

# Design of an AGV Transportation System by Considering Management Model in an ACT

Satoshi Hoshino <sup>a,1</sup>, Jun Ota <sup>a</sup>, Akiko Shinozaki <sup>b</sup>, and Hideki Hashimoto <sup>b</sup>

<sup>a</sup> *Dept. of Precision Engineering, The University of Tokyo, Japan*

<sup>b</sup> *Mitsubishi Heavy Industries, LTD.*

**Abstract.** This paper focuses on the design of a highly efficient Automated Guided Vehicle (AGV) transportation system. Therefore, we attempt to construct detailed system management models that include agent cooperation, container storage scheduling, and container transportation planning. We then optimally design systems that are constructed with the use of these management models. The systems are compared to evaluate their operation efficiency based on their total construction cost. Finally, we describe a highly efficient management model for an AGV transportation system and discuss the need to consider an efficient system management methodology.

**Keywords.** Design, AGV transportation system, management model, ACT,

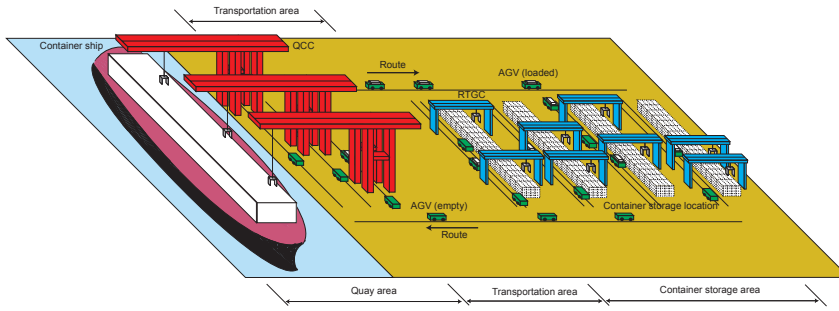
## 1. Introduction

The amount of container trade, especially in Asia, has increased significantly in recent years [1]. Following this trend, several studies have analyzed automation from various viewpoints [2,3]. In this paper, we consider the machines as the operational agents that operate in the automated container terminal (ACT) for unloading/loading, transportation, and storage. We then design a highly efficient automated transportation system in which the agents operate. For this purpose, it is necessary to consider the following problems: (I) optimal design of a transportation system [4], (II) comparison, evaluation, and analysis of a transportation system [5,6], and (III) efficient management of a transportation system.

For problem (I), we have proposed a hybrid design methodology for an automated guided vehicle (AGV) transportation system with the use of a queuing network theory and a transportation simulator [4]. For problem (II), we have compared and evaluated the characteristics of the layouts of the transportation systems, such as vertical and horizontal ones [5]. On the other hand, as an integrated study of problems (I) and (II), we have evaluated and analyzed the total construction cost of the transportation system on the basis of the comparison of the optimal design results. A comparison with the vertical system that has been used in conventional ACTs indicated that the horizontal system is

---

<sup>1</sup>Correspondence to: The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656 JAPAN.  
Tel.: +81 3 5841 6486; Fax: +81 3 5841 6487; E-mail: hosino@prince.pe.u-tokyo.ac.jp.



**Figure 1.** Actual Horizontal AGV Transportation System in an Automated Container Terminal (ACT)

more efficient [6]. Therefore, in this study, we focus on the horizontal AGV transportation system shown in Fig. 1; we then design a highly efficient transportation system while considering an efficient management methodology to overcome the existing problem (II I).

In a conventional study for ACT management, Hartmann has introduced an approach to generate scenarios of operations [7]. The generator is based on a large number of parameters. He then outlined the parameters that are important to produce realistic scenarios of high practical relevance. This study, however, focuses mainly on scenarios in a quay-side operation. As for yard-side container transportation and storage operations, he focused on the transportation destination of a container. Therefore, for this study, we constructed yard-side management models. For this purpose, we define the management models as follows.

- Agent cooperation between heterogeneous multi-agent.
- Container storage scheduling at a storage location.
- Container transportation planning in a container storage area.

After that, we implement the constructed models to a horizontal AGV transportation system and then derive the numbers of AGVs and rubber-tired gantry cranes (RTGCs) for various transportation demands by means of the proposed design methodology [4]. Based on the derived design parameters, we compare the construction costs of each transportation system and evaluate the influence of the management model on operation efficiency. Finally, we describe a highly efficient management model and discuss the need to consider an efficient management methodology.

## 2. AGV Transportation System in an ACT

### 2.1. Transportation System and Layout Settings

With regard to the layout of a transportation system for an optimal design, the horizontal AGV transportation system, shown in Fig.1, is divided into three parts and four areas, namely, a quay, two means of transportation, and a container storage area. A number of deployed quay container cranes (QCCs) is given as three, and it is not a design objective due to a space constraint. Here, container transportation orders are equally generated by

the three QCCs in the quay area. In the container storage area, the container storage locations show the temporal container storage space between the sea and land. Two RTGCs are used at each location. There is one work path adjacent to each location. Each location has a container storage capacity of 320 (4 Rows  $\times$  20 Bays  $\times$  4 Tiers). Let us define the capacity of one storage container is a 20-foot equivalent unit (TEU). The operation specifications of the AGV, RTGC, and QCC are based on the cited literature [8].

## 2.2. Problem Description

In addition to the numbers of AGVs and RTGCs, the management models, i.e. agent cooperation, container storage scheduling, and container transportation planning, are the design objectives. The detailed design process of the number of AGVs and RTGCs are discussed in the cited literature [4]. The derived numbers of AGVs and RTGCs in the designed system are the evaluation factors. Concerning storage constraints, the final storage rate at each location must not exceed the given limits. This constraint is enacted by the actual ACT field because effective land use is a serious issue.

## 2.3. Transportation Procedure

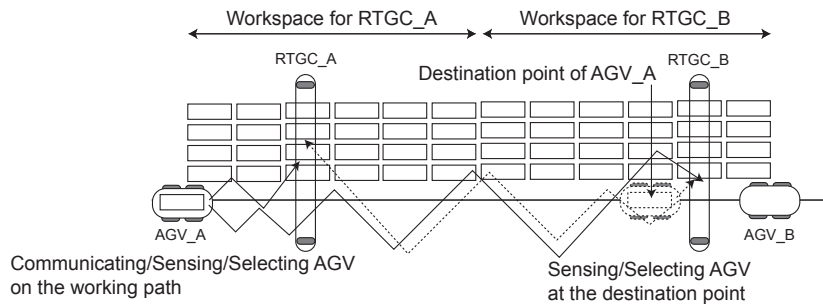
The AGVs circularly transport containers in the system shown in Fig.1 while cooperating with the RTGCs as follows.

- step 1. A QCC loads a container to an AGV from a container ship.
- step 2. A container storage location is assigned as the destination location of the container.
- step 3. The AGV begins to transport the container to the assigned location.
- step 4. The AGV goes into the work path and then arrives at a container transfer point.
- step 5. The AGV begins to transfer the container to an RTGC.
- step 6. The RTGC stores it at the storage point and waits for the next order.
- step 7. The AGV that has already transferred the container to the RTGC goes back to a QCC. Back to step 1.

## 3. Agent Cooperation

### 3.1. Framework of Agent Cooperation

In conventional studies, Yoshimura *et al.* and Ota *et al.* have focused on agent cooperation, such as handing over and transporting objects with the use of homogeneous multi-agent [9,10]. 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 various types of agents. Therefore, we focus on and design the following agent cooperation: (i) the RTGC selection method by AGV (distance-based RTGC selection and workspace-based RTGC selection), and (ii) RTGC selection and call-out timing by AGV (immediately after the AGV arrives at the destination point on the work path; immediately after the AGV goes onto the work path).



**Figure 2.** Cooperation Between the AGVs and RTGCs (top view)

### 3.2. Construction of Agent Cooperation

#### 3.2.1. Distance-based RTGC selection at the destination point

As shown by the dotted line in Fig.2, the AGV\_A measures the relative distance of each RTGC at the location when the AGV\_A arrives at the destination point. If two RTGCs are idling, RTGC\_B, which is nearer the AGV\_A than RTGC\_A, will be selected and identified as the transfer partner. However, if the RTGC\_B (a) has already been selected by another AGV or (b) is in a transfer or storage operation, the RTGC\_A is selected as the transfer partner. If both RTGCs are in the state of (a) or (b), the AGV\_A needs to wait at the destination point.

#### 3.2.2. Workspace-based RTGC selection at the destination point

The RTGCs have their own assigned workspace and operate in each workspace. Therefore, as shown in Fig.2, the AGV\_A selects and calls the RTGC\_B that operates in the assigned workspace. For this study, an equal scale of workspace was given to each of the RTGCs at the location. In other words, each RTGC has the following workspace: 4 Rows  $\times$  10 Bays  $\times$  4 Tiers.

#### 3.2.3. Distance-based RTGC selection on the work path

As shown by the solid line in Fig.2, immediately after the AGV\_A goes onto the work path, the AGV\_A begins to communicate with each RTGC to collect situational information and measure the relative distance for the AGV\_A's destination point; it then selects the RTGC\_B as the transferring partner. The selected RTGC\_B begins to move while the AGV\_A is transporting. As in the case described in 3.2.1, 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). 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. When this increase occurs, the rear AGV does not begin to communicate with the RTGC until the lead AGV finishes communicating with it.

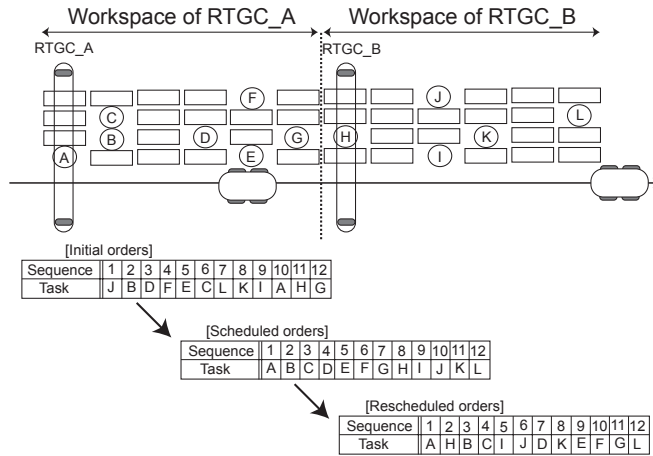


Figure 3. Example of Container Storage Scheduling (top view)

### 3.2.4. Workspace-based RTGC selection on the work path

As shown by the solid line in Fig.2, immediately after the AGV\_A goes onto the work path, the AGV\_A begins to communicate with each RTGC to identify its workspace and collect situational information. 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. The selected RTGC\_B begins to move while the AGV\_A is transporting. 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).

## 4. Container Storage Scheduling

### 4.1. Framework of Container Storage Scheduling

From among conventional studies of container storage scheduling with ACTs, several studies have focused on system performance, in which container storage orders are given on the basis of certain dispatching rules [11,12]. These studies, however, have been limited to discussions of how to assign the generated transportation and storage orders to the AGVs; there have been no studies regarding the assignment considering the sequence of orders at the container storage locations. Therefore, in this study, we construct the following container storage models: random container storage, in which the sequence of orders is not considered, and container storage scheduling, in which the sequence of orders is considered.

### 4.2. Random Container Storage

Random container storage is a container storage model that does not consider the sequence of the operation orders at the location. In Fig.3, the “initial orders” represent container transportation and storage orders that are randomly generated in the initial state.

Here, every container has information about its storage situation, including the “rows” and “bays” of available container storage space A~L. In the case of random container storage, the AGVs achieve the orders in sequence, and the transported containers are then stored in sequence by the RTGCs.

#### 4.3. Container Storage Scheduling

With regards to container storage scheduling, we arrange the initial orders based on the following objectives: (A) minimizing the total moving distance of the RTGCs and (B) equalizing the workloads at the locations and on work paths. Here, we use the workspace for the RTGC. All orders are known a priori. First, the positions are defined as RTGC\_A and RTGC\_B, which are shown in Fig.3 as the initial positions. We then replace the initial orders based on (A) and define them as “scheduled orders.” These scheduled orders, however, cause a heavier workload at the workspace of RTGC\_A. Therefore, we again replace the scheduled orders based on (B) as the second scheduling in each workspace and define them as “rescheduled orders.” The AGVs achieve the rescheduled orders.

### 5. Container Transportation Planning

#### 5.1. Framework of Container Transportation Planning

With regards to container transportation planning, we construct the following models: random, equivalent, and quay-side-weighted transportation. Based on the constructed models, the number of containers that are transported and stored at each location is determined in a few seconds under a storage constraint. With regards to the storage constraint at the location, the maximum number of stored containers, i.e., the container storage capacity, is assumed to be 320 [TEU].

#### 5.2. Random Transportation

Under the random transportation rule, the destination locations of the containers are randomly planned. Therefore, the number of containers transported to each location is affected by random numbers.

#### 5.3. Equivalent Transportation

Under the equivalent transportation rule, the destination locations of the containers are equivalently planned. For instance, the number of containers is 600 [TEU], and the number of locations is 4. Thus, the number of containers transported to each location is planned to be 150 [TEU] (see Fig.4). As for the x-axis of Fig.4, the locations are arranged from the quay side in the order of the location number. In addition, due to the container storage capacity at one location (320 [TEU]), the final storage rate at each location reaches 46.9 [%]. Here, a final storage rate denotes (the number of stored containers) / (the container storage capacity).

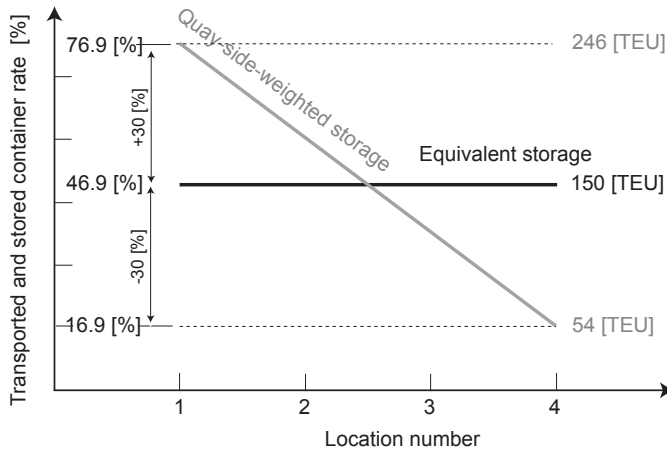


Figure 4. Example of the equivalent and quay-side-weighted transportation rule

#### 5.4. Quay-side-weighted Transportation

As shown in Fig.4, under the quay-side-weighted transportation rule, the destination locations of the containers are preferentially determined from the quay side. With regard to the storage constraint described in 2.2, the maximum and minimum storage rate must fall within  $\pm 30\%$  at each location. Under this constraint, the number of transportation and storage containers is planned at a slant from the quay side. For instance, the total number of containers is 600 [TEU], and the number of locations is 4. Thus, the numbers of containers transported to the 1st ~ 4th locations are 246, 198, 102, and 54 [TEU], respectively.

## 6. Optimal Design of the AGV Transportation System

### 6.1. Design Process

The design process is described from the given demand, i.e., required throughput, to the design solutions, as follows. Here, the throughput is given as follows: (total number of containers) / (required transportation time). First of all, under random transportation, we construct the transportation systems based on management model 1)~6), as shown in Table1. In order to derive the number of AGVs and RTGCs, we apply the design methodology [4]. Model 1) represents a conventional management model assumed in the literature [4]. Under this model, the AGV selects an RTGC at random with the use of the random container storage when the AGV arrives at the destination point.

Process 1. Input a throughput.

Process 2. Implement the management models.

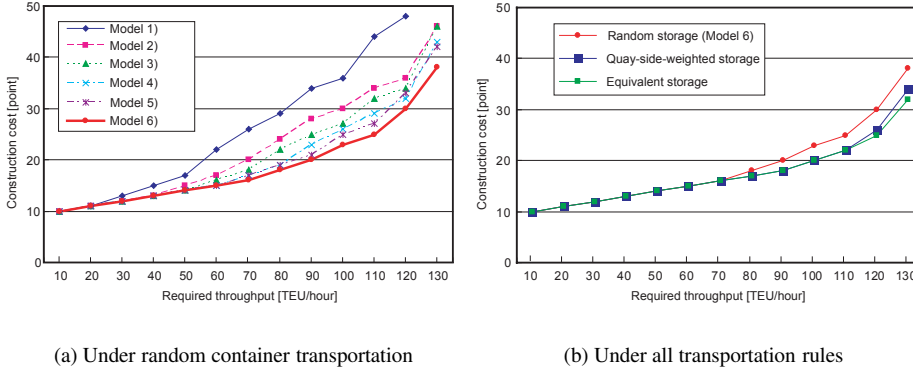
Process 3. Derive the deployed number of agents, evaluate operation efficiency, and derive a more efficient management model.

Process 4. Apply the equivalent and quay-side-weighted transportation rules to the management model that is derived from process 3.

**Table 1.** System management models under random transportation

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

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

**Figure 5.** Comparison Results of the Total Construction Costs

Process 5. Derive the deployed number of agents, evaluate the operation efficiency, and design the most efficient management model. Design the numbers of AGVs and RTGCs as the design solutions.

In processes 3 and 4, we use the following cost model in order to derive the construction cost. Based on the cost of equipment for the AGV and RTGC,  $a$  and  $b$  denoting the cost, the coefficients are as follows:  $a : b = 1 : 2$ .

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

## 6.2. Evaluation of the Operation Efficiency Based on the Total Construction Cost

As shown in Fig.5(a), except model 1), notable differences of the total construction costs are noticeable as the required throughput becomes higher. As a result, the difference in the total construction costs between models 1) and 6) at the point of the required throughput is 120, i.e., higher by 18 [point]. This result indicates that model 6) is more efficient than the conventional management model by about 38 [%].

From the results of models 2)~4) that were obtained in order to evaluate the validity of agent cooperation under the random container storage, model 4), that is, the model in which the AGV selects and calls out the RTGC by means of workspace-based selection at the destination point, is the most efficient one. Under container storage scheduling, model 6) is more efficient than model 5).



Therefore, model 6), that is, the management model in which the AGV selects and calls out the RTGC by means of workspace-based selection on the work path under container storage scheduling, is the most efficient one.

### 6.3. Discussion of a Highly Efficient Management Methodology

Fig.5(b) shows the results of a comparison of the total construction costs of transportation systems designed with the use of equivalent and quay-side-weighted transportation in addition to management model 6). At the point at which the required throughput is 130, the differences in the total construction costs under equivalent and quay-side-weighted transportation are higher by 32 and 34 [point], respectively. In terms of operation efficiency, it is noticeable that the 16.3[%] system efficiency is improved under equivalent transportation and the 10.5[%] system efficiency is improved under quay-side-weighted transportation for model 6) with the use of random storage under random transportation. Even if a required throughput becomes greater, the tendencies in which equivalent transportation is more efficient will not be changed because of the operating RTGCs that are deployed equally at each location.

From the results shown above, we designed the following highly efficient management model: the AGV selects and calls out the RTGC with the use of workspace-based selection on the work path under container storage scheduling after the container transportation and storage destinations are planned on the basis of equivalent transportation. Furthermore, these results clarified a need to take efficient system management into account.

## 7. Conclusion and Future Work

In this paper, the focus was on the design of a highly efficient AGV transportation system. We constructed system management models that included agent cooperation, container storage scheduling, and container transportation planning. In the result, we designed a highly efficient management model and clarified the need to consider an efficient system management.

In future works, we will address the issue of reliability and robustness of the transportation system in case of failure of one of the operations. On the other hand, the problem discussed in this paper is probably formulated from a viewpoint of mathematical programming. In that case, it will be necessary to consider the computational cost.

## References

- [1] D. Steenken *et al.*, Container Terminal Operation and Operations Research - A Classification and Literature Review, *OR Spectrum*, **26** 1 (2004) 3–49.
- [2] P. Ioannou *et al.*, Advanced Material Handling: Automated Guided Vehicles in Agile Ports, CCDoTT Technical Report, Center for Advanced Transportation Technologies, (2001).
- [3] J. Zhang *et al.*, Automated Container Transport System between Inland Port and Terminals, 83rd TRB Annual Meeting Interactive Program, (2004).
- [4] S. Hoshino *et al.*, Optimal Design Methodology for an AGV Transportation System by Using the Queuing Network Theory, 7th International Symposium on Distributed Autonomous Robotic Systems, (2004) 391–400.

- [5] S. Hoshino *et al.*, Comparison of an AGV Transportation System by Using the Queuing Network Theory, Proc. 2004 IEEE/RSJ Int. Conf. Intell. Robots and Systems, (2004) 3785–3790.
- [6] S. Hoshino *et al.*, Optimal Design, Evaluation, and Analysis of AGV Transportation Systems Based on Various Transportation Demands, Proc. IEEE Int. Conf. Robotics and Automation, (2005) 1412–1418.
- [7] S. Hartmann, Generating Scenarios for Simulation and Optimization of Container Terminal Logistics, OR Spectrum, **26** 2 (2004) 171–192.
- [8] MITSUBISHI HEAVY INDUSTRIES, LTD., Advanced Technology Cargo Handling Systems, Products Guide, (2004).
- [9] Y. Yoshimura *et al.*, Iterative Transportation Planning of Multiple Objects by Cooperative Mobile Robots, 2nd International Symposium on Distributed Autonomous Robotic Systems, (1996) 171–182.
- [10] J. Ota *et al.*, Flexible Transport System by Cooperation of Conveyer-load AGVs, Proc. IEEE Int. Conf. Robotics and Automation, (2000) 1144–1150.
- [11] Martin Gunow *et al.*, Dispatching Multi-load AGVs in Highly Automated Seaport Container Terminals, OR Spectrum, **26** 1 (2004) 211–235.
- [12] Chin.I. Liu *et al.*, A Comparison of Different AGV Dispatching Rules in an Automated Container Terminal, The IEEE 5th International Conference on Intelligent Transportation Systems, (2003) 3–6.