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DESIGN AND COST-EFFECTIVENESS ANALYSIS OF LARGE-SCALE AS/RS-AGV SYSTEMS

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ABSTRACT

Looped-truck Automated Guided Vehicles (AGVs) systems considered in this paper comprise the automated warehouse with stacker cranes and conveyance systems. 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, the number of both incoming and outgoing conveyors, and the buffer size of the conveyors connected to the warehouse. Analysis to measure cost effectiveness is performed, especially based on the number of AGVs to install. In addition, sensitivity analysis is performed to seek the optimum system from both efficient and economic standpoints.

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).

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, designing policies and operational specifications are examined from the efficient standpoint, and analytical results are indicated. In addition, cost-effectiveness analysis and optimization analysis are performed in an attempt to determine the optimum and/or reasonable number of AGVs to meet the management goals from both economic and efficient standpoints.

2 LARGE-SCALE AS/RS-AGV SYSTEM

2.1 AS/RS Material Flow

Before considering the models in detail, it is essential to specify the general features of a large-scale AS/RS-AGV system considered in this research. A 3-D layout for a large-scale AS/RS is depicted in Figure 1. 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 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.

2.2 Movement of the AGV

Movement of AGVs in looped-track AGVs systems

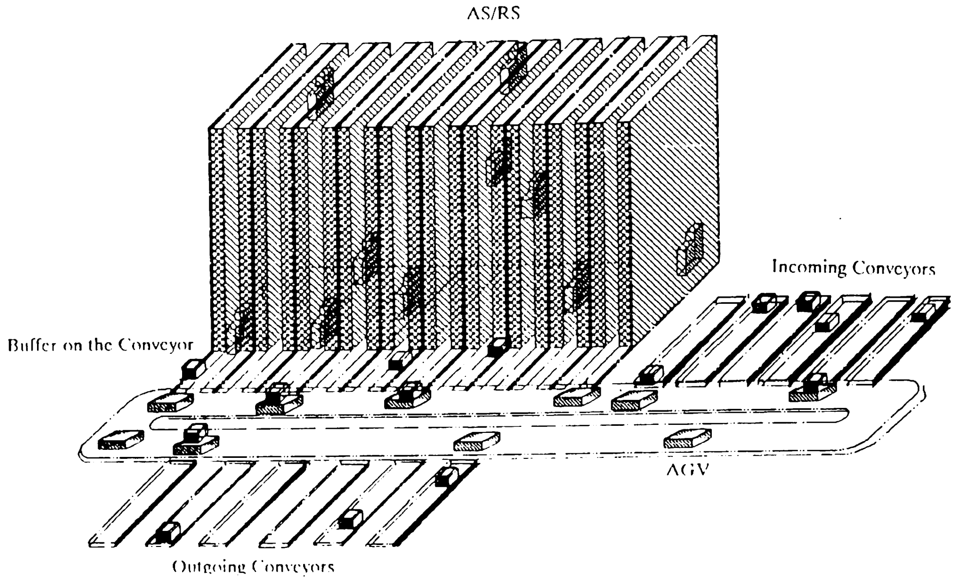

Figure 1: 3-D Layout of Large-Scale AS/RS-AGV System

consists of several major parts.

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

2.2.2 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.

2.2.3 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.

3 PROBLEM STATEMENTS

When introducing large-scale AS/RS-AGV systems,

Table 1: Specifications of the System

Items	Parameters
Number of Stacker Cranes	10 (units)
Velocity of Stacker Cranes	1.33, 1.67 (m/sec)
Number of Cells in AS/RS	12,160 (units)
Loading/Unloading Time by Stacker Crane	13 (sec)
Buffer Size of Conveyors from/to AS/RS	2 - 4 (pcs.)
Velocity of the Conveyor	0.2 (m/sec)
Length of the Conveyor	6 (m)
Number of Incoming Conveyors	6 - 10 (units)
Velocity of Incoming Conveyor	0.2 (m/sec)
Length of Incoming Conveyor	6 (m)
Minimum Distance between Incoming Conveyors	1.2 (m)
Number of Outgoing Conveyors	6 - 10 (units)
Velocity of Outgoing Conveyor	0.2 (m/sec)
Length of Outgoing Conveyor	6 (m)
Minimum Distance between Outgoing Conveyors	1.2 (m)
Number of AGVs	5 - (units)
Velocity of AGV	0.5, 1.67 (m/sec)
Loading/Unloading Time by AGV	8 (sec)
Total Length of Looped Track	214 (m)

there are a lot of alternatives. Management has to decide particular specifications of the system. A set of specifications is summarized in Table 1.

There are two stages for management to decide, in installing this particular type of the system. First stage is determining the overall layout of the system.

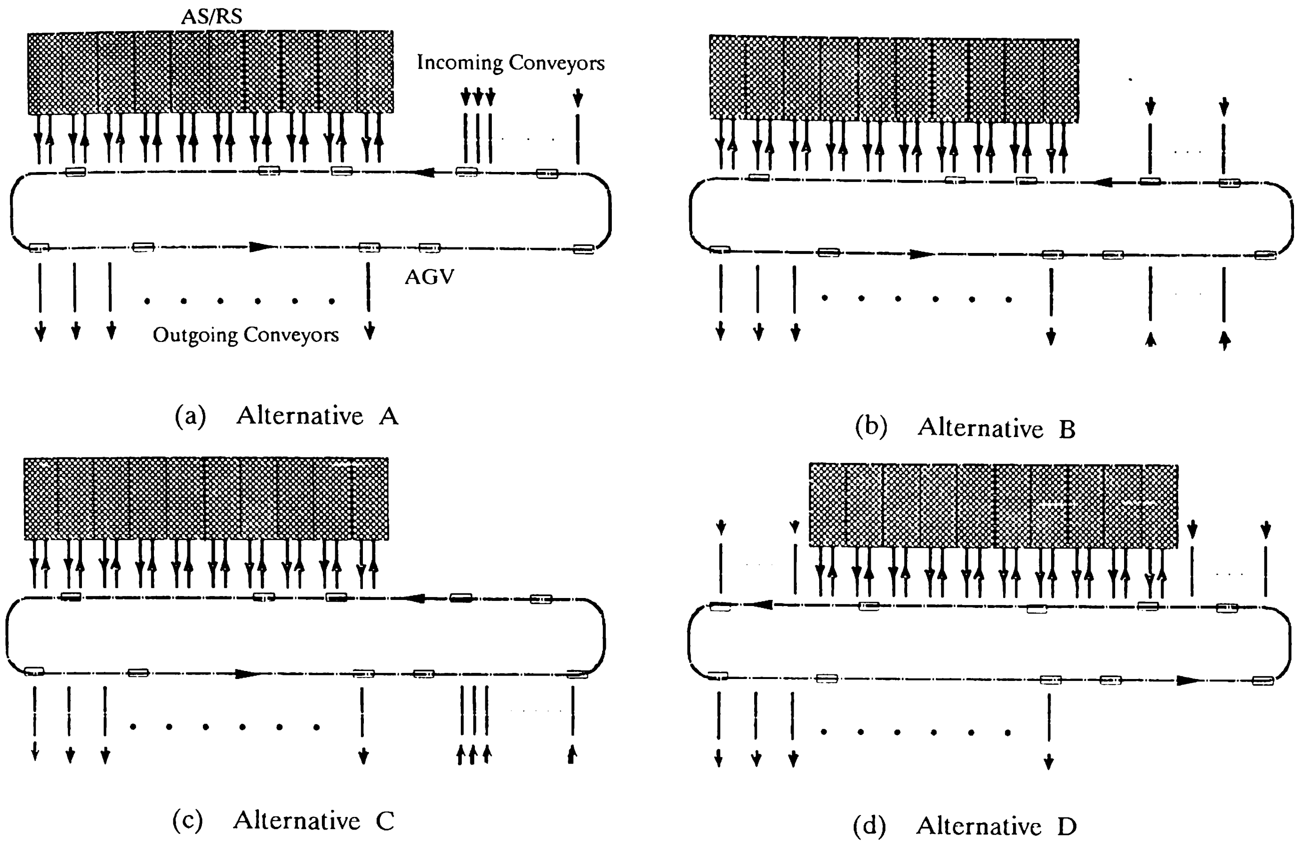

Figure 2: Overall Layout of the System

Four major possible layouts are indicated in Figure 2. Relative locations of AS/RS, incoming conveyors, and outgoing conveyors are different from each other for four alternatives on layout. Second stage is determining more detailed specifications of the system. They include the number of AGVs, the number of incoming and outgoing conveyors, and the buffer size on each conveyor connected to the AS/RS.

Especially in the second stage, it is difficult to determine the optimum and/or reasonable number of vehicles that should be stationed on the track to carry the expected number of items between the warehouse and handling stations from both efficient and economic standpoints.

4 SIMULATION ANALYSIS

4.1 Experimental Conditions

Parameters already shown in Table 1 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).

4.2 Measure of Performance

Each simulation run is executed until 30 incoming and 220 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.

4.3 Determining the Effects of Specifications on Efficiency

In this section, design 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 four factors:

Factor A: Overall Layout (see Figure 2).

A_1: Alternative A.
A_2: Alternative B.
A_3: Alternative C.
A_4: Alternative D.

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

Factor C: Number of Outgoing Conveyors.
C_1: 6 units.
C_2: 10 units.

Factor D: Buffer Size on Each Conveyor Connected to the AS/RS.
D_1: 2 units.
D_2: 4 units.

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 4x3x2x2, where factor A is the layout alternatives with four levels, factor B is the number of AGVs with three levels, factor C is the number of outgoing conveyors with two levels, and factor D is the buffer size on the conveyors from/to AS/RS with two levels. The number of outgoing conveyors is adopted as the factor in this experiment, considering the situation of the maximum flowout.

Table 2: Analysis of Variance for the Output Variable

Source	F Ratio	Sig.
A	1,491.28	1 %
B	18,173.74	1 %
C	13.43	1 %
D	71.26	1 %
A x B	2.85	5 %
A x C	4.55	1 %
A x D	0.60	N/A
B x C	0.79	N/A
B x D	4.37	5 %
C x D	0.51	N/A
A x B x C	0.38	N/A
A x B x D	0.32	N/A
A x C x D	0.24	N/A
B x C x D	1.36	N/A
A x B x C x D	0.32	N/A

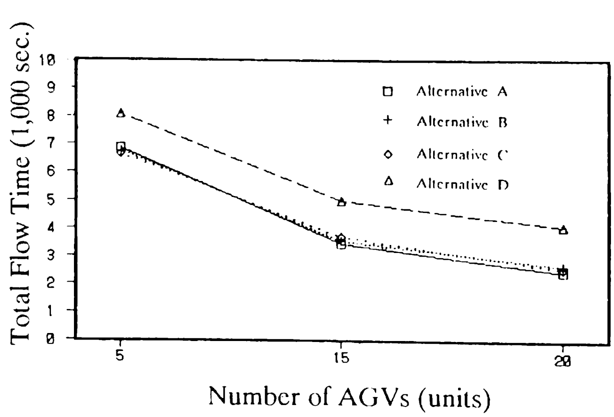

Figure 3: Total Flow Time

Summary results of the analysis of variance for the output variable (the total flow time) are given in Table 2. In addition, the comparison among the layout alternatives is shown in Figure 3. A single simulation replication has been executed for approximately 15 to 38 minutes, depending on the number of AGVs. The overall layout, factor A, has a significant effect on this variable. It is concluded that the alternative A is the most effective than any other alternatives, especially in installing more AGVs. On the contrary, the alternative D is the least effective. This may be because the loading and unloading positions (i.e., the incoming conveyors and the AS/RS, and the AS/RS and the outgoing conveyors) are closest in the alternative A.

Contrary to our expected results, the more the number of outgoing conveyors are to be installed, the less effective the system becomes. The reason might be that the unloading time is relatively short compared with those of other handling activities. In addition, the buffer size on the conveyors from/to the AS/RS, factor D, affects the total flow time as well.

From the above-mentioned issues, the most desirable layout of the large-scale AS/RS-AGV system is the alternative A and it consists of ten incoming- and six outgoing- conveyors, and the buffer size of four (units) on each conveyor from/to the AS/RS. The next problem is determining the optimum number of AGVs to install in the system.

5 OPTIMIZATION AND COST EFFECTIVENESS

5.1 Determining Specifications of the System

Once an appropriate layout of AS/RS-AGV system is decided to install, then it is necessary to determine the optimum specifications of the system, i.e., the number of AGVs, the numbers of incoming/outgoing conveyors, the buffer size on the conveyors from/to AS/RS, and so forth.

An economic analysis of alternatives would be necessary to select the economical system. When performing cost comparison among alternatives it is necessary to collect the following information:

(1) initial cost.
(2) annual maintenance cost.
(3) annual operation cost.
(4) any irregular cost.

Table 3: Cost Comparisons for Cost-Effectiveness Analysis

Item	Initial Cost ($)	Maintenance/ Operating Cost ($)	Salvage Value ($)	Service Life (years)	Unacost ($)
AGV	56,000	3,240	5,600	12	11,200
Incoming Conveyor	20,000	480	2,000	12	3,230
Outgoing Conveyor	17,500	480	1,750	12	2,970
One More in Queue	6,500	350	650	12	1,270

(5) service life.
(6) salvage value.
(7) service life.

These estimates should be collected for a single unit of each mechanical device, in case of performing cost-effectiveness analysis. Cost comparisons for cost-effectiveness analysis is shown in Table 3, based on an actual case. Annual interest rate of 10 % is selected for this case. The term "unacost", as used here implies uniformity from year to year with the end of the year as part of the definition (Jelen and Black 1983). For example, the unacost of holding one unit of AGV is $11,200. The unacost for installing one more in the buffer queue on each conveyor in front of the AS/RS is relatively small; hence, the buffer size of these queues is set to four in the following case.

5.2 Determining the Optimum Number of AGVs

From the efficient standpoint, the procedure to obtain the optimum number of vehicles is proposed (Takakuwa 1989). Furthermore, when the profit obtained by performing operations is known, both the maximum-profit number of vehicles and the minimum-cost number of vehicles can be obtained (Takakuwa 1991).

Sometimes it is not possible to measure return, service, or profit in terms of dollars. It is possible, however, to measure unit costs, or cost effectiveness. In this study, the total flow time is adopted as the measure of performance. First of all, the percentage decrease on the total flow time is obtained by:

$$\text{Percentage decrease} = \frac{T.F._{(n-1)} - T.F._{(n)}}{T.F._{(n-1)}} \times 100$$

where $T.F._{(n-1)}$ is the total flow time observed at the previous number of AGVs, and $T.F._{(n)}$ is the total flow time observed at the current number. Actually the sample means of observations are used for obtaining both $T.F._{(n-1)}$ and $T.F._{(n)}$.

Then cost effectiveness is given by:

$$\text{Cost effectiveness} = \frac{\text{unacost for one unit of AGV}}{\text{percentage decrease in T.F.}}$$

Suppose that there is currently twelve units of AGVs. The unacost for one unit of AGV is $11,200. If $11,200 per year is spent additionally (the number of AGVs is to be thirteen), the total flow time can be reduced (6.86 percent reduction). Hence, cost effectiveness at this point is $1,633.50/year for a 1 percent reduction. The total flow time and cost effective at the corresponding numbers of AGVs are depicted in Figure 4.

The minimum-time units of AGVs is 17 (units), because the total flow times at more than 17 units are almost equal to that at 17 units. An efficient approach, which was originally proposed for determining the optimum number of AGVs, may be applied for this case. On the other hand, the cost-effectiveness curve can be found to increase drastically at 14 units and over. Providing cost effectiveness as well as the systems performance is quite helpful for management.

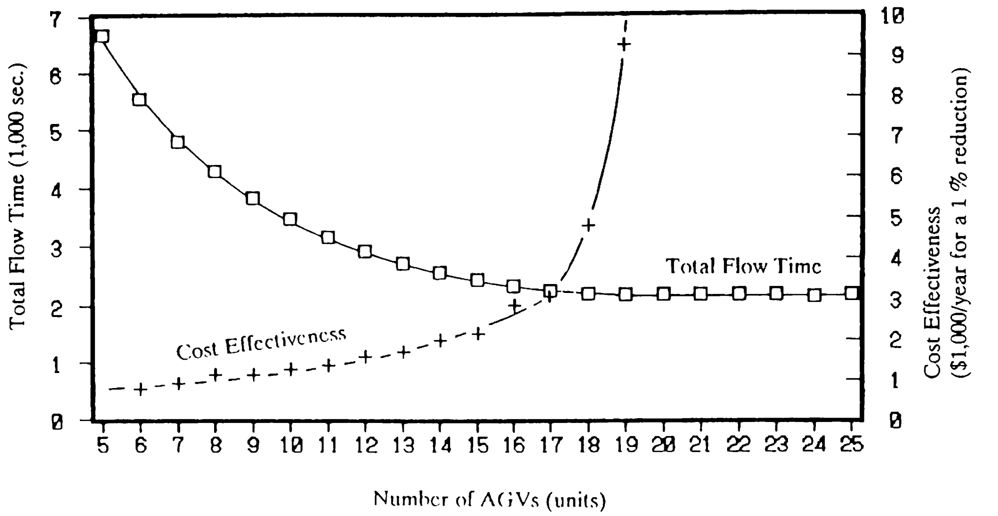

Figure 4: Total Flow Time and Cost Effectiveness

An optimum selection from among eligible solutions should be done from the managerial standpoint.

6 SUMMARY

This paper presents analytical results of a large-scale AS/RS-AGV system. Characteristics of this system are clarified from the standpoint of efficiency. In addition, cost-effectiveness analysis is performed to seek the reasonable number of AGVs to install in the system. The procedure is also presented using a numerical example based on an actual case.

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