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EFFICIENT MODULE-BASED MODELING FOR A LARGE-SCALE AS/RS-AGV SYSTEM

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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 efficiently and to execute simulation experiments. The first stage is to generate a simulation program by placing appropriate modules and 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 puts 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. Generally, it takes a lot of time to build a complex program for a particular type of large-scale AS/RS-AGV system. It is found that simulation/ animation models can be made quickly, by using a module-based modeling method developed in this study.

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 of 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 studies, the AS/RS is modeled precisely and realistically to behave as a real system (Takakuwa 1994, Takakuwa 1995).

Generally, when introducing a large-scale AS/RS-AGV system, there are a lot of alternatives. Management should 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 that describe 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, analyzing and comparing alternatives is a time-consuming task. In this paper, an efficient modeling system is proposed to build simulation programs for the AS/RS-(looped-track) AGVs system, and the flexibility of the proposed system is described together with some analytical results explored by the previous studies.

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. 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 dropping stations, which are called

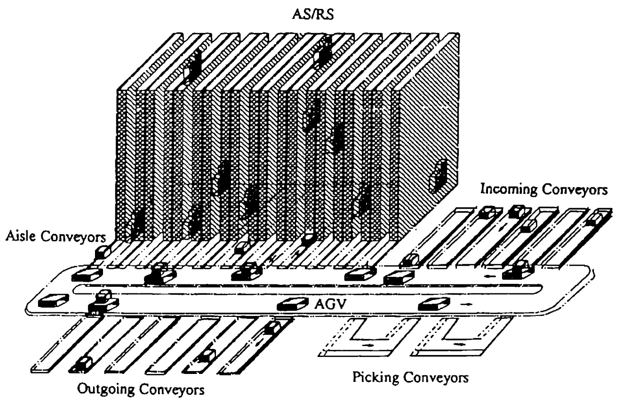


Figure 1: Layout of Large-Scale AS/RS-AGV System

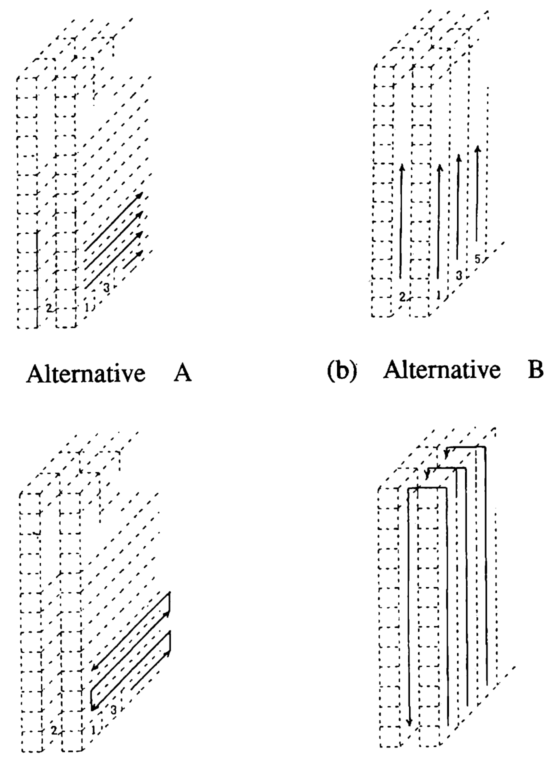
the home position (HP), of a stacker crane at one end of the aisle.

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 consecutive operations of extending its shuttle into the rack, dropping/picking the item and pulling the shuttle back are 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 finally 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 one of the four different ways shown in Figure 2.



(a) Alternative A (b) Alternative B

(c) Alternative C (d) Alternative D

Figure 2: Storing/Retrieving Policy

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 needed 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 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, namely, the automated warehouse, the conveyance system and the handling system. There are two types of material flow, namely, 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 incoming isle 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.

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

Table 1: Specifications of the System

Items	Parameters
Stacker Cranes:	
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:	
Velocity	1(m./sec.)
Length	5(m.)
Outgoing Conveyors:	
Velocity	1(m./sec.)
Length	5(m.)
Picking Conveyors:	
Velocity	1(m./sec.)
Length	10(m.)
AGVs:	
Velocity	0.500 - 1.667(m./sec.)
Acceleration	0. 490(m./sec.^{2})
Loading/unloading time	8(sec.)
Items to be handled:	
Number of kinds of items on each rack	1 - 5(kinds)
Number of cases put on each rack	1 - 20(cases)

3 MODULE-BASED MODELING SYSTEM

3.1 Efficient Modeling System for Large-Scale AS/RS-AGV System

The basic idea of the proposed procedure is based upon a flexible modeling system described in the previous paper (Takakuwa 1995). The system comprises ten major items, and 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 (the model and experiment programs) are generated automatically.

In the proposed procedure in this paper, on the other hand, there are two steps to execute simulation experiments. The first step is to generate simulation programs, by selecting and allocating the required modules of the Arena template for describing a particular AS/RS-AGV system. There are 23 modules for the particular type of the large-scale AS/RS-AGV system, as shown in Table 2. Although, in this study, the simulation is performed by SIMAN/Arena, the basic idea of this procedure can be applied to other simulation languages as well (Pegden et al. 1994).
The template system comprises the following major items;
(1) AS/RS.
(2) Inventory files.
(3) AGV system.

(4) Incoming conveyors.
(5) Outgoing conveyors.
(6) Picking conveyors.
(7) Aisle conveyors.

3.2 Building a Simulation Model

The movement system is modeled using the SIMAN/Arena 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. In addition to the typical model and experimental simulation program, 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.)

Figure 3 shows an illustrative example of Arena template and a series of associated modules for the large-scale AS/RS-AGV systems. In Arena, simulation models are built by placing modules in a working area of the model window, providing data for these modules, and specifying the flow of entities through modules. A module defines the underlying logic that is applied when an entity is directed to the module, as well as the associated graphical animation, to depict the module's activities during a simulation run.

After a module has been placed in the model windows, its associated data may be edited. The module for defining the initial conditions inside AS/RS (named 'Zaiko Sakusei' in Table 2) is shown in Figure 4. Furthermore, each item has more detailed parameters to be set interactively. By responding to the prompt for each parameter, appropriate figures may be inputted. Another module for creating incoming/outgoing items (named 'Nyuko Shuko' in Table 2) is shown in Figure 5. This module is prepared for creating entities of incoming and outgoing items, and specifying case assignments.

To define the flow of entities among modules, either direct connections or station transfers may be used. A direct connection is formed by placing a connection from a module exit point to a module entry point. Entities that leave a module through an exit point transferred through the connection to the entry point with no time delay. A station transfer takes place when an entity leaves a module by means of a route, transport, or convey. In these cases, a station destination is specified and the entity is sent to the module that defines the station. Allocating stations for the looped track of AGVs is shown in Figure 6. Dummy stations might be

Table 2: List of Modules for Large-Scale AS/RS-AGV System

Module		Corresponding Subsystem	Description
No.	Name		
1	Zaiko Sakusei	N/A	Assign the initial condition on each rack of AS/RS.
2	Nyuko Shuko	N/A	Create incoming and outgoing entities.
3	AisleConv	Aisle Conveyor	Define the specifications of aisle conveyors.
4	ASRS1	AS/RS	Define the specifications of each pair of high- rise rack lanes.
5	ASRS2	AS/RS	Define the specifications of the oveall AS/RS.
6	InCnvBegin	Incoming Conveyors	Specify the starting point of each incoming conveyor.
7	InCnvEnd	Incoming Conveyors	Specify the ending point of each incoming conveyor.
8	OutCnvBegin	Outgoing Conveyors	Specify the starting point of each outgoing conveyor.
9	OutCnvEnd	Outgoing Conveyors	Specify the ending point of each outgoing conveyor.
10	InAslBegin	Incoming Aisle Conveyor	Specify the starting point of each incoming aisle conveyor.
11	OutAslEnd	Outgoing Aisle Conveyor	Specify the ending point of each incoming aisle conveyor.
12	PickCnvBegin	Picking	Specify the starting point of each picking conveyor.
13	PickCnvEnd	Picking	Specify the ending point of each picking conveyor.
14	PickWorker	Picking	Specify the picking operation.
15	DummyStation	AGV	Set each dummy Station.
16	STV	AGV	Define the specifications of AGVs.
17	STVTrack	AGV	Set the looped track of AGVs.
18	Conveyors	Conveyor Related	Specify the specifications of conveyors.
19	STVFileInit	AGV	Initialize the file to control AGVs.
20	STVFileCheckSTV	AGV	Check and/or modify the file to control AGVs.
21	FreeSTV	AGV	Free the AGV.
22	Hikiate	AGV	Assign the AGV to be allocated.
23	Oidashi	AGV	Push ahead the unloading AGV.

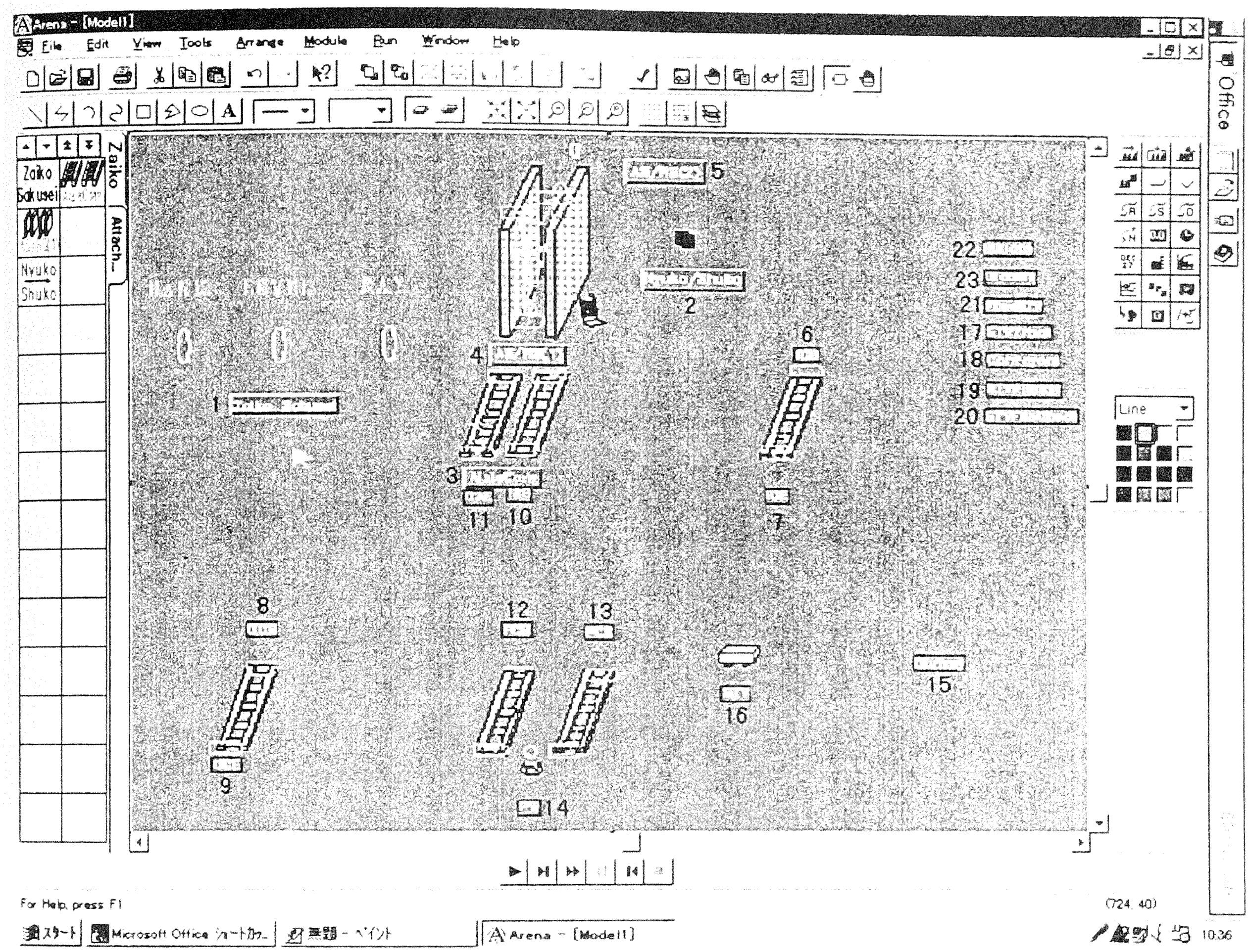


Figure 3: Arena Template and Modules

placed in the system, if necessary. Furthermore, AS/RS, aisle conveyors, incoming conveyors, outgoing conveyors, and picking conveyors are placed and allocated in the appropriate positions on the working area of the window, as shown in Figure 7. After all necessary modules are placed in an appropriate fashion for a particular model and the corresponding values are provided for their operands, a simulation run may be performed.

3.3 Advantages of the Proposed Approach

As mentioned in Section 1, it takes a lot of time (possibly a couple of months even for skilled programmers) to build a complex program for a large-scale AS/RS-AGV system. If the system developed in this study is utilized, it would take only a few hours even for a programming newcomer to develop a simulation program for the similar large-scale AS/RS-AGV system. Thus, the time required to build simulation programs could be reduced drastically, by utilizing the proposed module-based modeling method.

In addition, as the model is developed to be a completed one, the animation model is also built together with the model. When construction of the simulation model is completed, the corresponding animation can be run immediately. This is a great advantage of the module-based modeling method over the flexible modeling system developed in the previous paper.

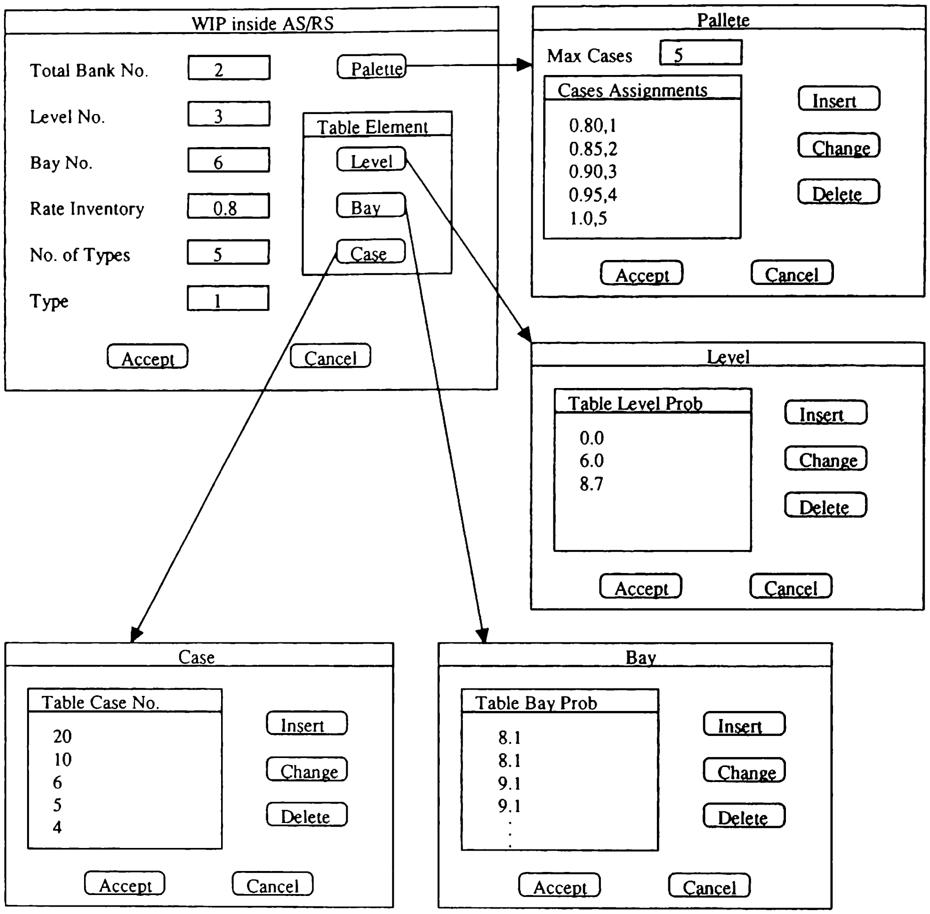


Figure 4: Module for Defining the Initial Conditions inside AS/RS

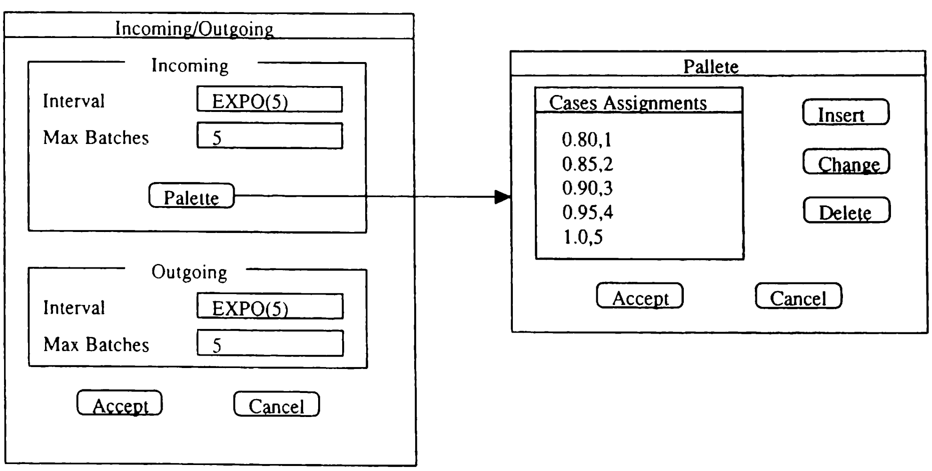


Figure 5: Module for Creating Incoming/Outgoing Items

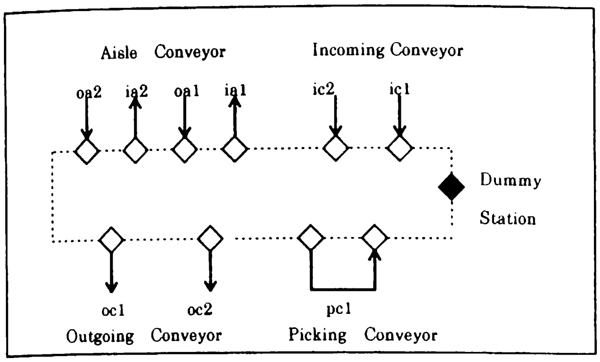


Figure 6: Allocating Stations for the Looped Track

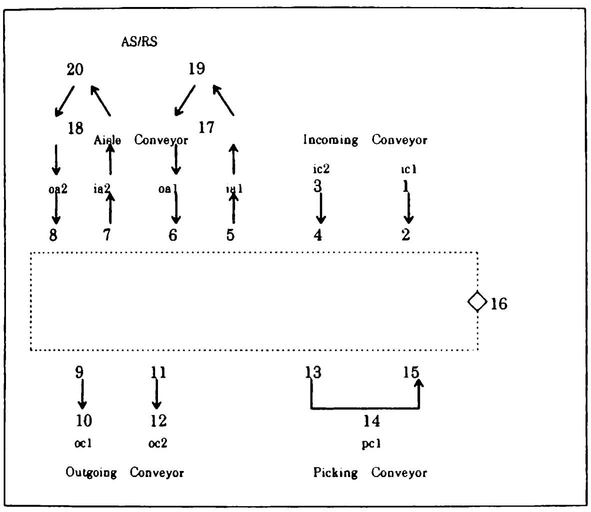


Figure 7: Allocating Appropriate Modules

4. MODELING FLEXIBILITY AND ANALYTICAL FINDINGS OF PREVIOUS STUDIES

4.1 Major Selected Alternatives

As described in Section 1, when introducing large-scale AS/RS-AGV systems, there are a lot of alternatives. Therefore, management will have to decide particular specifications of the system. In this section, some of the typical alternatives are reviewed and some important analytical results found in the series of the previous papers are summarized. The following three issues are considered for evaluation:

(1) Storing/retrieving policy.
(2) Overall layout on the conveyors.
(3) Arrangement of racks inside AS/RS.

4.2 Storing/Retrieving Policy

As mentioned in Section 2.2, there are four typical alternatives typically on the control logic of the AS/RS. The logic is designated so that storage and retrievals are made to the rack in the four different ways shown in Figure 2 (i.e., the alternatives A1 through A4).

According to the previous study, it is concluded that the alternatives A1 and A3 are more effective than other alternatives especially in installing more AGVs, regardless of the percentage of occupied racks (Takakuwa 1994). This may be because the travel time by the vertical movement is relatively longer than by the horizontal movement. In addition, the inventory level does not affect the total flow time. Therefore, the desirable storing/retrieving policy with the search by the horizontal direction basis is recommended.

4.3 Overall Layout on the Conveyors

In general, there are two stages, for management to decide, in installing the particular type of the system described in this study. First stage is determining the overall layout of the system. Relative locations of AS/RS, incoming conveyors, and outgoing conveyors might be different from each other for four alternatives on layout. Second stage is determining more detailed specifications of the system, such as the number of AGVs, the number of incoming and outgoing conveyors.

According to the previous study, the system can be operated more efficiently by locating the loading and unloading positions (i.e., the incoming conveyors and the AS/RS, and the AS/RS and the outgoing conveyors) are located as close as possible (Takakuwa 1993).

4.4 Arrangement of Racks inside AS/RS

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. The total number of racks are same inside the AS/RS, whereas the numbers of the corresponding bank, bay, and level of three types of AS/RS are different from each other.

According to the previous study, it is concluded that the systems with more stacker cranes are more effective (Takakuwa 1995). This may be because of the difference of the number of stacker cranes; they might have enough stacker cranes to handle incoming and/or outgoing items under the current condition. Hence, even though the total number of racks are the same, if the number of stacker cranes are a few, the items cannot be handled efficiently in AS/RS-AGV systems.

5 SUMMARY

(1) In this paper, an efficient module-based modeling method is presented for generating simulation programs for complex and large-scale AS/RS-AGV systems.
(2) Flexibility of the proposed system is summarized. In addition, by utilizing the proposed module-based modeling method, the time to build simulation programs could be drastically reduced,
(3) Some important analytical results are reviewed on major alternatives of the large-scale AS/RS-AGV systems.

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