

MODULE MODELING AND ECONOMIC OPTIMIZATION FOR LARGE-SCALE AS/RS

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ABSTRACT

A method of decomposing models for large-scale Automated Storage/Retrieval Systems (AS/RS) is proposed in an attempt to determine the optimum combination of warehouses and material handling systems. AS/RS which is considered in this paper comprises the automated warehouse with stacker cranes, the conveyance system and the handling systems. There are three alternatives in the conveyance system, i.e., single-track AGV (Automated Guided Vehicle) systems, looped-track AGVs system and conveyor systems. Effectiveness of the proposed approach is confirmed by performing both simulation and animation of models based upon an actual example. In addition, a procedure for obtaining the optimum combination of subsystems for constructing AS/RS warehouses is presented with numerical examples from an economic 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) is utilized for keeping documents as well. Performance analysis of AS/RS is a complex problem. Some approaches exist for performing such an investigation [Pulat, 1988].

This paper presents an approach of module modeling for any scale of AS/RS which comprises the automated warehouse, the conveyance system, and the handling system. In addition, this paper proposes a procedure for obtaining the optimum combination of subsystems for constructing an AS/RS warehouse from the economic standpoint.

2. PROBLEM STATEMENTS

When the AS/RS warehouse is to be introduced in plants or warehouses, there are many alternatives to consider. The alternatives comprise many factors such as the number of racks/stacker cranes in the automated warehouse, the type of conveyance systems, the location of handling facilities, and so on. It is essential to analyze the above-mentioned problem by using a simulation technique. However, considerable time would be required for the analysis if all possible models and combinations of each subsystem were constructed for simulation analysis, because of the number of simulation models that would be required.

In this paper, a module method of decomposing models for representing large-scale AS/RS warehouses is proposed in constructing simulation models. In the proposed method, three major subsystems, i.e., warehouses, conveyance systems and handling systems, are modeled separately. The conveyance system should be selected from among a single-track AGV system, a looped-track AGVs system, and a looped-conveyor system to connect the automated warehouse and the handling stations. In the handling system, the number and the location of conveyors for arrivals, departures

and/or picking operations should be decided from the standpoint of the effective material flow. Once the possible specifications for the designated AS/RS are given, the corresponding simulation model will be constructed with ease by combining ready-made modules for appropriate subsystems. By adopting the module-modeling method, the time required for building simulation models could be reduced substantially. Effectiveness of the proposed approach is confirmed by performing animation as well as simulation based upon an actual example. The simulation program is written in SIMAN [Pegden, 1986].

In the looped-track AGVs system, it is necessary to determine how many vehicles should be stationed on the track. A simple procedure for obtaining the optimum number of vehicles is proposed with numerical examples. In addition, the procedure for obtaining the optimum combination of subsystems for any scale of AS/RS is presented with a numerical example from the economic standpoint.

3. MATERIAL FLOW

3.1 AS/RS Material Flow

Before considering the models in detail, it is essential to specify the general features of a large-scale AS/RS. A 3-D layout for a large-scale AS/RS is depicted in Figure 1. Any scale of AS/RS to be analyzed comprises three major subsystems, i.e., the automated warehouse, the conveyance system and the handling system.

There are three types of material flow, i.e., incoming, outgoing and picking, 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 for the designated high-rise rack lane, moving on the conveyance devices. The AS/RS receives items solely from the arrivals stations. As for the conveyance system, there are three alternatives, i.e., a single-track AGV system, a looped-track AGVs system, and a looped-conveyor system. Feasible conveyance systems depend upon the scale of automated warehouse. Single-track AGV systems are utilized for the small-scale AS/RS, and not for the large-scale AS/RS. In addition, the number of handling stations might be determined based upon the amount of items to be handled.

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. In some cases, the high-rise warehouse has approximately 600 storage racks in each lane.

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.

When an item is appointed to be picked and/or operated, it requests

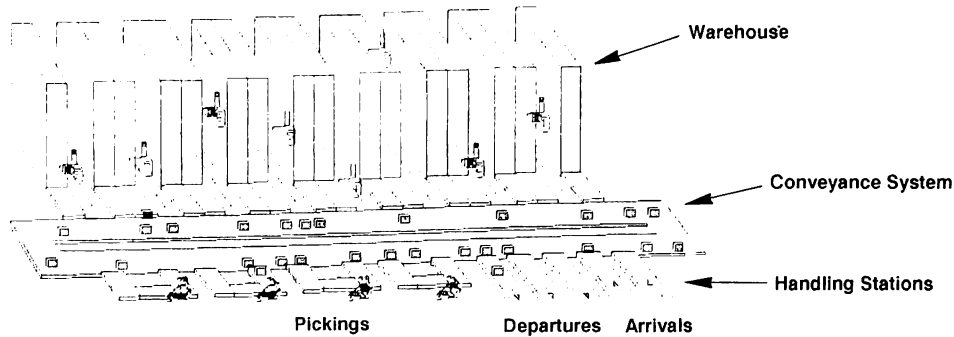


Figure 1. 3-D Layout of AS/RS (Looped-track Conveyor System)

a stacker crane as in the case of departure. For example, an operator may wish to pick up one particular document inside the box stored on some rack. The item starts to move on a rack in the warehouse, and then moves toward the designated picking stations by means of one of the conveyance systems. At the picking station, an operator performs a picking operation, and then puts the item on the conveyor to return it to the rack from which it came.

3.2 Simulation Model of Looped-track AGVs Systems

Simulation models of AGVs in looped-track AGVs systems consist of several major parts.

3.2.1 Requesting a Vehicle

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

3.2.2 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.

3.2.3 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.

4. COMPUTER SIMULATION

4.1 Structure of the Model

In this paper, three modules, corresponding to the warehouse (WARE), the conveyance system (AGVS, AGVL, or CONV) and the handling system (INOUT), are modeled and programmed separately. In constructing a simulation model three appropriate modules are selected and put together to obtain a single simulation program. The relationship among modules are illustrated in Figure 2. Station numbers, for example, of the program modules written in SIMAN are assigned as follows:

The conveyance system: 1 - 70.

The warehouse: 71 - 145.

The handling system: 146 - 176.

The conveyance system should be selected from three alternative subsystems, i.e., a single-track AGV system (AGVS), a looped-track AGVs system (AGVL) and a looped-conveyor system (CONV). In Figure 1 the looped-conveyor system is illustrated as the conveyance system located between the warehouse and the handling systems.

The number and the size of racks in the automated warehouse would be specified in some range based upon the conditions of space and the requirements for the amount of handling. They might be influenced by the rates of arrivals, departures, and/or pickings operations.

In the handling system, the number of conveyor lanes for arrivals and departures and/or picking operations should be determined to meet possible operation requirements. In addition, the material flow might be influenced by the location of the lanes. Hence, it is essential to build the corresponding simulation model quickly when a system to be modeled is different only in location from systems already analyzed. The combinations of the subsystems for constructing AS/RS warehouses are summarized in Table 1.

4.2 Data Input

Data Input for WARE The data input for the model of the warehouse, WARE, is:

- number of racks (i.e., bay and level) in the rack lane of the warehouse.
- number of stacker cranes in the warehouse.

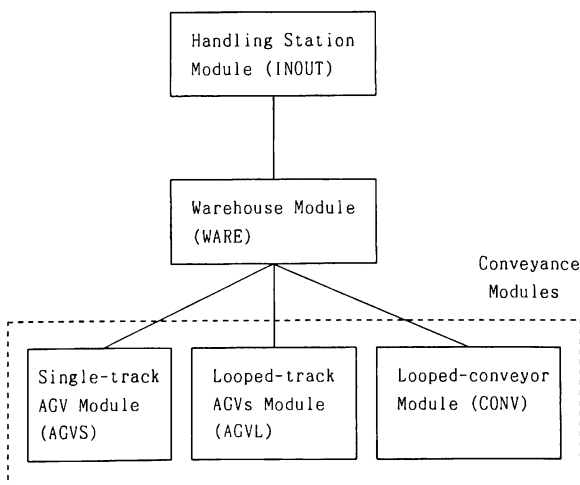


Figure 2. Module Structure of AS/RS Simulation Model

Table 1. Combination of Subsystems for AS/RS

Scale	Warehouse	Conveyance System			Handling Stations		
	No. of Stack-er Cranes	Single-track AGV System	Looped-track AGVs System	Looped-conveyor System	Arrivals No. of lanes	Departures No. of Lanes	Pickings No. of lanes
Small-scale AS/RS	1 - 2	Applicable	Not Applicable	Not Applicable	1 - 2	1 - 2	0 - 2
Medium scale AS/RS	3 - 8	Applicable	Applicable	Applicable	1 - 5	2 - 10	0 - 8
Large-scale AS/RS	9 - 15	Not Applicable	Applicable	Applicable	1 - 5	2 - 10	0 - 8

- number of conveyor lanes to and from the automated warehouse.

Data Input for INOUT The data input for the model of the handling system, INOUT, is:

- number of arrival conveyors (i.e., loading stations).
- number of departure conveyors (i.e., unloading stations).
- number of picking stations.

Data Input for CONV The data input for the model of the conveyor system adopted as the conveyance system is:

- number of conveyor lanes to and from the warehouse.
- number of arrival conveyors (i.e., loading stations).
- number of departure conveyors (i.e., unloading stations).
- number of picking stations.
- relative location of connected points to the conveyor system.

Data Input for AGVS The data input for the model of a single-track AGV system adopted as the conveyance system is:

- number of conveyor lanes to and from the warehouse.
- number of arrival conveyors.
- number of departure conveyors.
- number of picking stations.

Data Input for AGVL The data input for the model of a looped-track AGVs system adopted as the conveyance system is:

- number of conveyor lanes to and from the warehouse.
- number of arrival conveyors.
- number of departure conveyors.
- number of picking stations.
- number of AGVs.
- control points (stations) for checking the location of AGV on the track.

Data Input for simulation experiments The typical data input required to operate the designated system is:

- arrival rates.
- departure rates.
- number of items to be picked simultaneously.
- number of arrival conveyors.
- number of departure conveyors.
- number of picking stations.
- number of rack lanes in the warehouse.
- number of conveyor lanes to and from the warehouse.
- initial amount stored in each rack of the warehouse.
- data concerning a looped-conveyor system.
- data concerning a single-track AGV system.
- data concerning a looped-track AGVs system.

4.3 Output

The simulation model provides a number of outputs. These includes:

- throughput time.
- number in queue waiting for stacker crane.
- stacker crane utilization.
- number in each rack lane in the automated warehouse.
- number of arrivals.
- number of departures.
- number of pickings.
- AGV utilization, for single-track AGV system and looped-track AGVs system.
- conveyor utilization for looped-conveyor system.

4.4 Model Verification

Verification is concerned with determining if the simulation program is working as intended. The animation provides a visual means to rapidly and easily be sure that a model correctly represents the actual system [Miles, 1988]. By monitoring the movement of entities and the state of resources, transporters, and conveyors, the analyst can quickly identify any errors in logic which would be difficult to detect with only standard summary statistics. In this study, a Cinema model was developed for animation since Cinema animation is driven by the SIMAN simulation language. It is also an easy method for constructing models. Summary statistics for the number of pieces handled were compared to model statistics for deriving input probability distributions.

5. ANALYSIS

5.1 Simulation Analysis

The simulation study for this paper comprises two major aspects. One is to examine whether a proposed system satisfies required handling conditions, such as frequency of incoming and outgoing items and picked items. Another is to identify the minimum number of vehicles in order to convey (1) a certain number of items, or (2) as many items as possible in a looped-track AGVs system of AS/RS.

5.2 Determining Optimum Number of AGVs

In the case of analyzing a looped-track AGVs system, it is necessary to determine the number of vehicles that should be stationed on the track to carry the expected number of items between the warehouse and handling stations. For a large-scale AS/RS system it is necessary to determine the minimum number of AGVs to need to meet the predetermined conditions

before performing cost comparisons among the alternative conveyance systems. Simulation analysis can be performed by using the model mentioned in 4. At the same time statistical analysis should be done with multiple simulation runs.

The following approach is described in terms of goal programming, by using simulation and statistical tests in order to determine the optimum number of AGVs under a given scale of automated warehouse.

Problem Formulation

$$\text{lexicographic-min } \mathbf{a} = \{g_1(n, \mathbf{p}), g_2(n, \mathbf{p})\}$$

such that:

$$G_1: f_1(x) + n_1 - p_1 = b_1$$

$$G_2: f_2(x) + n_2 - p_2 = b_2$$

and:

$$x, n_1, n_2, p_1, p_2 \geq 0$$

where x is a number of AGVs; hence it should be a positive integer or zero. a is an achievement function of this problem. In the goal of G_1 , $f_1(x)$ stands for the number of items handled, and b_1 is an aspiration level on G_1 , the number of items handled. In the goal of G_2 , $f_2(x)$ stands for the number of vehicles, and b_2 is an aspiration level on G_2 , the number of vehicles. n_1 and n_2 are negative deviation variables, and p_1 and p_2 are positive deviation variables. If b_1 is set to be large enough, and b_2 is set to be small enough, then the corresponding achievement function will be $\mathbf{a} = (n_1, p_2)$.

The Algorithm

- Step 1.** Determine the original search interval $R_1, [x_a, x_b]$ ($R_1 = x_b - x_a$), and specify the maximum number of search points, M , and the interval of uncertainty, U .
- Step 2.** Find the second search interval R_2 , using the table of Fibonacci numbers. Then, compute the two search points x_1 and x_2 .
- Step 3a.** Execute simulation with multiple runs, by setting $x = x_1$ and $x = x_2$ respectively. Perform tests involving differences of variances and means in order to examine a significant difference between the performance of the two classes, $f(x_1)$ and $f(x_2)$. If $a(x_1) < a(x_2)$, go to Step 3b. Otherwise, go to Step 3c.
- Step 3b.** Eliminate the interval $[x_2, x_b]$. Set $x^* \leftarrow x_1$. Go to Step 4.
- Step 3c.** Eliminate the interval $[x_a, x_1]$. Set $x^* \leftarrow x_2$. Go to Step 4.
- Step 4.** If the number of search points is greater than M , or the current interval of uncertainty is less than U , go to Step 6. Otherwise, go to Step 5a.
- Step 5a.** Calculate the next search interval R_j ($j = 3, 4, \dots$). If $a(x_1) < a(x_2)$ in Step 3a, go to Step 5b. Otherwise, go to Step 5c. New points are denoted by \bar{x} .
- Step 5b.** Set $\bar{x}_a \leftarrow x_a$ and $\bar{x}_b \leftarrow x_2$ as the new search interval. Set $\bar{x}_1 \leftarrow \bar{x}_b - R_j$ and $\bar{x}_2 \leftarrow x_1$ as the new search points. Go to Step 3a.
- Step 5c.** Set $\bar{x}_a \leftarrow x_1$ and $\bar{x}_b \leftarrow x_b$ as the new search interval. Set $\bar{x}_1 \leftarrow x_2$ and $\bar{x}_2 \leftarrow \bar{x}_a + R_j$ as the new search points. Go to Step 3a.
- Step 6.** Terminate the search. The solution is x^* .

5.3 Cost Comparison among Alternative Investments

By this time two or three investment alternatives should be determined, depending upon system requirements; they are a single-track AGV system, a looped-track AGVs system or a looped-conveyor system. With regard to warehouses and handling stations, their specifications will be the same regardless of the alternatives to be compared. Hence, the only difference is in the conveyance systems.

When performing cost comparisons among alternatives it is neces-

sary to collect the following information:

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

These estimates should be collected for all of the conveyance 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 economical system to install. The outline of the procedure proposed in this paper is summarized in a flow chart in Figure 3.

6. ANALYSIS FOR NUMERICAL EXAMPLES

Three possible scenarios, described in Table 2, for various scale of AS/RS were modeled and examined using a variety of measures in order to check the feasibility of their systems. These measures include AGV utilizations, rack utilizations, stacker crane utilizations, conveyor utilizations, and the time an item was delayed to wait for AGVs, conveyors or stacker cranes.

A simulation program for each scenario was constructed by combining three modules. Five independent simulation runs, using different random numbers, were made for each scenario, with each run being 240 minutes in length. Multiple runs are necessary because simulations produce random output. The simulation results are summarized in Table 3.

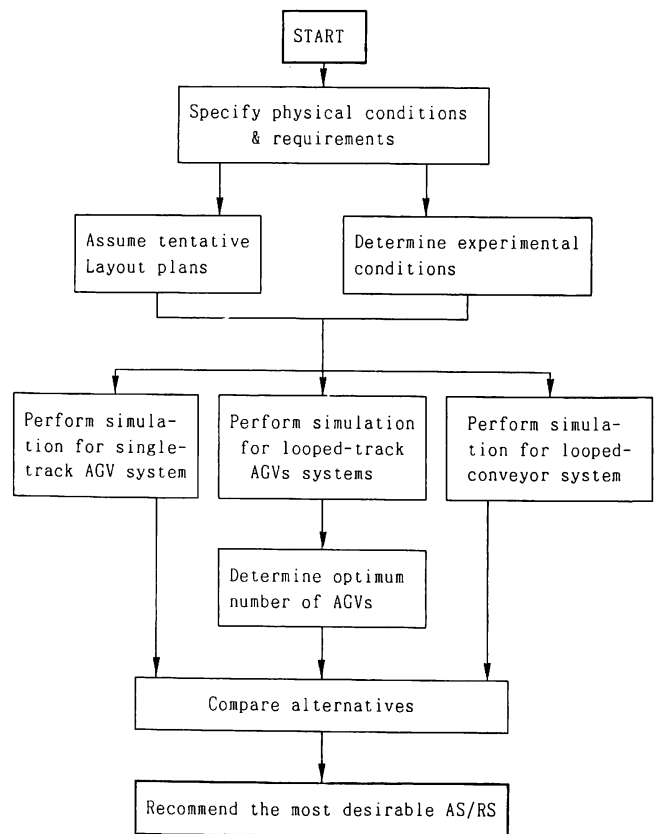


Figure 3. Outline Flow Chart of Proposed Procedure

Table 2. Scenarios for Simulation Runs

Scenario	Conveyance System	No. of AGVs	No. of Stacker Cranes	No. of Loading Stations	No. of Unloading Stations	No. of Picking Stations	Mean Time between Arrivals (min.)	Mean Time between Departures (min.)	Mean Time between Pickings (min.)
1	Single-track AGV System	1	3	1	1	1	3.00	3.00	1.50
2	Looped-track AGVs System	6	8	2	3	4	1.50	1.50	1.75
3	Looped-conveyor System	-	10	2	3	4	1.75	1.75	2.00

Table 3. Results of Simulation Runs

Scenario	Incoming Items (pcs.)	Outgoing Items (pcs.)	Items Picked (pcs.)	AGV Busy (%)	Items on the Conveyor (pcs.)	Stacker Crane Busy (%)	Picking Operator Busy (%)	Remarks
1	78	71	143	96.8	-	82.5	15.4	feasible
2	159	152	131	73.4	-	41.5	3.5	feasible
3	134	122	108	-	27.06	28.3	2.9	feasible

All three scenarios for AS/RS are suitable for handling material from the standpoint of the handling requirements, such as arrival rates, departure rates and pickings rates.

For the looped-track AGVs system it is necessary to determine how many AGVs should be allocated on the looped-track. The optimization process described in 5.2 was applied to the two systems; three rack lanes and eight rack lanes of the automated warehouse.

The optimization procedure can be seen graphically in Figure 4, where the number of picked items is plotted as a function of the number of AGVs. In applying the procedure, simulation was performed that allowed as many picked items to be handled as possible under the condition that both incoming and outgoing items were handled in a specified amount:

For three rack-lane system

- Mean time between arrivals = 3.00 min. (exponential)
- Mean time between departures = 3.00 min. (exponential)

For eight rack-lane system

- Mean time between arrivals = 1.50 min. (exponential)
- Mean time between departures = 1.50 min. (exponential)

Based on the optimization procedure, the following conclusions were reached:

- (1) Three AGVs are required for three rack lanes of the automated warehouse, and they are sufficient to convey the maximum number of items.
- (2) Seven AGVs are required for eight rack lanes of the automated warehouse, and they are sufficient to convey the maximum number of items.

These solutions may be confirmed as optimum conditions from Figure 4 as well. The proposed procedure is rather simple, but is found to be especially useful from a practical point of view.

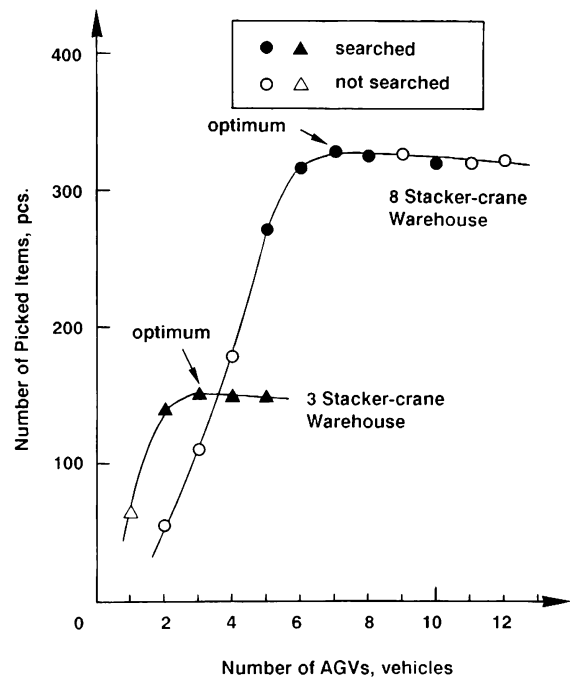


Figure 4. Finding Optimum Number of AGVs for a Looped-track AGVs System

Table 4. Cost Comparisons among Alternative Investments

Alternative	No. of Stackers Cranes	Conveyance System	Initial Cost (Yen 1 million)	Uniform End-of-year Expense (Yen 1 million)	Salvage Value (Yen 1 million)	Service Life (years)	Unacost (Yen 1 million)	Remarks
3A	3	Single-track AGV System	56	6.51	5.60	12	14.47	most economical
3B	3	Looped-track AGVs System	68	8.04	6.80	12	17.70	
3C	3	Looped Conveyor System	75	8.80	7.50	12	19.46	
8A	8	Single-track AGV System	98	11.77	9.80	12	-	infeasible
8B	8	Looped-track AGVs System	126	14.92	12.60	12	32.82	most economical
8C	8	Looped Conveyor System	140	18.22	14.00	12	38.11	

An economic analysis of the various alternatives would be necessary to select the most economical. Two sets of alternatives are described in Table 4. (Initial cost is indicated of the conveyance system except computers. Two vehicles and six vehicles are to be used in Alternatives 3B and 8B respectively.) An annual interest rate of 10 % was 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]. Handling requirements set in the economic analysis are:

For alternative 3A, 3B, and 3C

- Mean time between arrivals = 3.00 min. (exponential)
- Mean time between departures = 3.00 min. (exponential)
- Mean time between pickings = 1.50 min. (exponential)

For alternative 8A, 8B, and 8C

- Mean time between arrivals = 1.50 min. (exponential)
- Mean time between departures = 1.50 min. (exponential)
- Mean time between pickings = 1.75 min. (exponential)

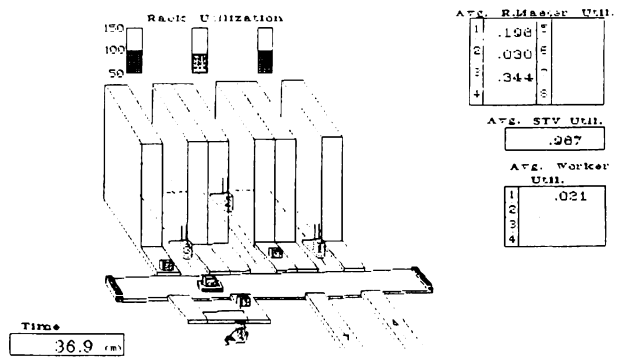
For the case of three rack lanes of an automated warehouse, a single-track AGV system was found to be the least cost system. The ratios of costs are 1.223 and 1.345, for alternatives 3B and 3C respectively. For the case of eight rack lanes, on the other hand, a looped-track AGVs system with six AGVs is recommended. The ratio of costs is 1.161. In this case, a single-track AGV system cannot meet the handling requirements. The animated display (Cinema) of the corresponding AS/RS is shown in Figure 5.

7. CONCLUSIONS

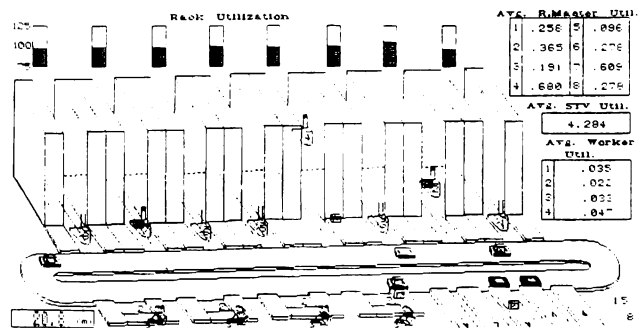
This paper presents a module method for separating large-scale AS/RS in constructing simulation models. In the proposed method three major subsystems, i.e., warehouses, conveyance systems and handling systems, are modeled separately. In addition, a general procedure is proposed to find the most economical equipment to construct AS/RS under any system requirements. The procedure is also presented using a numerical example based on an actual case.

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(a) Single-track AGV System (Alternative 3A)



(b) Looped-track AGVs System (Alternative 8B)

Figure 5. Animated Display of AS/RS

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