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FLEXIBLE MODELING AND ANALYSIS OF LARGE-SCALE AS/RS-AGV SYSTEMS

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ABSTRACT

A method of modeling large-scale AS/RS-AGV systems is proposed in an attempt to describe the AS/RS precisely and flexibly 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 looped-track AGV system, aisle conveyors connecting these two systems, and incoming and outgoing conveyors. There are two major stages to model large-scale AS/RS-AGV systems flexibly and execute simulation experiments. The first stage is to generate a simulation program by inputting the selected parameters such as the number of banks, the number of bays, the number of levels of AS/RS, and the number of AGVs. The second stage is to perform simulation experiments. In the proposed model, every item number put on each rack, the corresponding number of cases for each item, the time of arriving at the warehouse, and the time of departing from the system are stored and recorded. Regarding a large-scale AS/RS system, three particular types of the rack arrangement, which have the same number of racks inside the warehouse, are analyzed to examine their performance. The analysis is performed using both average flowtime and equivalent annual cost as performance measures.

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 an 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 some reports on applications of simulation to model an AS/RS (Harmonosky and Sadowski 1984, Medeiros, Enscore, and Smith 1986, Muller 1989, Gunal, Grajo, and Blanck 1993). In the previous study, the AS/RS is modeled precisely and realistically to behave as the real system does (Takakuwa 1994).

When introducing a large-scale AS/RS-AGV system, in general, there are a lot of alternatives. Management has to decide particular specifications of the system, such as the specifications of AS/RS, the number of AGVs, and the number of incoming/outgoing conveyors, considering the frequency of handling items. For analyzing and comparing possible alternatives of the system, it is necessary to model and perform simulation experiments of a number of models describing the alternatives. Because it takes a lot of time (possibly a couple of months even for skilled programmers) to build a complex program for a particular type of large-scale AS/RS-AGV system, it is a time-consuming task to analyze and compare alternatives. In this paper, a flexible modeling system is proposed to build simulation programs for the AS/RS-(looped-track) AGVs system, and some analytical results are indicated from both efficient and economic standpoints.

2 LARGE-SCALE AS/RS-AGV SYSTEM

2.1 The Storage System and the Conveyor Interface

A general view of the AS/RS is shown in Figure 1, together with the flexibility of modeling. In addition, 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. 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 picking and

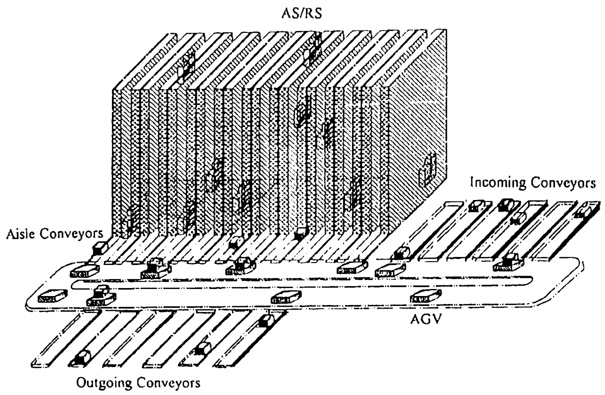
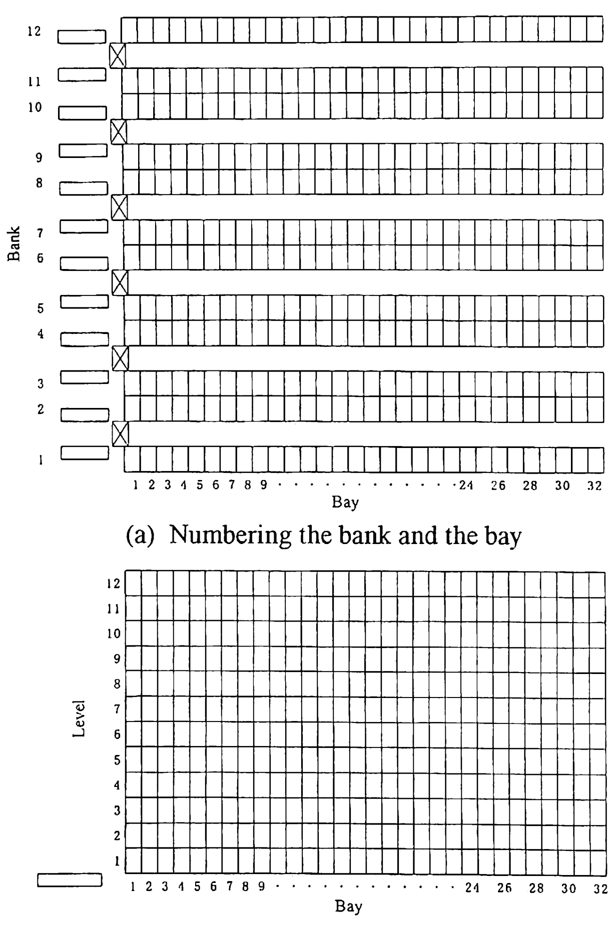


Figure 1: Layout of Large-Scale AS/RS-AGV System



(a) Numbering the bank and the bay

(b) Numbering the level and the bay

Figure 2: Large-Scale AS/RS

dropping 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 simultaneously. Once the stacker crane is positioned at a designated 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 similar movement applies to picking/dropping an item from/to the picking and dropping stations.

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 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.

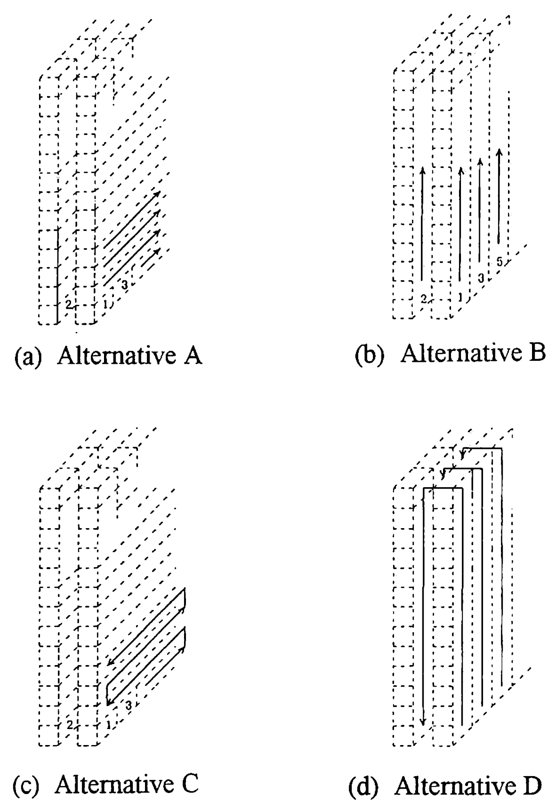
The searching method imposes two related constraints on the simulation model. First of all, the model needs to know the required time to travel to a given rack from the home position or, in general, the required time to travel from a given position in the aisle to another. The travel time is given by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

2.3 Movement of the AGV

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

2.3.1 Requesting a Vehicle

When an item arrives at the position to be loaded and transferred by a vehicle, the item tries to request the



(a) Alternative A (b) Alternative B

(c) Alternative C (d) Alternative D

Figure 3: Storing/Retrieving Policy

nearest available vehicle. If there is no vehicle available at that time, it would try again when a vehicle become available.

2.3.2 Moving a Vehicle

There are three major types of AGV movements. The first type is on the assigned (or requested) vehicle going to its destination point. The second type is on the loading (i.e., carrying items) vehicle. The third type is on the unloading vehicle which is pushed ahead by the above-mentioned two types of vehicles.

2.3.3 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.

2.4 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 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 warehouse 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.

Table 1: Specifications of the System

Items	Parameters
Racks:	
Number of racks	4,608 (= 16 x 24 x 12) (= 12 x 32 x 12) (= 8 x 48 x 12)
Stacker Cranes:	
Number of stacker cranes	8, 6, 4 (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	6 (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	3 - 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	200 (units/h.)
Number of outgoing items	200 (units/h.)
Number of kinds of items on each rack	1 - 5 (kinds)
Number of cases put on each rack	1 - 20 (cases)

3 FLEXIBLE MODELING SYSTEM

3.1 Flexible Modeling System for Generating Simulation Programs

In the proposed procedure, there are two steps to execute simulation experiments. The first step is to generate simulation programs, by inputting the required parameters for describing a particular AS/RS-AGV system. In this study, the simulation is performed by SIMAN (Pegden et al. 1994); however, the basic idea of this procedure can be applied to other simulation languages. The menu structure of the flexible modeling system is illustrated in Figure 4. The system comprises ten major items;

(1) AS/RS.
(2) Inventory file.
(3) AGV.
(4) Conveyor, picking.
(5) Pallet related.
(6) Looped track of AGV.
(7) Miscellaneous.
(8) Save.
(9) Generating model/experiment programs.
(10) End.

Furthermore, each item has more detailed parameters to be set interactively. For example, the item of "AS/RS" has the parameters of the number of banks, levels and bays, travel time of stacker cranes, and the loading/unloading time of stacker cranes. By responding to the prompt for each parameter, appropriate figures may be inputted. After all required parameters are inputted, the corresponding simulation programs (in this case, the model and experiment programs) are generated automatically. For illustrating the results of performing the flexible modeling system, three types of AS/RSs are shown in Figure 5. The numbers of the corresponding bank, bay, and level of three types of AS/RS are as follows:

Type 1: bank: 16, bay: 24, level: 12 = 4,608 (racks)
Type 2: bank: 12, bay: 32, level: 12 = 4,608 (racks)
Type 3: bank: 8, bay: 48, level: 12 = 4,608 (racks)

Then, simulation experiment can be executed quite easily.

3.2 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 requests for storage and retrievals, collecting various performance statistics, and monitoring the status of the system.

Requests for storage and retrievals are generated in the model based on the searching method described in Section 2.2. The simulation program consists of three major parts:

(1) the model program.
(2) the experimental files.
(3) external files.

3.3 External files

Five additional files are used for keeping information on storage and retrievals in the system. (A rack is identified by a particular combination of the bank number, the level number, and the bay number.)

(1) File 1: Comprehensive description of each rack
[PURPOSE] To determine the destination rack, based on the number of kinds of items and the total number of cases.
[FORMAT] Rack No., Bank No., Level No., Bay No., Number of kinds of items, Total number of cases, Travel time from HP

(2) File 2: Detailed description of each rack
[PURPOSE] To keep the record on each items put on every rack.
[FORMAT] Rack No., Item No., Number of cases of the item, Time of incoming, repeat

(3) File 3: Record of located items on each rack
[PURPOSE] To find the oldest item among those for the particular outgoing item.
[FORMAT] Item number, Number of cases, Time of Incoming, Rack No., Entry No.

(4) File 4: Record of outgoing items
[PURPOSE] To read and list the outgoing items in the order of time.
[FORMAT] Time of incoming, Rack No., Bank No., Level No., Bay No., Item No., Number of cases

(5) File 5: Record of incoming items
[PURPOSE] To record and list the incoming items in the order of time.
[FORMAT] Time of outgoing, Rack No., Bank No., Level No., Bay No., Item No., Number of cases

4 SIMULATION ANALYSIS

4.1 Alternatives of AS/RS

When introducing large-scale AS/RS-AGV systems, there are a lot of alternatives. Efficiency of the system is found to depend on specifications of the systems such as the locations of the system components, the number of AGVs (Takakuwa 1993). In this section, alternatives which differ in the rack arrangement inside the AS/RS are examined for the purpose of evaluating efficiency of the handling. Regarding the three systems (i.e. Type 1, Type 2, and Type 3), shown in Figure 5,

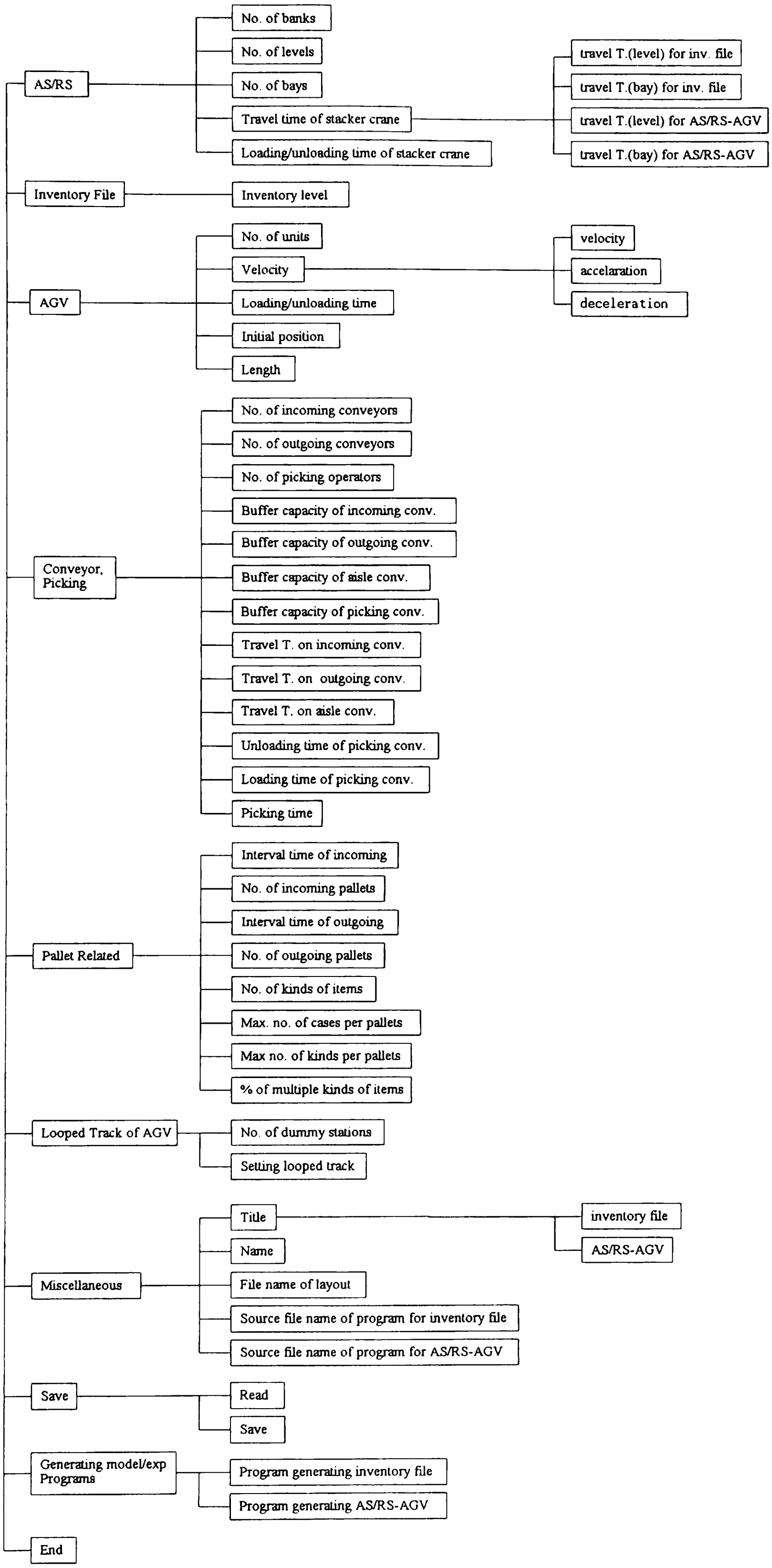
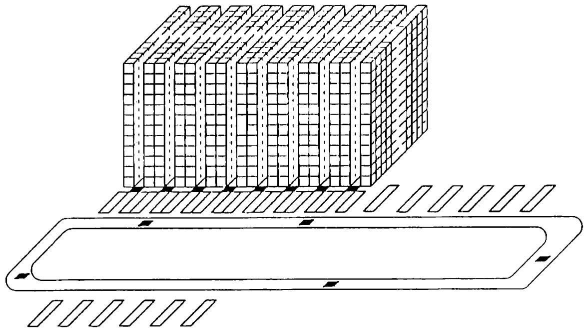
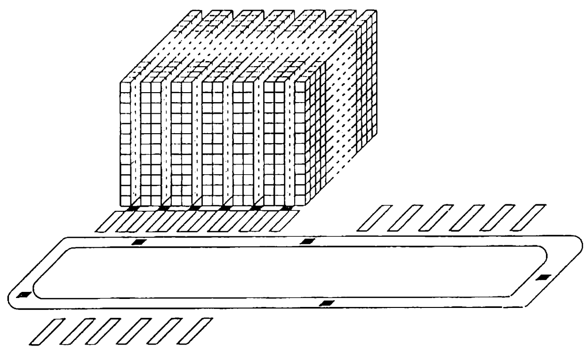


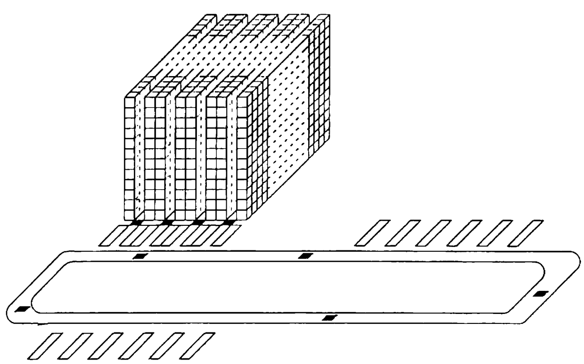
Figure 4: Menu of Flexible Modeling System for Generating Simulation Programs



(a) Type 1 (Bank: 16, Bay: 24, Level: 12)



(b) Type 2 (Bank: 12, Bay: 32, Level: 12)



(c) Type 3 (Bank: 8, Bay: 48, Level: 12)

Figure 5: Alternatives of AS/RS

simulation analysis is performed. The total number of racks are same on these three types of AS/RS. A set of parameters are summarized in Table 1, and the parameters listed in the table are used as experimental conditions of simulation. Ten independent simulation runs are made for each type.

4.2 Measure of Performance

Each simulation run is executed until 200 incoming and 200 outgoing containers are processed completely, and statistics are measured and recorded. While a number of performance measurement variables are recorded, the flowtime is selected as the principal variable from the efficiency standpoint.

4.3 Determining the Effects of Specifications of AS/RS on Efficiency

In this section, the arrangement of racks inside the AS/RS is established to seek more effective and economic 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 two factors:

Factor A: Arrangement of Racks (see Figure 5)
- A_1: Type 1.
- A_2: Type 2.
- A_3: Type 3.

Factor B: Number of AGVs
- B_1: 5 units.
- B_2: 10 units.
- B_3: 15 units.

In addition, the inventory level, i.e., the percentage of occupied racks in AS/RS, is assumed to be approximately 80 %.

Summary statistics of the output variable are analyzed via a factorial analysis of variance program for an experimental design. The design is 3 x 3, where factor A is the arrangement of racks inside AS/RS with three levels, factor B is the number of AGVs with three levels.

Summary results of the analysis of variance for the output variable (the total flowtime) are given in Table 2. In addition, the comparison among the three types on the arrangement of racks are shown in Figure 6. Ten simulation replications with SUN workstations has been executed for approximately 100 to 140 minutes, depending on the type of AS/RS and the number of

Table 2: Analysis of Variance for the Output Variable

Source of variation	Degree of freedom	Computed f
Type of AS/RS (A)	2	151.3 (1%)
No. of AGVs (B)	2	971.3 (1%)
Interaction (AB)	4	25.4 (1%)
Error	81	
Total	89	

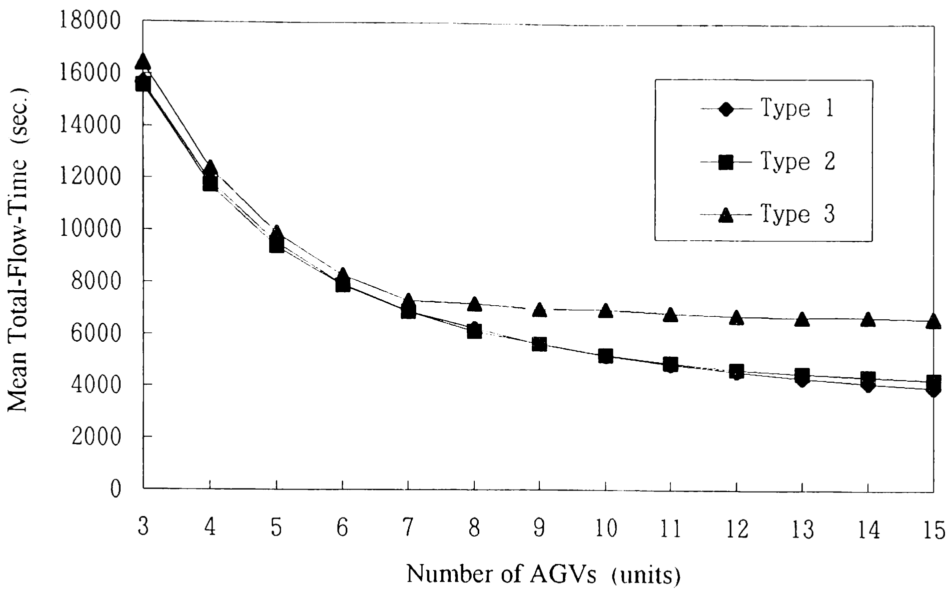


Figure 6: Mean Total-Flow-Time

AGVs. The arrangement of racks, Factor A, has a significant effect on this variable, as well as the number of AGVs to install, factor B.

It is concluded that Type 1 and Type 2 are more effective than Type 3 especially in installing more AGVs. This may be because of the difference of the number of stacker cranes; there might be enough stacker cranes to handle incoming and/or outgoing items under the current condition in Type 1 and Type 2. Hence, even though the total number of racks are same, if the number of stacker cranes are few, the items cannot be handled efficiently in AS/RS-AGV systems.

5 COST COMPARISON AMONG ALTERNATIVE INVESTMENTS

When performing cost comparison among alternatives it is necessary to collect the following information:

(1) initial cost.
(2) annual maintenance cost.
(3) any expenses.
(4) expected life.
(5) salvage value.

These estimates should be collected for all of the AS/RS-AGV systems considered. When this information has been collected, cost comparisons can then be made among the alternative systems on a before tax-basis. Then, recommendations can be made to management regarding the most economic system to install.

An economic analysis of the alternatives would be necessary to select the most economical. Nine alternatives are described in Table 3. An annual interest rate of 10 % is selected for this example. The term unacost, as used here implies uniformity from year to year with the end of the years as part of the definition (Jelen 1983). Management then would decide particular specifications of the system, considering both efficient and economic issues.

6 SUMMARY

(1) This paper presents a flexible modeling method for generating complex and large-scale AS/RS-AGV systems. The time to build simulation programs could be drastically reduced.
(2) Analytical results of alternatives on the arrangement of racks inside the AS/RS is presented; it is found that the number of stacker cranes (or banks) has a significant effect on the efficiency of the system.
(3) In addition, cost comparison among selected alternative investments are performed to seek more economical systems.

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Table 3: Cost Comparison among Alternative Investments

Type of AS/RS	No. of stacker cranes (units)	No. of AGVs (units)	Initial cost ($1,000)	Mainte-nance cost ($1,000/yr.)	Other direct/ indirect expenses ($1,000/yr.)	Salvage value ($1,000)	Service life (yr.)	Unacost ($1,000/yr.)
Type 1	8	5	3,620	68	33	362.0	12	615
Type 1	8	10	3,875	79	35	387.5	12	665
Type 1	8	15	4,130	90	37	413.0	12	714
Type 2	6	5	3,301	62	28	330.1	12	559
Type 2	6	10	3,556	74	30	355.6	12	609
Type 2	6	15	3,811	86	32	381.1	12	659
Type 3	4	5	2,979	57	21	297.9	12	501
Type 3	4	10	3,234	69	24	323.4	12	553
Type 3	4	15	3,489	81	27	348.9	12	604

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