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PRECISE MODELING AND ANALYSIS OF LARGE-SCALE AS/RS

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ABSTRACT

A method of modeling large-scale AS/RS is proposed in an attempt to describe the AS/RS precisely in which a lot of items are stored and retrieved. The system considered in this study consists of the large-scale AS/RS with stacker cranes, the material handling system, and isle conveyors connecting these two systems. In the proposed model, every item number put on each rack, the corresponding number of cases for each item, the time of arriving in the warehouse, and the time of departing from the system are stored and recorded. A framework of constructing simulation models is proposed, and an example is illustrated. It is shown that simulation proposed in this study can be used as a monitor of the real system for decision making. In addition, regarding a large-scale AS/RS system, four particular types of storing/retrieving systems are analyzed to examine their performance under various operation conditions. The analysis is performed especially from the efficient standpoint.

1 INTRODUCTION

The modern warehouse must play the role not only of storage for raw materials, parts, and end products, but also of a dynamic inventory control for a smooth logistic system, such as procurement, production, inventory, sales, and distribution, by establishing the information system to update kinds and quantities of stored items. Recently, the Automated Storage and Retrieval System (AS/RS) has been utilized together with AGVs in the above-mentioned fields. Performance analysis of AS/RS is a complex problem. Some approaches exist for performing such an investigation [Pulat 1988, Takakuwa 1989].

With regard to modeling AS/RS, the degree of preciseness for modeling depends on the purpose of analysis. There are reports of applications of simulation to model AS/RS [Harmonosky and Sadowski, 1984; Mederios, Enscore, and Smith, 1986; Muller, 1989; Gunal, Grajo, and Blanck, 1993]. In this paper, the AS/RS is modeled precisely and realistically. A modeled AS/RS does behave as if the real system did. Hence, simulation can be used as a monitor of the real system and as a powerful tool for operation planning.

When introducing a large-scale AS/RS-AGV system, there are a lot of alternatives. Management has to decide particular specifications of the system, such as the number of incoming/outgoing conveyors and the number of AGVs, considering the frequency of handling items. In this paper, the storing/retrieving policy is examined from the efficient standpoint, and analytical results are indicated.

2 LARGE-SCALE AS/RS-AGV SYSTEM

2.1 The Storage System and the Conveyor Interface

The AS/RS is composed of a ten-aisle (i.e., 20 banks) rack system with 38 bays and 20 levels. A general view of the AS/RS is provided in Figure 1; numbering the bay, the level, and the bank for the warehouse is illustrated in Figure 2. Storage and retrievals can be performed to/from the racks on either side of an aisle; each aisle consists of total of 1,520 racks with 760 on each side. The storage system is linked to the rest of the system through a peripheral aisle-conveyor system. Each aisle of the system is interfaced with the peripheral conveyor system through pick and drop stations, which are called the home position (HP), of a stacker crane at one end of the aisle.

Each aisle of the system is served by a stacker crane which can move in horizontal and vertical directions

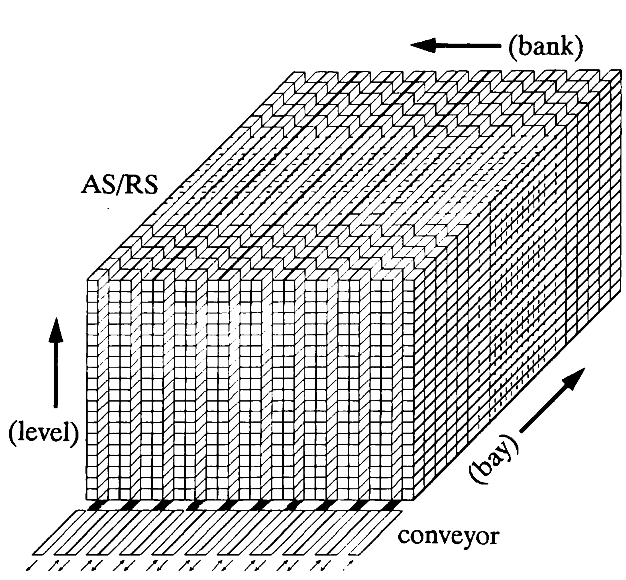
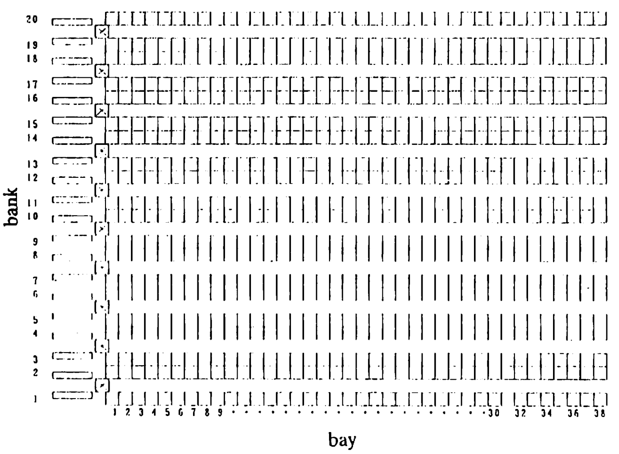
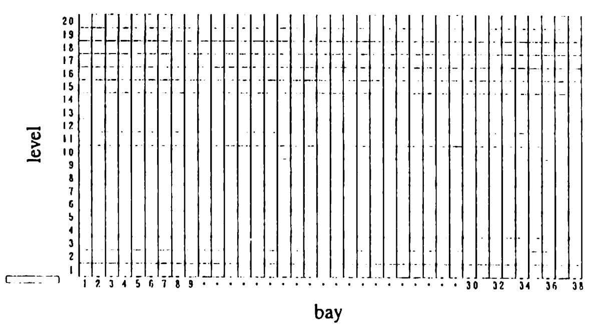


Figure 1: Sketch of Large-Scale AS/RS



(a) Numbering the bank and the bay



(b) Numbering the level and the bay

Figure 2: Large-Scale AS/RS

simultaneously. Once the stacker crane is positioned at a desired location for storage/retrieval to/from a certain rack, the operation of extending its shuttle into the rack, to drop/pick the item and to pull the shuttle back is performed. The same timing applies to picking/dropping an item from/to the pick and drop station.

Every incoming item is first moved onto the home position at one end of an aisle, and then picked by the stacker crane, and moved to its destination rack. On the other hand, an outgoing item is picked from its rack in the system by the stacker crane, and is transferred to the home position. Once dropped on the home position, the item is moved onto the outgoing conveyor. Typically, these incoming/outgoing aisle conveyors are connected to the AGV system.

2.2 Control Logic of AS/RS

A detailed examination of the system requirements reveals several interesting modeling issues that should be addressed for an accurate representation of the system. The control logic of the AS/RS is designated so that storage and retrievals are made to the rack in the four different ways shown in Figure 3.

The searching method imposes two related constraints on the simulation model. First of all, the model needs to know the time it takes to travel to a given rack from the home position or in general the time it takes to travel from a given position in the aisle to another. The travel time is given by the maximum value of those by the movement of horizontal and vertical directions. Secondly, it should perform a search of the available racks to determine the open location. The AS/RS in question is required to make more than 15,000 storage and retrievals in each operation. Thus, finding an efficient way of making those calculations is a necessity for a simulation model that is of some practical value in making timely analysis of the system under varying conditions.

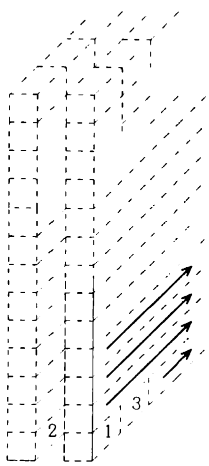
3 THE MODEL

3.1 The Model Structure

The movement system is modeled using the SIMAN simulation language constructs. In addition to the movement system, the external files are also used for generating retrieval and storage requests, collecting various performance statistics, and monitoring the status of the system.

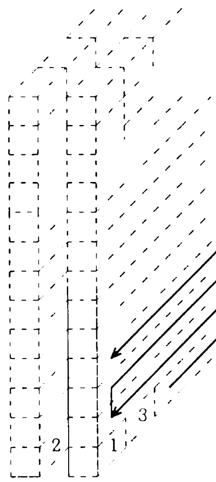
Storage and retrievals requests are generated in the model based on the searching method described earlier.

Sequence	Bank No.	Level No.	Bay No.
1	1	1	1
2	2	1	1
3	1	1	2
4	2	1	2
		:	
73	1	1	37
74	2	1	37
75	1	1	38
76	2	1	38
77	1	2	1
78	2	2	1
79	1	2	2
80	2	2	2
		:	
149	1	2	37
150	2	2	37
151	1	2	38
152	2	2	38
		:	
1517	1	20	37
1518	2	20	37
1519	1	20	38
1520	2	20	38
		:	



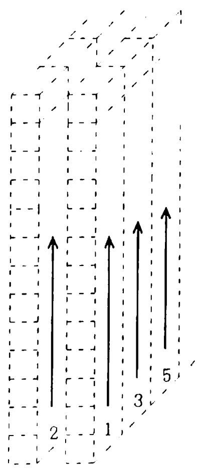
(a) Alternative A

Sequence	Bank No.	Level No.	Bay No.
1	1	1	1
2	2	1	1
3	1	1	2
4	2	1	2
		:	
73	1	1	37
74	2	1	37
75	1	1	38
76	2	1	38
77	1	2	38
78	2	2	38
79	1	2	37
80	2	2	37
		:	
149	1	2	2
150	2	2	2
151	1	2	1
152	2	2	1
		:	
1517	1	20	2
1518	2	20	2
1519	1	20	1
1520	2	20	1
		:	



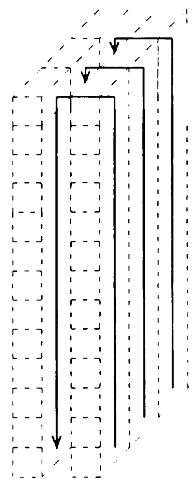
(c) Alternative C

Sequence	Bank No.	Level No.	Bay No.
1	1	1	1
2	1	2	1
		:	
19	1	19	1
20	1	20	1
21	2	1	1
22	2	2	1
		:	
39	2	19	1
40	2	20	1
41	1	1	2
42	1	2	2
		:	
59	1	19	2
60	1	20	2
61	2	1	2
62	2	2	2
		:	
79	2	19	2
80	2	20	2
		:	
1519	2	19	38
1520	2	20	38
		:	



(b) Alternative B

Sequence	Bank No.	Level No.	Bay No.
1	1	1	1
2	1	2	1
		:	
19	1	19	1
20	1	20	1
21	2	20	1
22	2	19	1
		:	
39	2	2	1
40	2	1	1
41	1	1	2
42	1	2	2
		:	
59	1	19	2
60	1	20	2
61	2	20	2
62	2	19	2
		:	
79	2	2	2
80	2	1	2
		:	
1519	2	2	38
1520	2	1	38
		:	



(d) Alternative D

Figure 3: Storing/Retrieving Policy

In this study, the simulation program consists of three major parts:
(1) the model program.
(2) the experiment program.
(3) five external files.

3.2 External files

Five additional files are used for keeping information on storage and retrievals in the system.
(1) File 1: Comprehensive description of each rack
[FORMAT] Rack No., Bank No., Level No., Bay., Number of kinds of items, Total number of cases, Travel time from HP
[PURPOSE] To determine the destination rack, based on the number of kinds of items and the total number of cases.
(2) File 2: Detailed description of each rack
[FORMAT] Rack No., Item No., Number of cases of the item, Time of incoming, repeat
[PURPOSE] To keep the record on each items put on every rack. If nothing is on the particular rack, '0' is assigned on each position.
(3) File 3: Record of located items on each rack
[FORMAT] Item number, Number of cases, Time of Incoming, Rack No., Entry No.
[PURPOSE] To find the oldest item among those for the particular outgoing item. After determining the outgoing item, the rack number and the associated position are read, and renewed in files 1 and 2.
(4) File 4: Record of outgoing items
[FORMAT] Time of incoming, Rack No., Bank No., Level No., Bay No., Item No., Number of cases
[PURPOSE] To record and list the outgoing items in the order of time.
(5) File 5: Record of incoming items
[FORMAT] Time of outgoing, Rack No., Bank No., Level No., Bay No., Item No., Number of cases
[PURPOSE] To record and list the incoming items in the order of time.

3.3 Setting Initial Conditions for Each Rack in the AS/RS

In the proposed simulation program, there are two different ways to set the initial conditions for each rack in the warehouse. One is to write the conditions (i.e., the content of items or open), into File 2, using random numbers. This is done to analyze the performance of the system. Another is to specify the initial conditions in File 2 directly. This can be used to monitor the dynamic activity inside the warehouse, by setting the actual status for each rack of the AS/RS.

3.4 Example on Renewal of External Files

In this section, a series of renewal of the contents in the external files is described through a trial execution of simulation, by adopting Alternative A for the storing/retrieving policy shown in Figure 3.

Before executing simulation, the initial condition should be set for each rack inside AS/RS. For simplicity, let the particular rack, say Rack No. 10, specified by the location of Bank No. 2, Level No. 1, and Bay No. 5, be taken note specially throughout this example. The referred part of Files No. 1 and No. 2 are assumed that there are not any item initially on the rack. In addition, suppose that the following items come in and go out at the corresponding time during the some amount of time interval:

Time	Item No.	No. of Cases	Incoming/ Outgoing
687.3	236	1	Incoming
748.2	101	9	Incoming
1381.7	236	1	Outgoing
1685.7	48	1	Incoming
1685.7	238	3	Incoming
1685.7	185	5	Incoming

Hence, There should be four kind of items (i.e., Nos. 101, 48, 238, and 185) and eighteen (18) cases in total on the rack after the time interval. The content of the corresponding File 2 is shown in Figures 4.

4 APPLICATION

4.1 Large-scale AS/RS-AGV System

As an application, looped-truck automated guided vehicles (AGVs) systems with AS/RS are considered and analyzed. A 3-D layout for a large-scale AS/RS-AGV system is depicted in Figure 5. Efficiency of the system is found to depend on specifications of the systems such as the locations of the system components, the number of vehicles [Takakuwa, 1993]. Material flow and movement of AGV are described briefly in this section, and simulation analysis is performed in 5, especially on the effects of storage and retrievals.

4.2 AS/RS Material Flow

Specifications of the system are summarized in Table 1. The system to be analyzed comprises three major subsystems, i.e., the automated warehouse, the conveyance system and the handling system. There

Rack No.	Item No.	Number of Kinds	Time	Item No.	Number of Kinds	Time	Item No.	Number of Kinds	Time	Item No.	Number of Kinds	Time · ·
1	620	12	5.0	212	5	300.2	909	3	706.7	0	0	.0 · ·
2	589	4	.0	838	12	135.3	836	3	833.9	763	1	1374.4 · ·
3	909	17	.0	280	2	1496.9	0	0	.0	0	0	.0 · ·
4	909	17	157.9	0	0	.0	0	0	.0	0	0	.0 · ·
5	375	16	320.4	0	0	.0	0	0	.0	0	0	.0 · ·
6	461	17	519.5	0	0	.0	0	0	.0	0	0	.0 · ·
7	907	14	559.7	360	6	676.9	0	0	.0	0	0	.0 · ·
8	846	16	.0	0	0	.0	0	0	.0	0	0	.0 · ·
9	752	7	601.8	78	12	633.7	0	0	.0	0	0	.0 · ·
→ 10	101	9	748.2	48	1	1685.7	238	3	1685.7	185	5	1685.7 · ·
11	356	1	.0	40	4	.0	78	3	.0	540	2	.0 · ·
:	:	:	:	:	:	:	:	:	:	:	:	:

Figure 4: The Content of File 2

are two types of material flow, i.e., incoming and outgoing, in the AS/RS system considered in this study. Each item enters at one of the arrival stations to the system. Then, the item will be conveyed to the entrance conveyor directly connected to the AS/RS for the designated high-rise rack lane, moving on one of AGVs. The AS/RS receives items solely from the arrivals stations.

After an incoming item reaches the warehousing gate, it must wait for a stacker crane to be transported to the assigned rack. Both incoming and outgoing items are handled by a stacker crane between the two high-rise rack lanes in the automated warehouse.

Outgoing items leaving the warehouse, on the contrary, are routed on a conveyance system toward an assigned departures station. After arriving at the station, the item leaves the system.

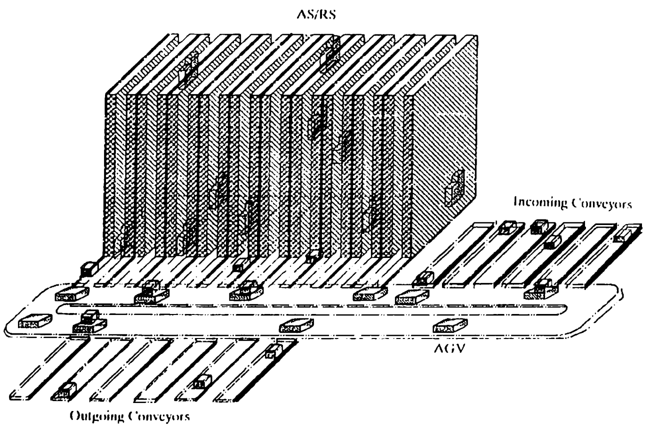


Figure 5: Large-Scale AS/RS-AGV System

4.3 Movement of the AGV

Movement of AGVs in looped-track AGVs systems consists of several major parts.

4.3.1 Requesting a Vehicle

When an item arrives at the position to be loaded and transferred by a vehicle, the item calls for the nearest available vehicle. If there is no available vehicle at that

Table 1: Specifications of the System

Items	Parameters
Racks:	
Number of racks	15,200 (= 20 x 38 x 20)
Stacker Cranes:	
Number of stacker cranes	10 (units)
Horizontal direction	
Velocity	0.083 - 2.667 (m./sec.)
Acceleration	0.294 (m./sec.^{2})
Vertical direction	
Velocity	0.083 - 1.050 (m./sec.)
Acceleration	0.294 (m./sec.^{2})
Loading/unloading time	13 (sec.)
Incoming Conveyors:	
Number of incoming conveyors	10 (units)
Velocity	1 (m./sec.)
Length	5 (m.)
Outgoing Conveyors:	
Number of outgoing conveyors	6 (units)
Velocity	1 (m./sec.)
Length	5 (m.)
AGVs:	
Number of AGVs	5, 15 (units)
Velocity	0.500 - 1.667 (m./sec.)
Acceleration	0.490 (m./sec.^{2})
Loading/unloading time	8 (sec.)
Items to be handled:	
Number of incoming items	30 (units/h.)
Number of outgoing items	220 (units/h.)
Number of kinds of items on each rack	1 - 5 (kinds)
Number of cases put on each rack	1 - 20 (cases)

time, the item will try again within a specified period of time.

4.3.2 Moving a Vehicle

There are three major types of AGV movements. The first type is on the assigned vehicle going to its destination point, the second type is on the loading vehicle, and the third type is on the unloading vehicle which is pushed ahead by the first two loading vehicles.

4.3.3 Controlling Vehicles

The function of controlling the vehicles is performed in searching control points (stations) on the way to the destination control points. This function is also performed in checking whether loading/unloading vehicles are in the same path to the destination point. In case there are vehicles in the path, these vehicles are pushed ahead to the appropriate positions. Then the loading vehicle is moved to its destination.

5 SIMULATION ANALYSIS

5.1 Experimental Conditions

When introducing large-scale AS/RS-AGV systems, there are a lot of alternatives. Management has to decide particular specifications of the system. Regarding the system shown in Figure 5, simulation analysis is performed. A set of specifications is summarized in Table 1, and the parameters listed in the table are used as experimental conditions of simulation. Five independent simulation runs are made for each scenario. The simulation is performed by SIMAN [Pegden et al. 1990].

5.2 Measure of Performance

Each simulation run is executed until 220 incoming and 30 outgoing containers are processed completely, and statistics are measured and recorded. While a number of performance measurement variables were recorded, the total flow time is selected as the principal variable from the efficiency standpoint.

5.3 Determining the Effects of Specifications on Efficiency

In this section, storage/retrieval policies are established to seek more effective handling. By performing simulation experiments together with statistical tests, corresponding hypotheses are examined from the standpoint of efficiency.

Simulation runs are differentiated by the following three factors:

Factor A: Inventory Level.
A_1: Percentage of Occupied Racks = 20 %.
A_2: Percentage of Occupied Racks = 80 %
Factor B: Number of AGVs.
B_1: 5 units.
B_2: 15 units.
Factor C:Storing/Retrieving Policy(see Figure 3).
C_1: Alternative A.
C_2: Alternative B.
C_3: Alternative C.
C_4: Alternative D.

Summary statistics of the output variable were analyzed via a factorial analysis of variance program for an experimental design involving single observation data. The design is 2x2x4, where factor A is the percentage of occupied racks with two levels, factor B is the number of AGVs with two levels, factor C is the storage/retrieval policy with four levels.

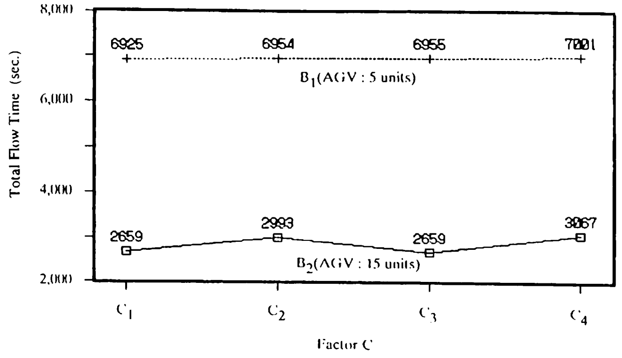
Summary results of the analysis of variance for the output variable (the total flow time) are given in Table 2. In addition, the comparisons among the alternatives on storing/retrieving policy are shown in Figure 6. A single simulation replication with SUN workstations has been executed for approximately 15 to 38 minutes, depending on the number of AGVs. The storing/retrieving policy, factor C, has a significant effect on this variable, as well as the number of AGVs to install, factor B.

It is concluded that the alternatives A and C are more effective than other alternatives especially in installing more AGVs, regardless the percentage of occupied racks. This may be because the travel time by the vertical movement is relatively longer than by the horizontal movement.

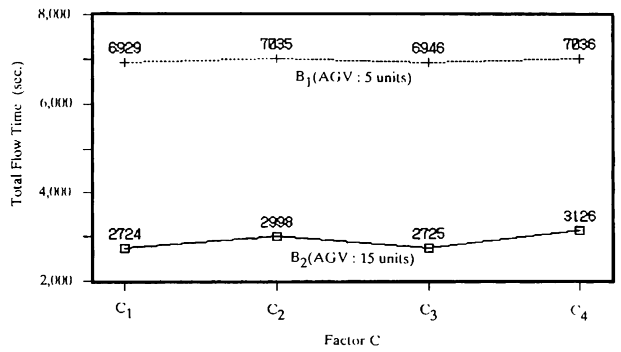
Contrary to our expected results, the inventory level does not affect the total flow time. From the above-mentioned issues, the desirable storing/retrieving policy with the search by the horizontal direction basis is recommended.

Table 2: Analysis of Variance for the Output Variable

Source	F Ratio	Sig.
A	3.06	N/A
B	34,893.29	1 %
C	32.23	1 %
A x B	0.24	N/A
A x C	0.03	N/A
B x C	14.85	1 %
A x B x C	0.62	N/A



(a) Inventory Level: 20 %



(b) Inventory Level: 80 %

Figure 6: Total Flow Time

6 SUMMARY

This paper presents a precise modeling of the large-scale AS/RS and analytical results of a large-scale AS/RS-AGV system. Characteristics of this system are clarified from the standpoint of efficiency, especially on the storing/retrieving policy. The procedure is also presented using a numerical example based on an actual case.

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