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Simulation of automated guided vehicle (AGV) systems based on just-in-time (JIT) philosophy in a job-shop environment

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Abstract

Automated Guided Vehicle (AGV) systems have been frequently used as material handling equipment in manufacturing systems since the last two decades. The use of AGV systems has taken attention of practitioners and researchers. Although there are numerous studies concerning with AGV systems in literature, a few of them deal with the adaptation of these systems into JIT systems. Moreover, the facility layouts considered in those studies have flow-shop environment. In this paper, a simulation model of a hypothetical system which has a job shop environment and which is based on JIT philosophy was developed. In addition, a dispatching algorithm for vehicles moving through stations was presented in order to improve transportation efficiency. In given layout, multiple vehicles can move and their bi-directional flow is allowed. After the model had been established, it was mentioned how to perform simulation output analysis. The factors which may be important for the system were determined by output analysis. An experiment plan was prepared by taking into account these factors. In this plan, two levels were selected for each factor and an experimental design was conducted. The effect of each factor on each performance measure and the interaction of these factors were examined.

Keywords: AGV systems; JIT; Simulation; Bi-directional flow; Experimental Design

1. Introduction

Conventional approaches used in modeling manufacturing systems can be divided into two types: Analytical models and simulation models. Both techniques have advantages and disadvantages. Analytical technique defines the system as mathematical equations and it can optimize the system. However, since modeling a system as mathematical equations requires a lot of assumptions about the system and the more assumptions are considered the more the system becomes unreal. On the other hand, simulation technique may not give optimum solutions. It investigates a system's long-term behavior. In spite of the fact that generating a solution about a system is more time-consuming in simulation technique, it is more convenient in modeling complex systems than analytical technique.

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In modeling AGV systems, because there are a lot of variables and parameters, simulation technique is extremely useful in modeling these systems.

According to Banks et al. [1], Free-path transporters can move through a system without concern for delays caused by other vehicles. Guided transporters move along a fixed path and may contend with each other for space along that path. Especially, if there are multiple vehicles traveling through a system and bi-directional paths are available, vehicle routing problem emerges. Vehicle routing is known as a difficult problem in literature. To solve this problem, different policies should be developed. Also in achieving an acceptable solution to this problem, the structure of considered system plays a crucial role.

According to Kimura and Terada [7], multi-stage production processes can be classified into two types: push systems and pull systems. Most of the American and European production systems employ push systems whereas the Japanese JIT systems employ pull systems. As pointed out in Baykoc and Erol [2] the main difference between the two systems is that in the pull system, the material is routed from the preceding stage to the succeeding stage according to the consumption rate of succeeding stage.

Although there are numerous studies examining and investigating behaviors of AGV systems, a few of them investigate the relationship between AGV systems and JIT production philosophy. At those studies, facility layouts of systems have a flow-shop environment. Such a job-shop environment, the factors which may be important were determined. This paper aims to examine how these factors affect performance measures specified in the job-shop environment. To accomplish this, experimental design, one of the statistical procedures, was applied.

By the aid of experimental design, main and interaction effects among factors and the statistical significances of these effects were clearly considered. In other words, it was desired to show that how this system reacted under different factor settings. In simulation model of considered system, demand arrivals are stochastic and, processing time of each job on each station is deterministic. The effects of four factors on the system performance measures, which are time in system (flow-time), time between consecutive jobs, throughput rate and number of jobs waiting on AGV queue, are tested.

Subsequent section considers some simulation studies related to AGV systems in literature.

2. A short literature review

In this literature survey, several simulation studies concerning with AGV systems are discussed.

Koo and Jang [8] presented stochastic vehicle travel time models for AGV based material handling systems with emphasis on the empty travel times of vehicles under flexible manufacturing system. A simulation experiment is used to evaluate and demonstrate the presented models.

Jeong and Randhawa [5] considered the dispatching problem associated with operations of AGVs. A multi-attribute dispatching rule for dispatching of an AGV was developed and evaluated. A neural network approach was used to obtain dynamically adjusting attribute weights based on the current status of the manufacturing system. Simulation analysis of a job shop was used to compare the multi-attribute dispatching rule with dynamically adjusting attribute weights to the same dispatching rule with fixed attribute weights and to several single attribute rules.

Nakano and Ohno [11] proposed an integrated analytical/simulation approach for designing an AGV system. Their objective was to determine the number of AGVs, the input buffer capacities and location of the machines that minimize a cost function under the constraint that the planned utilization of each machine is achieved. The integrated analytical/simulation approach employed a simulation model to evaluate the performance of the AGV system and an analytical approach to reduce the repetition number of simulations in searching an optimal solution.

Kim et al. [6] described a heuristic procedure for the control of materials flows of AGVs in a job-shop system. The procedure was based on the idea of workload balancing; it tried to balance the workload among machines as well as the workload between the machines and the transporters. They then presented the results of simulation experiments to evaluate the performance of the proposed procedure.

Sabuncuoglu [15] examined the effects of scheduling rules on the performance of FMS systems. Several machine and AGV scheduling rules were tested against the mean flowtime criterion. In his study, he compared the rules under various experimental conditions by using a simulation model. Objective was to measure sensitivity of the rules to changes in processing time distributions, various levels of breakdown rates and types of AGV priority schemes.

Sridharan and Babu [17] worked a detailed simulation study conducted on a typical FMS. Initially, the configurations of the FMS under study were established. Two types of FMSs were evolved: one was failure free and the other was failure prone. For each of these cases, simulation model was developed. Orders arriving randomly at the FMS were subjected to three levels of scheduling decisions namely, launching of parts into the system, routing of parts through machines and sequencing of parts on AGVs at a central buffer. The simulation results were used to develop metamodels for the two types of FMSs.

Taghaboni [18] focused on vehicle dispatching issues. Developed algorithm is a demand driven strategy which further prioritizes the loads requiring an AGV according to the value added to them as they go through the manufacturing processes. Simulation experiments used to show this algorithm's performance.

Mahadevan and Narendran [10] demonstrated the use of a two-stage approach for solving AGV system for an FMS. The required number of vehicles was estimated using an analytical model in the first stage. In the next stage, the effects of AGV failures and AGV dispatching rules on the system performance were observed through simulation studies based on which the AGV dispatching rule can be chosen.

Egbelu [3] presented a mathematical procedure for the selection of the best unit load sizes for all types manufactured in a shop that employs AGVs for handling. The problem was solved by a hybrid algorithm that includes numerical search, computer simulation, and statistical analysis.

Sinriech and Tanchoco [16] developed a multi-criteria optimization model using two goals: cost and throughput performance. By using a trade-off ratio between the goals the number of AGVs needed in the system is determined.

Occena and Yokota [12] described the modeling of an AGV system in a JIT environment in a way that is consistent with JIT principles. The influence of a JIT perspective was emphasized throughout the model by introducing threshold values for both input and output queues. Özden [13] investigated the effect of several key factors related to the AGVs on the overall performance of an FMS through a simulation program.

3. System description and model development

3.1. The simulation model

A simulation model was developed by using ARENA 3.0 simulation software package. It employs SIMAN blocks and elements. The reason of using ARENA in modeling this system is that it has the substantial capabilities about transportation. While a system is being modeled in ARENA, it creates two types of files: model file and experiment file. Whereas logical structures are established in the model file, parameters and variables related to system are saved in the experiment file. Model assumptions are as follows:

1. Demand arrival frequency for each product is considered as source of randomness.
2. One unit of raw material is used to produce one unit of finished product.
3. Initial inventory at each station is equal to the number of kanban.
4. Kanbans are sent instantly between the stations.
5. Vehicle velocity is fixed during simulation. Acceleration is not permitted.
6. All the vehicles circulating through the system have the identical properties.
7. Demand arrivals for each product are assumed to be exponentially distributed.
8. Breakdown and maintenance activities for both machines and vehicles are neglected.

According to Mahadevan and Narendran [10], when the number of vehicles required is more than one, some of the vehicle routing problems and the traffic control problems can be solved during the design process while the others must be tackled during operation. Dispatching the vehicles in pre-determined fixed paths reduces congestion at the junction of AGV tracks. This decision is implemented during operation.

While hypothetical system in our study was being constituted, system parameters and AGV layout were taken from Mahadevan and Narendran [10]. Parameters pertinent to this study such as number of different job, entry volume of each job into the system, sequence of each job and processing time of each job on each machine were obtained from that study. These parameters are shown in Table 1.

The layout given in Fig. 1 is regarded for the current study. The noticeable features about considered system are as follows.

- The system composes of eight machines (numbered 2–9) and a load station (numbered 1). Local storage is provided in front of each machine to serve as the buffer for input/output.
- Five types of jobs undergo processing simultaneously. The respective volume mix is shown in Table 1.
- The circles (including bold ones) indicate control zones. Only one vehicle can enter the control zone at a time. However, one vehicle can control more than one zone at a time. Control zones designated as three digits provide buffer for vehicles circulating in the system. The buffers can accommodate all the vehicles. Some of the AGV tracks permit bi-directional traffic (indicated by double sided arrows). Three digits are not written arbitrarily. A logical sequence is followed. Now consider a vehicle going from intersection 38 to 9 for unloading. After the vehicle carries out unloading task, it moves the buffer area not to block the link. But, which intersection is assigned for parking? When this intersection is chosen, the preceding intersection vehicle passes (38) and current intersection vehicle occupies (9) are regarded. Thus, the intersection vehicle will occupy is calculated as $10 * \text{preceding intersection}(38) + \text{current intersection}(9) = 389$.
- Each of loading and unloading of jobs takes one minute at any location. Inter arrival times of demands into the system follow exponential distribution.
- Distances among stations are given as metric measure.

3.2. Verification and validation

As pointed out by Law and Kelton [9] "Trace" is one the most powerful techniques in verifying the simulation program. In ARENA, by adding TRACE statement at the end of the program, it can be checked whether the model works as desired. When the TRACE statement is included into the program, the program writes all process which it executes. Thus, potential errors which appear in the program can be eliminated by following process-flow. In this study, model verification was carried out by using this technique and the model was found to work as intended.

As Fallon and Browne [4] mentioned, if the real data was not available, explicit validation is impossible. Since the manufacturing system modeled is hypothetical, explicit validation could not be reached.

3.3. AGV movement in the simulation language

In this section type of vehicle control will be discussed to perceive better guided vehicle movement in any system. Many factors such as type of vehicle control, the vehicle's speed attributes, vehicle's size, the link of movement direction, the number of zones and their length on the current link or the intersection size, and the degree of vehicle congestion influence the guided vehicle's activity within the system.

According to Pegden et al. [14] the form of control determines when zones are released, thereby allowing other vehicles to gain access. With the release-at-start form of control, the transporter releases its trailing zone

Table 1
Details of jobs undergoing processing

Job no	Volume mix (%)	Sequencing	Number of machines visited	Processing time[a]						
				$k=1$	$k=2$	$k=3$	$k=4$	$k=5$	$k=6$	$k=7$
1	18	2–4–3–7–6	5	34	32	26	22	26	–	–
2	12	2–3–9–5–4–8	6	24	31	30	31	26	18	–
3	25	2–9–3–4–7–6–8	7	23	29	25	28	30	21	24
4	23	2–9–5–6–7–8	6	23	24	17	26	29	21	–
5	22	3–9–5–7–8	5	28	21	24	27	30	–	–

[a] Processing time (min) for kth machine visited in the sequence.

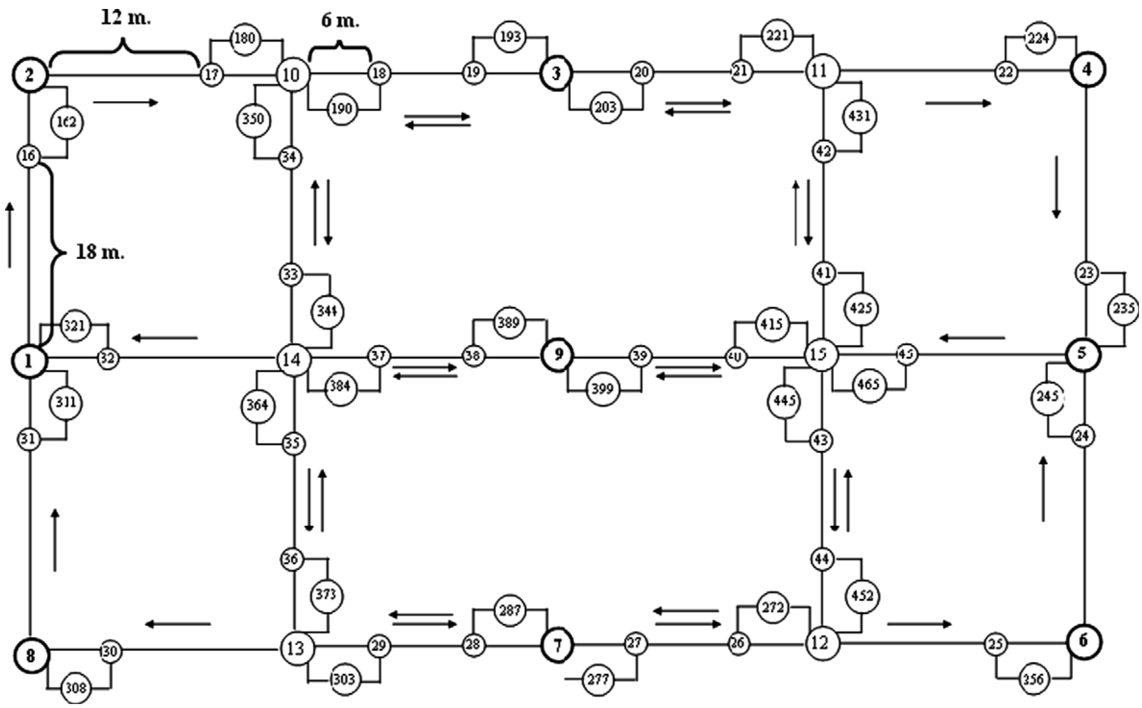

Fig. 1. Layout of the multi-vehicle loop configuration.

as soon as it gains control of the next required zone. Thus the vehicle always has control of the same number of zones. With the release-at-end form of control, the transporter waits to release the trailing zone until it reaches the end of the next zone. Thus the vehicle has control of one more zone during travel than when it stopped.

Consider the simple situation in which the size of vehicle equals one zone, the form of control is release-at-start, and all links in the network are unidirectional. Suppose that all intersections and zones are the identical size. Fig. 2 illustrates a sample section of the described network with one guided vehicle moving from left to right. This network part composes of four intersections (1–4) and three links (a, b and c). In link a three zones, in link b five zones and in link c two zones are available.

Suppose that the vehicle is currently in Zone a2, is going to Intersection 4 and is preparing to enter Zone a3, as shown in Fig. 2a. If a3 is not seized, the vehicle will have a control of a3 and immediately release control of Zone a2. Fig. 2b shows the vehicle part of the way into Zone a3; at this point it merely takes over Zone a3, although part of the vehicle may physically stay in Zone a2. Fig. 2c shows the vehicle when it is at Intersection 2. the vehicle will go on traveling in the same way until it arrives at Intersection 4, where it will stop, controlling only Intersection 4 as shown in Fig. 2d.

Now consider the same sample with the second form of control, release-at-end. Fig. 3 shows the AGV at Intersection 1. When it begins its travel to Intersection 4, it first gains control of Zone a1 while keeping control of Intersection 1; it then penetrates Zone a1, as shown in Fig. 3b. It keeps control of the previous zone or intersection until it arrives the end of its next zone (Zone a1). Once it releases Intersection 1, it only controls Zone a1; but, it will then seize control of Zone a2 and go on its travel.

Hence, when moving through the system, the AGV controls two zones, except when it reaches the end of its current zone. Providing that it stops because it has arrived its destination or because it is obstructed from seizing control of the next zone on its way, it only has control of the zone in which it currently occupies, as shown in Fig. 3c.

In the considered system, since we experienced that release-at-start control type provides better situations in terms of modeling the system, it is employed throughout the system. Also, since the system is a hypothetical and there is nothing restricting us, we defined that all zones, intersections and vehicle's size are the same (one meter).

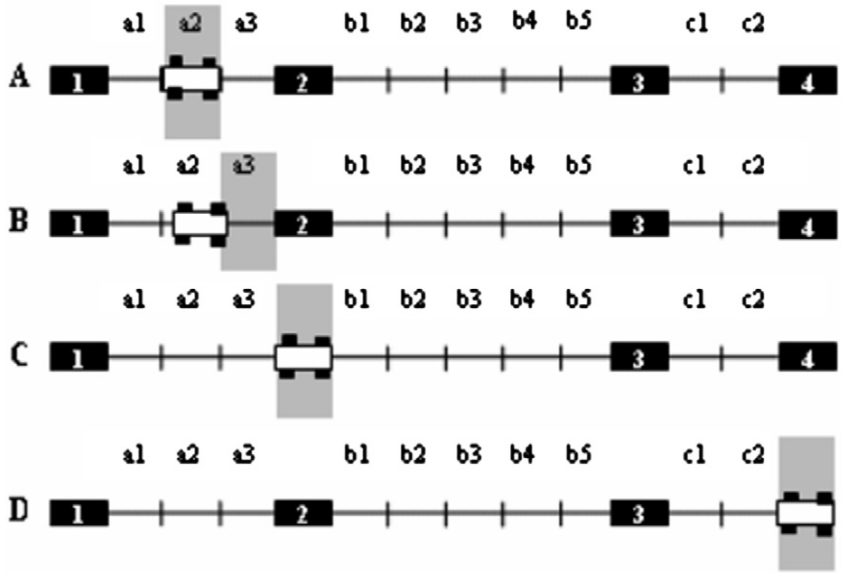

Fig. 2. Release-at-start control method.

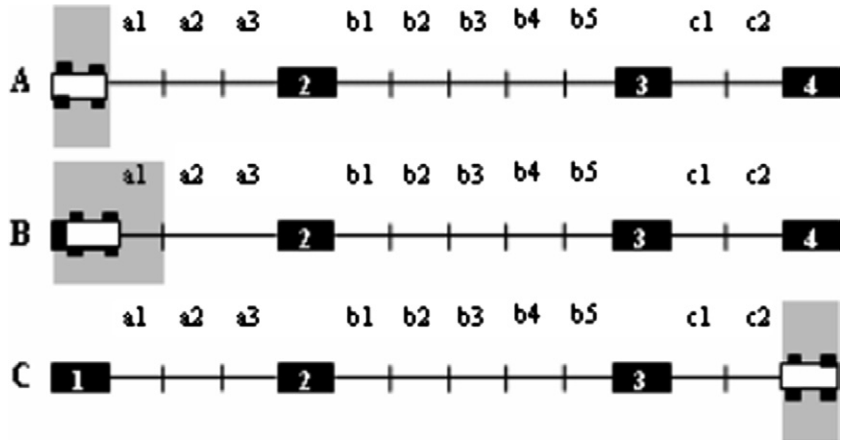

Fig. 3. Release-at-end control method.

4. Just-in-time philosophy and its implementation for considered system

As mentioned earlier, jobs entering the system have different routes (viz. job-shop flow). It is suggested that how JIT concept adapted to such a system below.

According to the Baykoc and Erol [2] concerning the number of types of Kanbans, JIT systems can be categorized into two: (i) two-card Kanban system and (ii) single-card Kanban system. In two cards Kanban system, each station has two inventory points: one is inbound inventory which keeps input items; one is outbound inventory which keeps processed items. In this type system, generally two types of Kanbans are used: (i) production Kanban and (ii) withdrawal Kanban. Production Kanban is used to authorize the production of the next unit within stage whereas withdrawal Kanban is used to pull a processed unit from a stage to a following stage.

On the other hand, in single-card Kanban system, each station has only outbound inventory and a single-type Kanban which is commonly known as conveyance Kanban.

In this article, two-card Kanban system was applied to considered system. Fig. 4 depicts the flow of parts and Kanbans through the system.

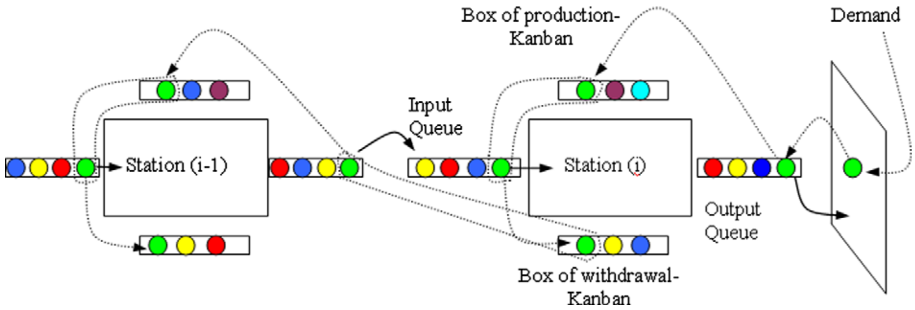

Fig. 4. Flow of parts and kanbans in a job-shop environment.

In Fig. 4, dashed curves indicate the flow of kanbans whereas continuous curves describe the flow of kanbans. In this model, if the matching is occurred between demand coming outside and output queue of succeeding station (viz. if the demand is meet), then matching item, which is output queue of succeeding station, leaves the system. Unless the demand is meet, one minute later it checks the corresponding output queue whether the item is in output queue or not. If the matching is not happened yet, this procedure continues. Prior to the item matching with the demand leaves the system; it puts the production kanban which is tied item to the production kanban box. At the same time, it is tried to match between the production kanbans and items which are in input queue in the same station. Providing the matching is occurred, the item which matches and is in input queue puts the withdrawal kanban which is tied item to the production kanban box and simultaneously it takes the production kanban which it matches. After that, it enters the machine to be processed. It is not important whether the item is in front of the input queue or not. Even if the item is not in front of the input queue, it is processed firstly. In addition, matching is done between the succeeding station's withdrawal kanbans and preceding station's output queue. If the matching is occurred; AGV comes to the preceding station (as long as it is free) and it carries the corresponding item to the succeeding station. When matching is performed, all items, which are in output or input queue, and their previous stations are checked. This procedure continues until the foremost station (station 1). It is assumed that foremost station's input queue has an infinite item.

5. Maximum priority (MP) dispatching rule algorithm

An algorithm is proposed to improve the efficiency of transportation which is executed by AGVs. While the algorithm was being developed, two types of demand strategies were taken into account. One of it was more intense, the other was less intense. Now consider such a circumstance; matching is occurred between any station's (station x) output queue and any station's (station y) withdrawal kanban. If station x does not have the identical item which is in output queue, station x is defined as "starve". This reflects the more intense situation of demand. If the corresponding item is available in the input queue, second phase of demand (less intense) emerges. The purpose of this algorithm is to prioritize "starve" station(s) over other(s). Steps of (MP) dispatching algorithm are as follows:

Step 1: If there exist a matching between preceding station's output queue and succeeding station's withdrawal kanban, then go to step 2. Otherwise, remain in step 1.

Step 2: If machine starvation occurs in the station(s) whose demanded part is waiting its output queue, go to step 3. Otherwise, go to step 4.

Step 3: Choose the station which has been starving for the longest time as the destination for the next AGV travel. Go to step 5.

Step 4: Choose the station which has been waiting for the longest time as the destination for the next AGV travel. Go to step 5.

Step 5: Identify the shortest route of trip between the station's buffer area in which AGV is waiting and the destination station.

Step 6: After the AGV completes unloading at the destination station and parks current station's buffer area, return to step 1.

6. Simulation experiments

The simulation model of this system was developed by using ARENA 3.0 simulation software package. As a result of statistical analysis which was performed for this model, truncation point was calculated as 2500 min by the aid of moving average statistical procedure. Statistics collected during transient phase (2500 min) were truncated to eliminate initial bias. Reasonable minimum run length for each replication was computed as 5000 min and five replications were performed in each simulation experiment. These replications were not considered as independence observation. Once the simulation began to run, it was waited the simulation time to elapse until 2500 (transient phase). When simulation time was 2500, all the statistics collected were discarded. However, physical status was not altered. After that simulation began to run for 5000 (first replication). At this point total simulation time was at 7500. At this time, statistical results were recorded and statistical values were again reset. This procedure continued until the end of fifth replication. Totally, simulation ran for 27,500 min ($2500 + 5 * 5000$). Thus, total simulation time was shortened 10,000 min ($4 * 2500$). If these replications had been considered as an independence observations, total simulation time would have been 37,500 min ($7500 * 5$). Since volume of the study would be larger and it does not the main issue of this work, statistical details related to output analysis were not given here.

7. Experimental design

In this article, four factors were considered and the effects of these factors were tested on the system performance.

7.1. Factors

1. Number of vehicle (NOV): This factor is tested in experimental design in two levels; 3, 2.
2. Vehicle dispatching rule (VDR): in this study two dispatching rules (task assignment rule for vehicle) such as shortest distance to station and longest distance to station were selected. This factor should not be confused with (MP) dispatching rule discussed earlier. In (MP) dispatching rule, priority is done among the stations which request a vehicle. However, in (VDR), it is determined that which vehicle will be assigned to the stations that are waiting for AGV service.
3. Number of kanban (NOK): In typical JIT system, there is at least one kanban for each item in the shop. Two levels selected for this factor as 1 and 2.
4. Arrival rate of demand (ARD): in contrast to above factors, this factor is not controllable. The reason of selecting this factor is to know the sensitivity of system against demand variation. For this factor two levels were selected. In first level, arrival rate of demand is exponentially distributed with a mean of 10 min. In second level this value is changed as 15. Table 2 presents factors and their levels in the study.

7.2. Performance measures

The following are the performance measures for the system under study: these measures are commonly used in literature and that is the reason why we select these performance measures.

Table 2
Factors and their levels used in the experiments

Factors	Level I	Level II
Number of vehicle (NOV)	3	2
Vehicle dispatching rule (VDR)	Shortest distance to the station (SDS)	Longest distance to the station (LDS)
Number of kanbans (NOK)	1	2
Arrival rate of demand (ARD)	Expo(10)	Expo(15)

1. Mean time in system of jobs (TIS)The throughput time of a job is measured as the time elapsed between the arrival of the job at the shop and departure from the shop after processing is completed. The average of the throughput times of all the completed jobs is the mean throughput time.
2. Mean queue length (MQL)The mean number of jobs waiting for the AGV during the simulation period is the mean queue length. A larger value of MQL indicates that scheduling rule is not good.
3. Mean output rate (OPR)This is a measure of the average number of jobs completed during the simulation period. In a typical JIT production system, the more demand feeds the shop; the more jobs leave the shop.
4. Mean inter departure time of jobs (MID)Inter departure time is measured as the time between two consecutive jobs during simulation period. An increasing in the mean inter departure time means that the shop is less sensitive to the fluctuation of the demand rate.

Because of fact that this study consists of four factors and two levels for each, $2^4 = 16$ design points are required. For each design point, five replications were made as stated earlier. Thus, 80 simulation runs were conducted. Table 3 shows the average values of five replications for all the performance measures.

In order to analyze the experimental results statistically, analysis of variance (ANOVA) was applied by using the SPSS statistical package. Statistical significance tests of effects were performed under $\alpha = 0.05$ significance level.

8. Experimental results

As stated earlier, four factors which may be important for this system is determined (each of two levels). Thus, experimental plan was prepared for $2^4 = 16$ design points. The purpose of this statistical effort is to demonstrate the effects of factors on performance measures. Also by the help of statistical procedure (ANOVA), interactions among the factors will be able to seen.

8.1. Main effects of factors

Table 4 presents the main effect of factors on performance measures. In this ANOVA table, last column (as labeled *P*) indicates whether the factor affect the performance measure or not. P value which is below 0.05 (α) means that this factor is important for this performance measure.

According to the Table 4, number of vehicle is extremely important for all the performance criteria, because all the *P* values are below the significance level for NOV factor. When the NOV decreases, TIS is remarkable increases.

Table 3
Values of performance criteria derived from simulation runs under different factor settings

Factors					Performance measures			
Exp. no	NOV	VDR	NOK	ARD	TIS (min)	MOL (unit)	OPR (unit)	MID (min)
1	1 (3)	1 (SDS)	1 (1)	1 Expo(10)	882	1.05	230.6	21.68
2	1 (3)	1 (SDS)	1 (1)	2 Expo(15)	1094	1.044	226.2	22.02
3	1 (3)	1 (SDS)	2 (2)	1 Expo(10)	1768	1.128	233	21.42
4	1 (3)	1 (SDS)	2 (2)	2 Expo(15)	2270	1.108	227	21.96
5	1 (3)	2 (LDS)	1 (1)	1 Expo(10)	894.8	1.414	230.6	21.68
6	1 (3)	2 (LDS)	1 (1)	2 Expo(15)	1082.6	1.078	226.4	22.12
7	1 (3)	2 (LDS)	2 (2)	1 Expo(10)	1776	1.26	233	21.46
8	1 (3)	2 (LDS)	2 (2)	2 Expo(15)	2262	1.242	227	22
9	2 (2)	1 (SDS)	1 (1)	1 Expo(10)	666.8	6.736	174.6	28.56
10	2 (2)	1 (SDS)	1 (1)	2 Expo(15)	678.4	6.774	173.8	28.8
11	2 (2)	1 (SDS)	2 (2)	1 Expo(10)	1224	16.3	176.2	28.36
12	2 (2)	1 (SDS)	2 (2)	2 Expo(15)	1256	15.98	176	28.54
13	2 (2)	2 (LDS)	1 (1)	1 Expo(10)	676	6.632	173.2	28.85
14	2 (2)	2 (LDS)	1 (1)	2 Expo(15)	677.8	6.712	173.8	28.72
15	2 (2)	2 (LDS)	2 (2)	1 Expo(10)	1228	15.98	173.8	28.62
16	2 (2)	2 (LDS)	2 (2)	2 Expo(15)	1234	15.7	177	28.22

Table 4
Main effects of factors on performance measures

Source	Dependent variable	Sum of squares	df	Mean square	*F*	*P*
NOV	TIS	6,018,142.050	1	6,018,142.050	425.773	.000
	MQL	2080.698	1	2080.698	4200.521	.000
	OPR	59,241.613	1	59,241.613	2801.022	.000
	MID	921.403	1	921.403	2580.509	.000
VDR	TIS	20.000	1	20.000	.001	.970
	MQL	.000	1	.000	.000	.997
	OPR	2.113	1	2.113	.100	.753
	MID	.028	1	.028	.079	.780
NOK	TIS	12,662,769.800	1	12,662,769.800	895.868	.000
	MQL	436.318	1	436.318	880.841	.000
	OPR	59.513	1	59.513	2.814	.098
	MID	1.035	1	1.035	2.899	.093
ARD	TIS	647,280.200	1	647,280.200	45.794	.000
	MQL	.204	1	.204	.412	.523
	OPR	99.012	1	99.012	4.681	.034
	MID	.990	1	.990	2.773	.101

We will see that factor 2 (vehicle dispatching rule) does not affect any performance measure, because *P* values are above 0.05 for all performance measures.

Factor 3 (NOK) is an important factor for TIS and MQL whereas it lose its effect for OPR and MID.

Factor 4 (ARD) affects the TIS and OPR but, same things cannot be said for MQL and MID.

8.2. Two-way interactions

After the main effects of factors have analyzed, the interactions between factors will be investigated. Firstly, two-way interactions will be examined. Table 5 (ANOVA Table) shows two-way interactions.

As can be seen from Table 5, there is a striking interaction between NOV and NOK on TIS and MQL. Also on TIS and OPR measures, there exists an interaction between NOV and ARD. Lastly, we can say that the interaction happens between NOK and ARD on TIS. Table 5 demonstrates that interactions especially occur on TIS criterion.

8.3. Three-way interactions

As we will see in Table 6, three-way interaction only occurs among NOV, NOK and ARD on TIS performance criterion. Except this, no three-way interactions occur for all criteria.

8.4. Four-way interaction

From Table 7, we see that no interaction happens for four performance criteria.

9. Conclusions

In this essay, the behavior of an AGV system which is based on JIT concept has been discussed via simulation. In spite of the fact that there are simulation studies concerning with JIT production system, this study differentiates at one point from past researches. The most contribution of this study is to show the applicability of JIT system in job-shop environment. Also, the study suggests the AGV dispatching algorithm (MP) to improve transportation efficiency. Finally, the study provides a detailed experimental design features and exact analysis on simulation results. Higher performance may be obtained from JIT production system by this study. From ANOVA tables, there is a statistical evident that number of vehicle, number of kanban and arrival rate of demand affect the time in system of each job. As the number of vehicle increases, flow-time of each

Table 5
Two-way interactions

Source	Dependent variable	Sum of squares	df	Mean square	*F*	*P*
NOV * VDR	TIS	36.450	1	36.450	.003	.960
	MQL	.738	1	.738	1.491	.227
	OPR	2.813	1	2.813	.133	.717
	MID	.001	1	.001	.003	.955
NOV * NOK	TIS	1,104,030.050	1	1,104,030.050	78.108	.000
	MQL	424.259	1	424.259	856.495	.000
	OPR	.612	1	.612	.029	.865
	MID	.078	1	.078	.219	.642
VDR * NOK	TIS	245.000	1	245.000	.017	.896
	MQL	.142	1	.142	.286	.595
	OPR	.013	1	.013	.001	.981
	MID	.021	1	.021	.059	.809
NOV * ARD	TIS	558,114.050	1	558,114.050	39.486	.000
	MQL	.008	1	.008	.015	.902
	OPR	171.112	1	171.112	8.090	.006
	MID	1.176	1	1.176	3.294	.074
VDR * ARD	TIS	1805.000	1	1805.000	.128	.722
	MQL	.028	1	.028	.057	.812
	OPR	7.812	1	7.812	.369	.545
	MID	.210	1	.210	.588	.446
NOK * ARD	TIS	117,351.200	1	117351.200	8.302	.005
	MQL	.068	1	.068	.138	.712
	OPR	.012	1	.012	.001	.981
	MID	.001	1	.001	.003	.955

Table 6
Three-way interactions

Source	Dependent variable	Sum of squares	df	Mean square	*F*	*P*
NOV * VDR * NOK	TIS	198.450	1	198.450	.014	.906
	MQL	.012	1	.012	.024	.878
	OPR	.013	1	.013	.001	.981
	MID	.012	1	.015	.042	.838
NOV * VDR * ARD	TIS	6.050	1	6.050	.000	.984
	MQL	.067	1	.067	.136	.713
	OPR	6.613	1	6.613	.313	.578
	MID	.325	1	.325	.911	.344
NOV * NOK * ARD	TIS	99264.050	1	99264.050	7.023	.010
	MQL	.293	1	.293	.592	.445
	OPR	13.612	1	13.612	.644	.425
	MID	.136	1	.136	.381	.539
VDR * NOK * ARD	TIS	20.000	1	20.000	.001	.970
	MQL	.046	1	.046	.093	.761
	OPR	1.012	1	1.012	.048	.828
	MID	.036	1	.036	.101	.751

job decreases. Also when the number of kanban increases, flow-time of each job strikingly increases. As demand rate decreases, time in system of each job also decreases. Besides, two-way interactions are detected on time in system (between number of vehicle and number of kanban, between number of vehicle and arrival rate of demand). Finally, three-way interaction occurred on time in system (among number of vehicle, number of kanban and arrival rate of demand).

Table 7
Four-way interaction

Source	Dependent variable	Sum of squares	df	Mean square	*F*	*P*
NOV * VDR * NOK * ARD	TIS	186.050	1	186.050	.013	.909
	MQL	.047	1	.047	.095	.759
	OPR	1.513	1	1.513	.072	.790
	MID	.006	1	.006	.017	.896

On the other hand, as number of vehicle increases from two to three, vehicle queue length extremely decreases. Another main effect on vehicle queue length is number of kanban. This factor is found statistically significant. Only two-way interaction on vehicle queue length is found between the number of vehicle and the number of kanban.

On output rate, number of vehicle and arrival rate of demand have an effect, as number of vehicle increases, number of finished jobs increases. Same things can be declared for arrival rate of demand. Only two-way interaction is shown between number of vehicle and arrival rate of demand.

On inter departure time of jobs, only number of jobs plays a crucial role.

According to the results, number of vehicle plays a crucial role on all performance measures. On the other hand, vehicle dispatching rule does not affect any performance measure.

This study can be extended in several points. Machine failures are ignored in this study. Naturally, it cannot be seen how the system respond machine failures. Considering machine failures make the system more realistic. Thus, various policies can be developed. In future researches, machine failures may be regarded.

Secondly, it is mentioned that a dispatching algorithm (MP) was proposed to improve transportation efficiency. However, the performance of this algorithm was not presented exactly. If this algorithm is thought as a factor, precise effect of it can be observed.

Lastly, it was stated that in experimental design two levels were selected for each factor. A regression equation (metamodel), which is a function of factors, can be suggested by increasing the levels of factors. Thus, the function constituted is able to yield the values of performance measures. As a result computer time, on which simulation runs must be performed, will be saved.

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