Iranian Journal of Management Studies (IJMS) *http://ijms.ut.ac.ir/*
Vol. 14, No. 1, Winter 2021 *Print ISSN: 2008-7055*
pp. 189-208 *Online ISSN: 2345-3745*
Document Type: Research Paper *DOI: 10.22059/ijms.2020.261618.673203*

Mathematical Modeling for a Flexible Manufacturing Scheduling Problem in an Intelligent Transportation System

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(Received: May 11, 2019; Revised: July 27, 2020; Accepted: July 27, 2020)

Abstract

This paper presents a new mathematical model for a production system through a scheduling problem considering a material handling system as an intelligent transportation system by automated guided vehicles (AGVs). The traditional systems cannot respond to the changes and customer's demands and for this reason, a flexible production system is used. Therefore, for this purpose, automated transportation systems are used for more flexibility in production. Thus, several AGVs are considered to perform various jobs among different machines and warehouses. In this production system, there are possibilities of failure and breakdown of AGVs and machines simultaneously. A modified rate is considered for determining the maintenance duration time as a percentage of the setup time when the maintenance time is dependent on the total setup time of machines and the total transfer jobs time of AGVs. Hence, we consider the probability of breakdown of AGVs and machines simultaneously and show the effect of these problems. The objective function is to minimize the maximum completion time (i.e., makespan or C_{max}), the tardiness penalty, and the total transportation cost bearing in mind that the impact of new constraints with mathematical innovation on how failure and repair time are affected by the entire production scheduling. The proposed model belongs to mixed-integer linear programming (MILP). Finally, several small-sized problems are generated and solved by the CEPLEX solver of GAMS software to show the efficiency of the proposed model.

Keywords

Flexible job shop scheduling, Automated guided vehicle, Tardiness, Makespan.

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Introduction

A scheduling problem in production planning (PP) is one of the most important studies in operations research (OR). PP is needed to characterize which job needs to be processed and which machine should be chosen. On the other hand, scheduling and planning can help to decide on the determination of priority allocate to work. Production resources are limits. So, customer orders usually face the waiting time of the shop, which is longer than their real processing time. The most important target of production scheduling is to efficaciously utilize the existing resources to earn some organizational goals, including decreasing the average time that jobs have to expend in the system and keeping down the penalty caused by late deliveries.

In recent years, new manufacturing technologies have been adapted to production systems and adopted; however, scheduling is still a fundamental duty to help production activities to competitive. Scheduling is the allocation of limited resources over time to perform a given set of jobs or activities. Also, it is one of the most important elements in PP. It calls for a thorough understanding of all aspects of the production process and is an outcome of the integration of the efforts of planners in the planning group and the people on the shop floor.

Scheduling integrates people, machines, materials, customers' demands, and quality requirements in finalizing the priorities. It makes it possible by determining the starting and completion times of each operation. Also, it is the process of arranging, controlling, and optimizing work and workloads in a production process. Companies use backward and forward scheduling to allocate plant/machinery resources, plan human resources, plan production processes, and purchase materials.

A job shop flow is one of the complex production processes in which small batches of different to customized products are produced. In this process, most of the products made need a unique sequence of process steps. However, sequencing and scheduling are some of the important issues and difficult problems that should use it.

A scheduling problem is a critical issue for all companies in different service or production systems. A flexible job shop scheduling problem (FJSSP) is so different and famous in the field of production management. In a basic FJSSP, several jobs can be processed on one of several identical machines on each stage of production. In other words, this is a definition of flexibility, in which jobs can be processed step by step on several machines. However, jobs have various routes for processing. Therefore, the process route is different, and each of the jobs has a varied process route. On the other hand, this is a definition of sequencing. Also, the processing time is predefined and different for each of the jobs on each needed machine. In initial papers, the machines are presupposed to be of no defect and consequently work without interruption or failures in a production environment.

However, in recent decades, that idea has changed, and researchers have been attracted by the idea that the breakdown of machines and the possibility of systems fails are considerable. Additionally, the movement times between machines in a production environment have not been considered. Researchers claimed that movement times were so small that they could be negligible. In recent decades, researchers have a different idea and have been attracted to study the transportation time and show the effect of this time on total time. So, they could show the impacts of that time on an optimal solution. However, in recent researches, vehicle breakdown in a production environment is not considered. When we use various vehicles for transferring jobs from a machine to another machine, we need to consider vehicle breakdown and we cannot be negligible. If the automated guided vehicle (AGV) fails to work correctly, the whole production system may fail. For example, an AGV can be used to move the jobs. Of course, there is a possibility that the AGV fails and needs maintenance. In other words, the maintenance time of AGVs and machines is important and should be considered in completion time. Therefore, if we do not consider these constraints, we cannot manage the production system exactly.

In this paper, a specific production system is considered containing several machines on each stage of production and several different jobs and several AGVs, in which there is a possibility of machines and closed-loop route failures. We consider transportation time and show the effect of this time on total time. So, we can show the impacts of that time on an optimal solution. Our goal is to offer sequence and schedule for jobs and, in the next step, the assignment jobs to AGVs for transfer between machines. Thus, the object is to minimize the tardiness penalty and the maximum completion time (i.e., makespan or C_{max}).

Literature Review

The job shop scheduling problem (JSSP) are so different and increases extremely. So, researchers are attracted to study these areas. Ulusoy et al. (1997) focused on the schedule machines and routes of AGVs. They offered a genetic algorithm (GA) and then compared the results obtained by the GA with time windows.

Jawahar et al. (1998) developed a three-phase heuristic algorithm for the problem and considered the path of moving AGVs as single-ringed packets. To solve the problem of the collision, the four rules of dispatch have been determined. By the end, with carrying out a heuristic method on 40 different issues, the shortest travel time was considered the best rule of the four existing rules. Jerald et al. (2006) suggested a multiple-machines and multi-parts problem an adaptive GA (AGA) and ant colony optimization (ACA). Their object included a decrease in penalty cost and machine free time.

Hamana et al. (2007) offered a job shop system with AGVs and its operation, in which sequencing was pre-determined. Rossi and Dini (2007) considered an FJSSP considered sequencing tuning times in their problem and obtained the sequence of jobs on machines from the network model and the critical path analysis. They proposed an ant colony algorithm to solve this problem. Corréa et al. (2007) solved the scheduling and routing problem by a hybrid method. Their hybrid method consisted of two sub-issues, in which the first sub-issue used limits programming and the second sub-issue contributed to the complex number programming method. They considered the AGV scheduling and routing on non-collisional paths without the scheduling of each machine.

Gnanavelbabu et al. (2009) considered an FJSSP in a manufacturing system with five cells and 16 machines. They also considered an automated warehousing system and two AGVs that could traverse in a single-loop path and their disability was not considered. They used an artificial immune system to solve the model that minimized error costs, minimized machine downtime, and minimized mileage by machines used in the warehouse. They specified machines assigned to each cell and the sequence of jobs on each cell.

Fazlollahtabar and Mahdavi (2009) considered uncertain processing time of jobs on machines and the waiting time of arriving AGVs and the time of fails machines consider with probability approach. Their goal was to minimize the time and cost of performing this issue simultaneously. They did not solve this problem with any algorithm. Fazlollahtabar et al. (2010) considered a flexible job shop that was responsible for transferring materials to AGVs. They considered several cells, in which some of them have similar machines; however, the layout of machines in each cell was different. The objective was to minimize the flow of materials between stations and determine the best sequence for routing and scheduling.

Udhayakumar and Kumanan (2010) carried out the near-optimal scheduling for two AGVs in job shop flow according to equal workload and the least transportation time. Then, a GA and ant colony optimization (AC)) were offered. Chaudhry et al. (2011) proposed two AGVs with the GA and machine scheduling. Ultimately, four GAs were compared. Zhang et al. (2012) considered an FJSSP with a constraint on transportation between machines. Also, they considered the disability of machines and vehicles. The objective function was to minimize C_{max} by the GA and Tabu Search (TS) algorithm.

Fazlollahtabar et al. (2015) presented a scheduling problem for multiple AGVs in a job shop production considering the pickup and the delivery time of AGVs that they need to transfer among shops in a job shop environment. Their earliness and tardiness were considered. So, they offered a mathematical program to decrease the penalized earliness and tardiness. Zeng et al. (2015) proposed a part scheduling problem. Some special parts were needed to meet machines between cells and move with an AGV to decrease the makespan. So, a nonlinear mathematical programming model was presented to characterize the sequences of the parts operation. Saidi-Mehrabad et al. (2015) presented the movement times of the jobs between machines in the JSSP. They offered a mathematical model combined with the JSP and CFRP at the same time. They used the ACO and their object was to decrease makespan.

From the perspective of innovation and research gaps summarized in Table 1, automated vehicle maintenance is one of the scarcely observed issues in flexible manufacturing environments.

In this study, given the flexible production environments and stations with parallel machines, we consider automated transport to the shop. The issue of moving the jobs in the production system cannot be eliminated when it has considerable timing. Automated vehicle as a whole or a semi-automatic device (like other devices) is capable of crashing. Thus, it is important to consider the failure of the device. In other words, another problem that would be investigated in this paper is the breakdown, maintenance, and repair time of the types of machinery and automated vehicles. An attempt is made to minimize the amount of automobile breakdown in an intelligent transportation system by presenting a mathematical model. Although these failures are unavoidable, reducing their breakdown time, or optimizing the use of automated replacement vehicles immediately can cause minimal damage to the input system.

Table 1. Related Literature Review

Reference	Year	environme	Number of AGVs		Kind of routing			Objective function		Failures		Maintenance
		Flexible job shop	Single	Multiple	Single loop	Multi loop	Network	Single	Multiple	Machines	AGV	
Jawahar et al.	1998	*	*		*			*				
Corréa et al.	2007	*		*				*				
Rossi & Dini	2007	*	*		*	*		*				
Gnanavelbabu et al.	2009	*		*	*				*			
FazlullahTabar et al.	2010	*	*	*	*			*				
Zhang et al.	2012	*		*	*			*				
Our article	2017	*	*		*			*		*	*	*

Problem Description and Formulation

In this section, the problem is first described and formulated as a mathematical model form.

Problem Description

The traditional systems cannot respond to the changes and customer's demands and for this reason, the flexible production systems are used. Therefore, for this purpose, the automated transportation systems are used for displacements for more flexibility in the production. While some components (like industrial trucks and vertical/horizontal conveyors) were used in the past, if proper management and correct planning are not carried out, these systems will perform weaker than the traditional systems. Therefore, decision making about these issues would be discussed in various aspects. In this paper, also a job shop production system is considered, in which, most of the types of machinery are used parallel to each other in each workstation for more flexibility. Also, in each workstation, a group of parallel and identical types of machinery is located and the functions performed on each job is planned and scheduled in such a way that for moving them, an AGV is ready to get or deliver the jobs for displacing them in workstation in the shortest time. The issue of moving the jobs in the production cannot be eliminated when it has considerable timing. Not considering this time in the production timing is a wrong action. Another problem investigated in this paper is the breakdown and maintenance and repair time of the types of machinery and automated vehicles that result in the possibility of unavailability of the automated vehicles to move the jobs. Therefore, expenses are sometimes needed for their availability, and not considering these times and expenses would be wrong.

In this case, a job shop or flexible job shop is a production system. There are several kinds of jobs, machines, and AGVs. Jobs should be processed by machines. These jobs may require many machines or perhaps one machine in each of the stages. Jobs can be processed on one of the machines in each stage of production, and jobs may visit one or more stages of production in the duration of processes so that the routes of the process for each of jobs can be various. Furthermore, at the beginning of planning periods, all of AGVs and jobs are in the warehouse. So, one job should allocate to each AGV, and they have one capacity. AGVs and machines cannot work continuously without failure. The operations can break off. So, the possibility of fails is considered. AGVs loading and unloading times are determined and included in setup time. Machines are similar in each step of production. Machines cannot process more than one job at the same time. In this problem, when a job is assigned to an AGV, after that, that AGV may be allocated to other jobs.

Problem Formulation

Before presenting the formulation of the model, the indices and parameters of the model can be defined as follows:

Sets

In this paper, an FJSSP consisting of *n* parts (i=1,…,n) and *m* machines (*k*=1,…,*m*) is considered. Several pre-determined processes or a stage of the process should be done on each part. *j* represents the processes (*j*=1,…, j_j) and J_j represents the number of processes to be done on part *i*. Operations required for manufacturing parts are determined in PP on each stage of products. The first section of the process i is *Ai* and the end section of process i is Z_j. The set of vehicles for material handling (e.g., AGV) is *m* and the objective function tries to minimize the penalty of tardiness for all parts and transportation costs.

Parameters

PT_{ijk}: Processing time of part *i* on machine *k* in process *j*

ST_{ijk}: Setup time of part *i* on machine *k* in process *j*

PMT_{mjj1}: Traveling time of *m* between sections of process

α_m: Rate of AGVS maintenance

B_j: Rate of machines maintenance in each stage

DD_i: Due date for part *i*

TD_i: Tardiness penalty for part *i* per time unit

CT_{mi}: Completion time of part *i*

Variables:

C_{ijk} Completion time of part *i* on machine *k* in section *j*; 0, otherwise

Y_{ijk} 1 if operation *j* of part *i* is processed at machine *k*; 0, otherwise

$YY_{mijj'}$ 1 if AGV of type *m* handling part *i* between sections of process *j* and *j'*; 0, otherwise

$X_{ii'jk}$ 1 if part *i* is processed by machine *j* just before part *i*; 0, otherwise

t_i Variable that indicates makespan

Mathematical Model

$$\text{Min } C = \sum_i TD_i * (ti - DD_i) + \sum_j \sum_{j'=j-1} \sum_i \sum_m CT_{MI} * YY_{mijj'} \quad (1)$$

s.t.

$$ti \geq MAX \sum_{K \in k} C_{ijk} \qquad \forall i \in I, J = z_i \quad (2)$$

$$\sum_{\substack{i \in I \\ i \neq i}} \sum_{i' \in I} X_{ii'jk} \leq 1 \qquad \forall j \in J, \forall k \in K \quad (3)$$

$$\sum_{k \in Kij} Y_{ijk} \leq 1 \qquad \forall i \in I, \forall J \in J_i \quad (4)$$

$$\sum_m YY_{imjj'} = 1 \qquad \forall\, i, J, J' = J - 1 \quad (5)$$

$$C_{ijk} \leq MY_{ijk} \qquad \forall i \in I, J \in J_i, K \in K_{ij} \quad (6)$$

$$C_{ijk} \geq \sum_{k'} C_{ij'k'} + ST_{ijk} + (\beta_j * ST_{ijk}) + PT_{ijk} + \sum_m \left((\alpha_m * PMT_{mjj'}) + PMT_{mjj'} \right) * YY_{mijj'} - M(1 - Y_{ijk}) \qquad \forall i \in I,\ j, j' \in J_i, j \neq Ai, j' = j - 1, K \in K_{ij} \quad (7)$$

$$C_{ijk} \geq Y_{ijk} * (ST_{ijk} + (\beta_j * ST_{ijk}) + PT_{ijk}) \qquad \forall i \in I, J \in Ai, K \in K_{ij} \quad (8)$$

$$X_{ii'jk} + X_{i'ijk} \leq 1 \qquad \forall i, i' \in I, i < i', j \in j_i \cap j_{i'}, K \in K_{iJ} \cap K_{i'j'} \quad (9)$$

$$2X_{ii'jk} \leq Y_{ijk} + Y_{i'jk} \qquad \forall i, i' \in I, i \neq i', j \in j_i \cap j_{i'}, K \in K_{iJ} \cap K_{i'j'} \quad (10)$$

$$Y_{ijk} + Y_{i'jk} \leq X_{i'ijk} + X_{ii'jk} - 1 \qquad \forall i, i' \in I, i \neq i', j \in j_i \cap j_{i'}, K \in K_{iJ} \cap K_{i'j'} \quad (11)$$

$$C_{ijk} \geq C_{i'jk} + ST_{ijk} + (\beta_j * ST_{ijk}) + PT_{ijk} + \sum_m \sum_{j'=j-1} \left((\alpha_m * PMT_{mjj'}) + PMT_{mjj'} \right) * YY_{mijj'} - M * X_{i'ijk} - 2M + MY_{ijk} + MY_{i'jk} \qquad \forall k \in K, : N_k > 1, j = J_K, i, i' \in I_k, i < i' \quad (12)$$

$$C_{i'jk} \geq C_{ijk} + ST_{ijk} + (\beta_j * ST_{ijk}) + PT_{ijk} + \sum_{m} \sum_{j'=j-1} \left((\alpha_m * PMT_{mjj'}) + PMT_{mjj'} \right) * YY_{mijj'} - M * X_{ii'jk} - 2M + MY_{ijk} + MY_{i'jk} \quad \forall k \in K, : N_k > 1, j = J_K, i, i' \in I_k, i < i' \tag{13}$$

$$C_{ijk}, T \geq 0 \tag{14}$$

$$Y_{ijk}, X_{ii'jk}, YY_{mijj'} \sim (0,1) \tag{15}$$

The objective function (1) is to minimize a penalty of the tardiness and transportation cost. Constraint (2) says each part has a different completion time. Of course, we know that the total time is equal to the last part processed on machines. Constraint (3) shows the sequencing of jobs on machines. Constraint (4) shows each job should be assigned to one machine. Constraint (5) says each job should be allocated to one automated guided vehicle for transfer. Constraint (6) shows there is a relation between C_{ijk} variable and Y_{ijk} variable. Constraint (7) shows the completion time of each part, which is composed of four items: setup time, processing time, the processing time for the previous jobs completion, and maintenance time for AGV and machines. Constraint (8) shows the completion time for the first stage of production. Constraints (9) to (11) show sequencing between jobs and relationships between variables in the model. Constraint (9) says that part i should be processed before i' or after i' and Constraint (10) says that if part i is processed before i', variable $X_{ii'jk}$ takes a number and variables Y_{ijk} and $Y_{i'jk}$ should take a number as well, which is a problem because it indicates that both parts i and i' are proceed on the same machine, which is not correct. Therefore, we used Constraints (11) and (9) to solve this problem to show that part i is processed before i' or the process of part i' is done before i. Constraints (12) and (13) show the conflict of parts and try to avoid the respective conflict. Constraints (14) and (15) show the variable of the model that is binary and continuously.

In the next section, this issue would be investigated and evaluated by solving some small and medium-sized problems by GAMS software after presenting the proposed mathematical model. Then, the sensitivity analysis is performed for the obtained results from the proposed model.

Computational Experiment and Sensitivity Analysis

Example 1

In this section, an example of a small-sized problem is generated and solved by GAMS commercial software to show the efficiency of the presented model. We explain a small-scale example for a better understanding of the model. In this section, we solve a small-scale example. Suppose there are 5 parts, 3 stages, 2 AVGs, and 3 machines in each stage. First, we want to identify which AGV is used to transport parts between stages and allocation parts to stages for operation. The information on the rates of AGV and machine maintenance in each stage is summarized in Table 2. We also assume the processing time and setup time of each part (equal to 5). Table 3 shows the due date and tardiness penalty for each part, respectively. The proposed model is solved by GAMS. Table 4 shows the travel cost of AGVs. In Table 5, the route of each part between machines, completion time, and used AGVs is reported. Finally, the objective function value is 158540.

Table 2. Rate of AGVs Maintenance and Stages

AGV m	α_m	Stage j	β_j
1	0.4	1	0.1
2	0.6	2	0.2
		3	0.4

Table 3. Due Date and Tardiness Penalty for Parts

Part i	DD_i	TD_i
1	10	4500
2	10	3600
3	20	1600
4	15	1100
5	30	2800

Table 4. Travel Cost of AGVs

	I1	I2	I3	I4	I5
M1	100	50	150	100	150
M2	70	50	150	100	100

Table 5. Summary of the Final Results

Part	Stage 1			Stage 2			Stage 3			AGV	
	m_{11}	m_{21}	m_{31}	m_{12}	m_{22}	m_{32}	m_{13}	m_{23}	m_{33}	v_1	v_2
1	*						*				✓
2			*	*					*		✓
3						*		*			✓
4		*							*	✓	
5			*			*					✓

Example 2

In this section, an example of a medium-sized problem is generated and solved by the GAMS commercial software for showing the efficiency of the presented model. In this section, we solve a medium-scale example. Suppose there are 8 parts, 4 stages, 2 AVGs, and 11 machines in a total of stages. First, we want to identify which AGV is used to transport parts between stages and allocation parts to stages for operation. The information on the rates of AGV and machine maintenance in each stage is summarized in Table 6. We also assume processing time and setup time of each part (equal to 5). Table 7 shows the due date and tardiness penalty for each part, respectively. The proposed model is solved by GAMS. Table 8 shows the travel cost of AGVs. In Table 9, the route of each part between machines, completion time, and used AGVs is reported. Finally, the objective function value is 161410.

Table 6. Rate of AGVs Maintenance and Stages

AGV *m*	α_m	Stage *j*	β_j
1	0.4	1	0.1
2	0.6	2	0.2
		3	0.4
		4	0.7

Table 7. Due Date and Tardiness Penalty for the Part

Part *i*	DD_i	TD_i
1	10	4500
2	10	3600
3	20	1600
4	15	1100
5	30	2800
6	5	200
7	15	100
8	10	500

Table 8. Travel Cost of AGVs

	I1	I2	I3	I4	I5	I6	I7	I8
M1	100	50	150	100	150	100	100	150
M2	70	50	150	100	100	50	250	100

Table 9. Summary of the Final Results Table 9 Summary of the Final Results

Part	Stage 1			Stage 2			Stage 3			Stage 4		AGV	
	$m_{11_{11}}$	m_{21}	m_{31}	m_{12}	m_{22}	m_{32}	m_{13}	m_{23}	m_{33}	m_{14}	m_{24}	v_1	v_2
1	*						*						√
2		*		*			*				*		√
3						*			*				√
4			*					*				√	
5	*			*									√
6			*		*					*			
7									*			√	
8					*						*		√

Example 3

In this section, an example of a medium-sized problem is generated and solved by the GAMS commercial for showing the efficiency of the presented model. In this section, we solve a medium-scale example. Suppose there are 8 parts, 4 stages, 3 AVGs, and 11 machines in a total of stages a. First, we want to identify which AGV is used to transport parts between stages and allocation parts to stages for operation. The information on the rates of AGV and machine maintenance in each stage is summarized in Table 10. We also assume processing time and setup time of each part (equal to 5). Table 11 shows the due date and tardiness penalty for each part, respectively.

Table 10. Rate of AGVs Maintenance and Stages

AGV m	α_m	Stage j	β_j
1	0.2	1	0.1
2	0.4	2	0.2
3	0.1	3	0.4
		4	0.3

Table 11. Due Date and Tardiness Penalty for Parts

Part *i*	DD_i	TD_i
1	10	4500
2	10	3600
3	20	1600
4	15	1100
5	30	2800
6	5	200
7	5	100
8	10	500

The proposed model is solved by GAMS. Table 12 shows the travel cost of AGVs. In Table 13, the route of each part between machines, completion time, and used AGVs is reported. Finally, the objective function value is 156310.

Table 12. Travel Cost of AGVs

	I1	I2	I3	I4	I5	I6	I7	I8
M1	100	50	150	100	150	100	100	150
M2	70	50	150	100	100	50	250	100
M3	70	50	100	100	50	50	100	50

Table 13. Summary of the Final Results

i	Stage 1			Stage 2			Stage 3			Stage 4		AGV		
	m_{11}	m_{21}	m_{31}	m_{12}	m_{22}	m_{32}	m_{13}	m_{23}	m_{33}	m_{14}	m_{24}	v_1	v_2	v_3
1	*						*							✓
2			*	*				*			*		✓	
3						*			*				✓	
4		*						*		*		✓		
5	*			*										✓
6		*			*						*			
7									*			✓		
8						*				*				✓

Example 4

In this section, an example of a large-sized problem is generated and solved by the GAMS commercial software for showing the efficiency of the presented model. In this section, we solve a large-scale example. Suppose there are 8 parts, 4 stages, 3 AVGs, and 11 machines in a total of stages. First, we want to identify which AGV should be used to transport parts between stages and allocation parts to stages for operation. The information on the rates of AGV and machine maintenance in each stage is summarized in Table 14. We also assume processing time and set-up time of each part (equal to 5).

Table 14. Rate of AGVs Maintenance and Stages

AGV type (m)	α_m	Stages type (j)	β_j
1	0.2	1	0.1
2	0.4	2	0.2
3	0.1	3	0.4
		4	0.7

Table 15 shows the due date and tardiness penalty for each part, respectively. The proposed model is solved by GAMS. Table 16 shows the travel cost of AGVs. In Table 17, the route of each part between machines, completion time, and used AGVs is reported. Finally, the objective function value is 160510.

Table 15. Due Date and Tardiness Penalty for Parts

Part *i*	DD_i	TD_i
1	10	4500
2	10	3600
3	20	1600
4	15	1100
5	30	2800
6	5	200
7	5	100
8	10	500
9	10	100
10	15	100

Table 16. Travel Cost of AGVs

	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10
M1	100	50	150	100	150	100	100	150	100	50
M2	70	50	150	100	100	50	250	100	70	50
M3	70	50	100	100	50	50	100	50	70	50

Table 17. Summary of the Final Results

Part	Stage 1			Stage 2			Stage 3			Stage 4		AGV		
	m_{11}	m_{21}	m_{31}	m_{12}	m_{22}	m_{32}	m_{13}	m_{23}	m_{33}	m_{14}	m_{24}	v_1	v_2	v_3
1	*						*							√
2			*	*				*		*			√	
3						*			*		*		√	
4		*						*				√		
5			*		*								√	
6		*				*					*			
7									*			√		
8				*						*				√
9							*							√
10	*													√

We can see the impacts of transportation time on an optimal solution with an increased rate of maintenance, the total time of production increases. This point shows the impacts of transportation time on an optimal solution that can be shown in Figure 1.

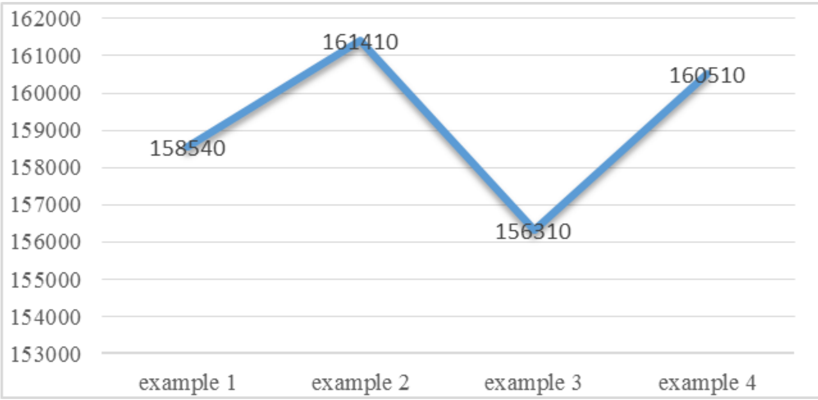

Fig. 1. Objective Function Value

To analyze the sensitivity level and show the complexity coefficient of the model by changing the problem variables (e.g., parts and automated vehicles), it is realized that the number of production costs may vary. The production managers need to choose the correct mechanism about the costs incurred on the system correctly and carefully. In the examples given, it is observed that automated vehicles are selected based on the number of manufactured parts and the layout of the devices, and if not meticulously accurate, it can incur additional costs. Transporting automated vehicles and their infrastructure are so expensive and costly that the managers need to be vigilant in choosing the number of vehicles. Therefore, it is important to show how important the number of vehicles is at the same time as the number of parts manufactured and, of course, their dependence on the layout of the production lines.

Conclusion and Further Research

This paper considered a production scheduling problem in a flexible job shop (FJS) system with an automated guided vehicle (AGV) as a transportation system consisting of several machines on each stage of production and several different jobs and several AGVs in which there was the possibility of equipment failures and a closed-loop path. We considered the transportation time and showed the effect of this time on total time. Thus, we could show the impacts of that time on an optimal solution so that the maximum completion time (i.e., makespan) was minimized as an objective function. We knew that the use of this AGV caused flexibility in the production system. In this production system, there were the possibilities of failure and the breakdown of AGVs and machines simultaneously. A modified rate for determining the maintenance time as a percentage of the setup time was considered, in which the maintenance time was dependent on the total setup time and transportation time. After breaking down the machines and AGVs, they should be stopped and repaired, which was time-consuming. Moreover, we could show the impacts of that time on an optimal solution. This could be shown in the objective function value. Thus, a mixed-integer linear programming (MILP) model was presented to optimize this production system with AGVs. The object function tries to minimize the tardiness penalty with the failure possibility of the machines and AGVs simultaneously. Furthermore, to validate this presented model, an example of small-sized problems was generated and solved by the CEPLEX solver of GAMS software.

Finally, the computational results and conclusions are presented, the results were explained, and we could see the impacts of transportation on an optimal solution with an increased rate of maintenance and the total time of production. This point could show the impacts of transportation time on an optimal solution that could be shown in the objective function value. Future studies in the field of intelligent manufacturing and intelligent material handling systems are as follows: Providing a fully intelligent manufacturing environment without human intervention and considering human errors in the management and control of automated vehicles. In the area of management, it is important to consider the workforce training to maintain and repair these smart devices as well as the way to control and manage them in the control room. The other issues include an application of routing types, the use of automated vehicles in other types of production environments about fuzzy or probabilistic times, the consideration of the sequences of different and dynamic operations, and finally, the presentation of different solutions to these issues will be the exciting challenges.

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