units.

### C. Comparison Factors of the Systems

The inputted numbers of AGVs and RTGCs described as follows are the design parameters. These parameters used to construct the system are the comparison factors. In a design process, the inputted numbers of AGVs and RTGCs should be optimized at the same time; namely, the minimum numbers of AGVs and RTGCs are derived. Therefore, in this combinatorial optimization design problem, we attempt to derive one combinatorial solution with the use of a cost model described latter.

TABLE I  
SPECIFICATIONS OF THE AGV, RTGC, AND QCC

AGV		Loaded / Empty
Max. traveling velocity	[m/s]	5.56 / 6.94
Acceleration	[m/s <sup>2</sup> ]	0.15 / 0.15
Deceleration	[m/s <sup>2</sup> ]	0.63 / 0.63
RTGC		
Max. traveling velocity	[m/s]	2.5
Acceleration	[m/s <sup>2</sup> ]	0.1
Deceleration	[m/s <sup>2</sup> ]	0.4
Storing time	[s]	30
Transfer time	[s]	30
QCC		
Loading time	[s]	60

- Number of AGVs
- Number of RTGCs

### D. Heterogeneous Agent Specifications

Table I shows the specifications for the AGV, RTGC, and QCC [7]. The AGV specification is shown as "Loaded" and "Empty." As for the RTGC specification, container transfer and storage times in the container storage area are described in addition to the traveling velocity. Because the QCC does not move itself, only the container loading time is described.

### E. System Settings

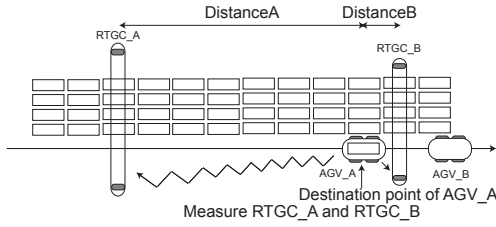
With regard to the system layout, in an actual ACT, the number of inputted QCCs is determined based on a fixed scale of a berth. In general, as well as in this study, a 350 [m] scale of the berth is established, as shown in Fig.1; three QCCs are inputted. As for the container storage area, one work path is established at each location. Additionally, based on the literature [8], two RTGCs are inputted at one location (i.e., the number of RTGCs = the number of locations  $\times$  2).

A container transportation order to the AGV can be equally given by the three QCCs. In addition, the destination location of the container is also equally assigned to every location. Here, the container storage orders in the location (raw, bay) are generated randomly in an initial state.

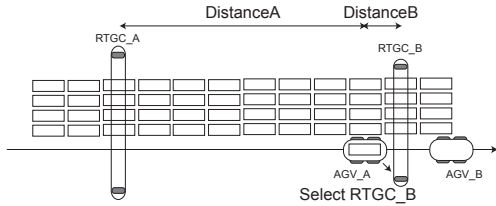
## III. AGENT COOPERATION

### A. Concept of Agent Cooperation

With regard to research that focuses on a transportation system by a multi-agent, Yoshimura *et al.* have proposed a hierarchical architecture for an iterative transportation problem between two positions [9]. However, there is no description for extending an actual transportation problem in which transportation requirements are made among many positions. Ota *et al.* have proposed a flexible transport system in cooperation with conveyer-loaded AGVs [10]. The conventional studies above have focused on cooperation, such as handing over and transporting objects with the use of homogeneous multi-agent. On the other hand, since we deal with heterogeneous multi-agent, it is impossible to realize highly efficient agent cooperation using a uniform agent-behavior strategy for the different types of agents. For this challenge, by considering the actual agent specifications described above, we design the agent cooperation, (i) the RTGC selection method by



(a) The AGV\_A measures the relative distances of the RTGC\_A and RTGC\_B



(b) The AGV\_A selects the RTGC\_B based on the relative distances

Fig. 3. Distance-based RTGC selection: An AGV selects an RTGC based on each relative distance when the AGV arrives at the destination point (top view)

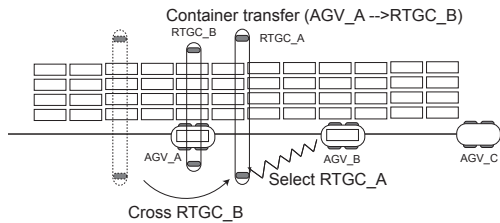


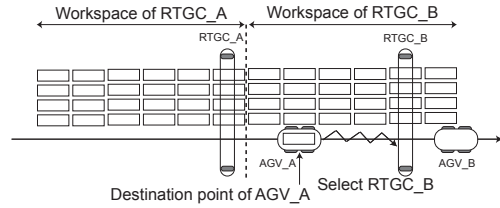
Fig. 4. Two RTGCs of different sizes cooperate in one location (top view)

AGV, and (ii) RTGC selection and call-out timing by AGV, as follows:

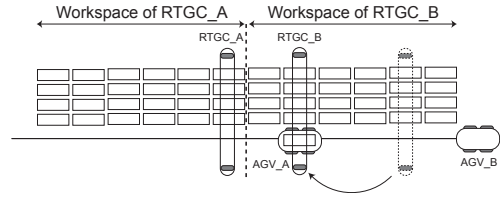
- RTGC selection method by AGV
  - Distance-based RTGC selection
  - Workspace-based RTGC selection
- RTGC selection and call-out timing by AGV
  - Right after the AGV arrives at the destination point on the work path
  - Right after the AGV goes into the work path in the container storage area

#### B. Selection method 1: Distance-based RTGC Selection

As shown in Fig.3(a), the AGV\_A measures the relative distance of each RTGC on the location when the AGV\_A arrives at the destination point. In a case in which two RTGCs would be idling, the RTGC\_B, which is nearer the AGV\_A than the RTGC\_A, would be selected as the transferring partner, as shown in Fig.3(b). However, if the RTGC\_B is (a) already selected by another AGV or (b) in transfer or storage operation, the RTGC\_A is selected as the transferring



(a) The AGV\_A selects the RTGC\_B based on the workspace



(b) The RTGC\_B moves to the point

Fig. 5. Workspace-based RTGC selection: An AGV selects an RTGC based on the workspace of the RTGC (top view)

partner even if it is located farther from the AGV\_A than the RTGC\_B. Here, since two RTGCs of different sizes can cross each other while operating, the RTGCs do not have individual workspace. Therefore, the RTGC\_A is selected as the transferring partner by the AGV\_B, since the RTGC\_B is in the transfer operation with the AGV\_A when the AGV\_B selects the RTGC. The selected RTGC\_A begins to cross the RTGC\_B; it then moves to the destination point, as shown in Fig.4. If both RTGCs are in the state of (a) or (b), the AGV needs to wait at the destination point.

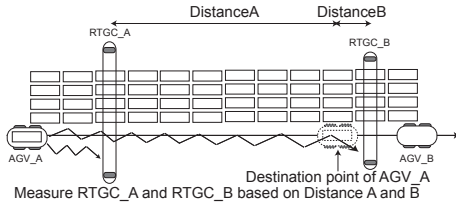
#### C. Selection method 2: Workspace-based RTGC Selection

Fig.5 shows the cooperation between the AGV and RTGC in a case in which two RTGCs of the same size are in one location. The RTGCs do not cross each other; however, they have their own assigned workspace and operate in each workspace. As shown in Fig.5(a), the AGV\_A selects the RTGC\_B as the transferring partner based on the workspace even if the RTGC\_A is located nearer the AGV\_A than the RTGC\_B when the AGV\_A selects the RTGC. The selected RTGC\_B begins to move to the destination without crossing another RTGC\_A, as shown in Fig.5(b).

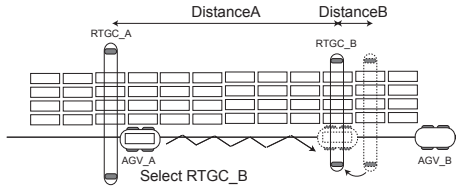
#### D. RTGC Selection and Call-Out Timing by AGV

From Table I, the RTGC moves slowly on the location. Accordingly, it probably takes time only using the RTGC selection methods described in III-B and III-C. In this study, we consider the time that the AGV should select and call out the RTGC as the transferring partner. For a more efficient system, we use the following Point to Point Protocol for the agent communication between the AGV and RTGC when the AGV goes into the work path.

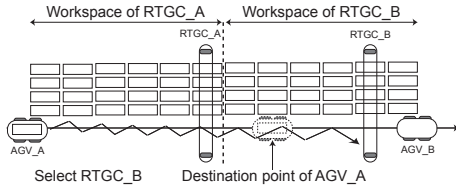
Fig.6 shows the RTGC selection and call-out timing in selection methods 1 and 2. In selection method 1, right after



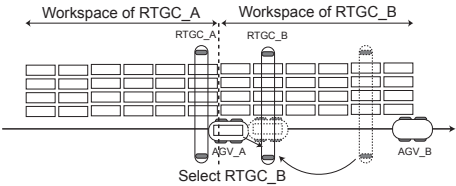
(a) The AGV measures the relative distances of the RTGC\_A and RTGC\_B; it selects and calls the RTGC\_B



(b) The RTGC arrives at the destination point before the AGV arrives



(c) The AGV selects and calls the RTGC\_B based on the workspace



(d) The RTGC arrives at the destination point before the AGV arrives

Fig. 6. RTGC selection and call-out timing by AGV based on each relative distance or workspace when the AGV goes into the work path (top view)

the AGV\_A goes into the work path, the AGV\_A begins to communicate with each RTGC to collect their information about the situations and measure the relative distance for the AGV\_A's destination point; it then selects the RTGC\_B as the transferring partner based on the distance (see Fig.6(a)). The RTGC\_B is ordered to move to the destination point of the AGV\_A (Fig.6(b)). In selection method 2, right after the AGV\_A goes into the work path, the AGV\_A begins to communicate with each RTGC to identify its workspace and collect information about the situation. After that, the AGV\_A selects the RTGC\_B based on the workspace in which the container is stored; it orders the RTGC\_B to move to the destination point (see Fig.6(c)). The selected RTGC\_B begins to move (Fig.6(d)). In the case of the distance-based RTGC

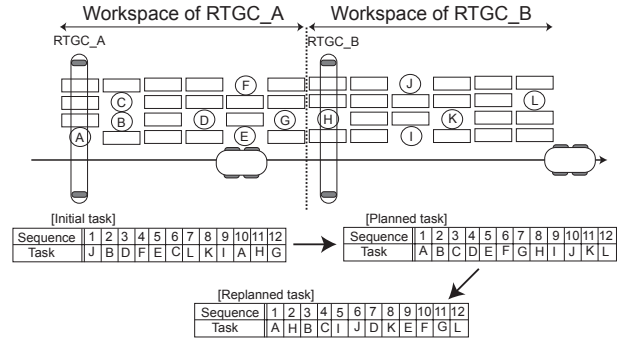


Fig. 7. Example of container storage planning (top view)

selection, the AGV has to select the more distant RTGC even if another RTGC is near the AGV's destination point. This occurs even if the nearby RTGC is in the state of (a) or (b), as described in III-B and III-C. On the other hand, in the case of the workspace-based RTGC selection, the AGV maintains communication or waits on the work path until the RTGC is in the idling state, if the RTGC is in the state of (a) or (b).

In addition, the increase in the workload on the work path causes an increase in the number of AGVs that have already been communicating with the RTGCs as the number of AGVs increases. In such a case, the backward AGV does not begin to communicate with the RTGC until the forward AGV finishes communicating with the RTGC.

#### IV. CONTAINER STORAGE METHOD

##### A. Random Container Storage

The "initial tasks" in Fig.7 represent initial orders for container transportation and storage.

Based on the information about container storage spaces A~L available at the location, the container transportation and storage orders are randomly generated. Here, every container has information about its storage situation, including the "rows" and "bays" of available container storage space A~L. In case of random container storage, the AGVs achieve the generated initial tasks in sequence, and the transported containers are then stored in sequence by the RTGCs.

##### B. Container Storage Planning

Random container storage, as described in IV-A, causes a needless increase in the total moving distance of the RTGC. Moreover, since the traveling velocity of the RTGC is less than half of that of the AGV, as can be seen from Table I, the system efficiency is expected to deteriorate due to the transportation congestion by the AGV.

Therefore, for container storage planning, we arrange the initial tasks based on the following objectives: (1) minimizing the total moving distance of the RTGCs, and (2) equalizing the workloads on the locations and work paths. Here, we use the workspace for the RTGC. All tasks is known a priori. First, the positions are defined as RTGC\_A and RTGC\_B, shown in Fig.7 as the initial positions, respectively. We then replace the initial tasks based on (1) and define them as "planned tasks." These planned tasks, however, cause heavier workload at the workspace of RTGC\_A. Therefore, we again

TABLE II  
SYSTEM MANAGEMENT MODELS

RTGC selection method	RS	DS	DS	DS	DS	WS	WS	WS	WS
Selection & call-out timing	DP	DP	WP	DP	WP	DP	WP	DP	WP
Container storage method	×	×	×	○	○	×	×	○	○
Model number	1)	2)	3)	–	–	–	4)	5)	6)

DS: Distance-based RTGC Selection, WS: Workspace-based RTGC Selection, RS: Random RTGC selection  
DP: on the Destination Point, WP: on the Work Path, ×: Random storage, ○: Storage planning

replace the planned tasks based on (2) as the second planning in each workspace and define them as “replanned tasks.”

## V. EVALUATION OF THE MANAGEMENT EFFICIENCY

### A. Management Models and Design Conditions

In order to evaluate the efficiency of the management models designed in III and IV, we construct a horizontal AGV transportation system on the basis of the models shown in Table II. Eight systems can be considered because there are eight models: two ways of RTGC selections (DS, WS) × two ways of RTGC selection and call-out timings (DP, WP) × two ways of container storage methods (×, ○). However, since the container storage planning is based on the workspace of the RTGC, we construct the system on the basis of the models with the use of the random container storage, under the distance-based RTGC selection. Moreover, under the workspace-based RTGC selection, it is obvious that the RTGC selection and call-out when the AGV goes into the work path is more efficient. For these reasons, we construct 5 systems that are numbered from 2) to 5). In addition to the 5 models, for comparison, we construct a system on the basis of the conventional management model 1). In this model 1), the AGV carries out the random container storage and selects the RTGC randomly after the AGV arrives at the destination point. Under models 4)~6), the two inputted RTGCs in one location have the same scales of the workspaces. In other words, each RTGC has 160 [m] and a 10 [bay] workspace in Fig.2. These models are implemented into the developed transportation simulator.

For the optimal design of these systems under each model, we use the proposed optimal design methodology to derive the design parameters [3]. Here, the inputted numbers of AGVs and RTGCs are designed not to exceed 30 and 20 in order to avoid adding the AGVs and RTGCs recklessly. The total number of containers is 600 [TEU], and the same kinds of orders, i.e., initial tasks are given for each model. As for the transportation demands, we use the system throughput [TEU/hour]; then, the systems are designed based on the throughput of 10~130.

### B. Optimal Design Parameters

Fig.8 indicates the derived combinatorial optimal design parameters of the AGVs and RTGCs under each model. To solve the combinatorial optimization design problem, we use the following cost model and then derive the one combinatorial optimal design parameter. However, even if we use the following cost model, there is a case in which multiple combinatorial optimal design parameters that construct the system at the same cost are derived. Therefore, we derive

the multiple combinatorial optimal design parameters in such cases (e.g., Fig.8(c) and Fig.8(e)).

$$\text{Construction cost} = a \times \text{AGVs} + b \times \text{RTGCs},$$

where  $a$  and  $b$  represent cost coefficients. By considering the relationship of the actual ratio of the input costs of the AGV and RTGC, these coefficients are determined as follows:  $a : b = 1 : 2$ .

In Fig.8(a), the system constructed by model 1) can not satisfy the throughput 130. From this result, it is difficult to construct a high-efficiency transportation system by the conventional management model. When multiple design parameters are derived as in Fig.8(c) and Fig.8(e), adding more RTGCs sometimes leads to a noticeable decrease in AGVs. Fig.8(b)~Fig.8(d) show that, by adding more agents, AGVs are particularly needed when throughputs are increased from 120 to 130 under the random container storage to satisfy throughput 130. From the results above, under the random container storage, it might be supposed that a system constructed with the use of the agent cooperation model could not satisfy throughputs in excess of 130.

### C. Comparison of Cost Effectiveness and Evaluation of the Validity of the Management Models

Fig.9 shows a comparison of the results of the total construction costs. From Fig.9, the conventional model 1) is obviously inefficient in transportation. Additionally, due to the lack of design parameters for throughput 130, there is no construction cost at this point. In other models, the marked increase in each cost difference is noticeable as the throughput increases. As a result, the maximum cost difference at throughput 130 comes up to 8 [point] (max. 46, min. 38); then, a cost-savings of 17 [%] and high efficiency are noticeable.

A review of the systems constructed with the use of the models 2)~4), which are shown to evaluate the validity of agent cooperation under the random container storage, indicates that model 4), that is, RTGC selection and call-out when the AGV goes into the work path based on the workspace-based RTGC selection, is the most efficient model. With regard to models 2) and 3), because of the marked increase in the number of AGVs as the demand increases at the point of throughputs from 120 to 130, the validity of agent cooperation when the AGV goes into the work path is not noticeable (see Fig.8(b) and Fig.8(c)). The reason is that a large number of agents in the system cause the heavier workloads. In other words, while the number of AGVs on the work paths increases, the number of idling RTGCs on the locations decreases, and the agents can not communicate well with each other; then, the RTGC can not move to the



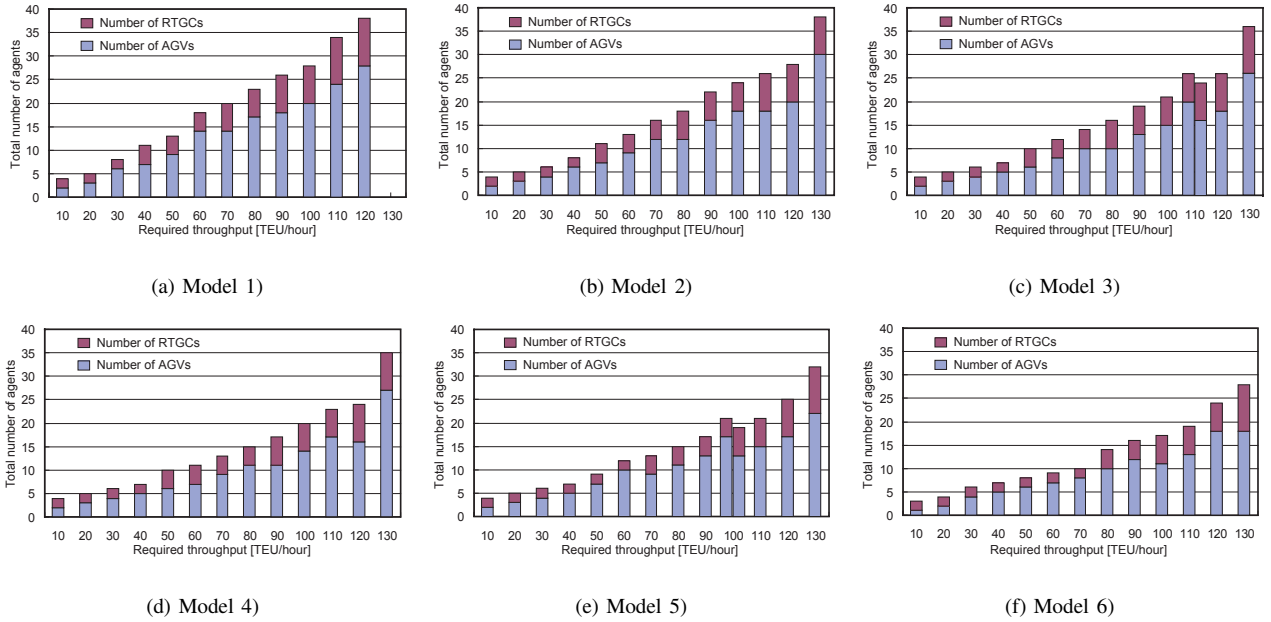


Fig. 8. Number of AGVs and RTGCs that construct a system for a required throughput

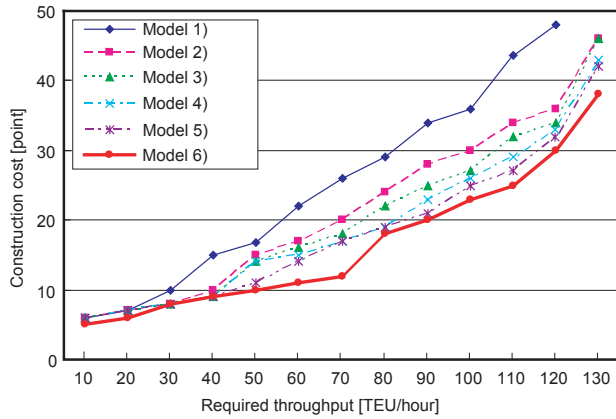


Fig. 9. Comparison results of the total construction costs

destination point before the AGV arrives at the destination point. When container storage planning is executed, model 6), compared to model 5), is more efficient. The reason is that the assigned workspace reduces the workload; finally, on the work path, the agent communication between the AGV and RTGC works properly.

From these results, system management model 6), which uses agent cooperation, such as that in the workspace-based RTGC selection when the AGV goes into the work path under container storage planning, is the most efficient system management model. The agents automatically operate in the system with the use of the proposed system management model.

## VI. CONCLUSION

In this study, we designed detailed system management models that included agent cooperation and container storage planning. We then designed optimal systems that are constructed with the use of the designed management models. Finally, we proposed the most efficient management model based on the results of the comparison of cost effectiveness and evaluations of the validity of the models.

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