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Research Article

A Job Shop Scheduling and Location of Battery Charging Storage for the Automated Guided Vehicles (AGVs)

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Abstract

When the Automated Guided Vehicles (AGVs) are transferring the parts from one machine to another in a job shop environment, it is possible that AGVs stop on their guide paths since their batteries are discharged. Consequently, it is essential to establish at least one Battery Charging Storage (BCS) to replace full batteries with empty batteries for the stopped AGVs. Due to non-predictable routes for AGVs in the manufacturing systems, to find the best place to establish the BCS can impact performance of the system. In this paper, an integrated mathematical model of job shop and AGV scheduling with respect to the location of a BCS is proposed. The proposed nonlinear model is transformed into a linear form to be efficiently solved in GAMS software. Finally, several numerical examples are presented to test the validity of the proposed mathematical model. The results show that the optimal cost and location of BCS can be obtained with respect to the number of AGVs, machines, parts, and other problem parameters. In addition, it is concluded that the increasing number of AGVs in a manufacturing system cannot be always a suitable policy for reducing the cost because in such conditions. Further to that, the conflict of AGVs may increase leading to the increase of the makespan. In other words, following the optimal point, increasing AGVs leads to the increase in costs.

***Keywords*:** job shop scheduling; Battery Charging Storage (BCS); AGV; GAMS software.

1. Introduction and Review

The Job shop environment is a production system in which each part should be processed on some or all of the given machines. Moreover, the parts have different processing routes in such systems. In other words, the processing route for each part differs from the processing route of other parts. In addition, the processing time for each part on each required machine is given (Saidi-Mehrabad, Dehnavi-Arani, Evazabadian and Mahmoodian, 2015).

In most of the presented papers related to the job shop area, only the processing times of parts on the machines are considered. In these papers, the transportation times between the machines are not considered because these times are very small in comparison with the processing times. In such cases, ignoring the transportation times is logical; as a result, the optimal solutions obtained by models are very close to optimal solutions existing in real environment. However, in environments where the transportation times are considerable in comparison with the processing times, it is very essential to consider the transportation times in order to acquire the exact optimal solutions.

The various vehicles, such as truck, conveyor, crane, Automated Guided Vehicle (AGV), or even manpower, can be as responsible for transferring the parts among the machines. From among above-mentioned vehicles, AGVs need more management to navigate in production systems because they are driverless and automatic control (Vis, 2006).As a result, many researchers concentrate on the management of AGVs problems such as guide path layout design, traffic management, location, AGV routing and scheduling, AGV control, AGV assignment, AGV breakdown, and battery management in their papers. For example, a guide path layout design can be seen in written papers by ElMekkawy and Liu (2009). They developed a new memetic algorithm for optimizing the partitioning problem of tandem AGV systems. Also, (Asef-Vaziri et al. (2007) designed a unidirectional loop flow pattern along with the pickup and delivery station locations for unit load automated material handling vehicles. Lee et al. (1998)considered a two-staged traffic control scheme in their paper. Digani et al. (2014)also proposed a hierarchical traffic control algorithm. Ventura and Rieksts (2009)determined the optimal location for idle AGV. For routing and scheduling, Corréa et al. (2007)developed a simultaneous assignment, scheduling and conflict free routing of the AGVs. Qiu et al. (2002)published a survey about scheduling and routing algorithms for AGVs. Weyns et al. (2006), Ho and Hsieh (2004)studied the AGV assignment in their paper.

One of most important AGVs' management aspects is battery management for AGVs. Driverless vehicles usually use batteries, which need to be charged or changed. If AGVs use batteries, the battery changing

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might be required. McHaney (1995) presented an overview of AGV battery technology. The time required for replacing or charging of batteries can affect the number of needed vehicles. The simulation results from McHaney (1995) compared an integrated model of battery management issues and simulation with a single simulation model. The results showed that the required times for charging of batteries can affect the throughput, congestion and costs.

For manufacturing systems or distribution areas that AGVs travel over relatively short distances, batteries can be replaced or charged during the idle times. On the other hand, in manufacturing systems with non-predictable AGV routes, container terminals and transportation systems, AGVs need to travel long distances and, as a result, they have short idle times that this means that AGVs should be charged or changed along theirs movements on the guide-paths (Vis, 2006).

McHaney (1995) was right in arguing that battery usage is frequently omitted in AGV research. The author provides the reader with guidelines when to incorporate battery management issues into simulation studies. He indicates that it might not be necessary to incorporate these issues for systems with off-shift times for AGVs, low utilization of AGVs (less than 50%), and on-line charging systems. Ebben (2001) developed the control rules to consider battery constraints in an underground transportation system with large numbers of AGVs. With simulation, the author compared the performance and costs of systems in which batteries are charged during travelling and systems in which batteries are replaced.

It is concluded that battery management is hardly addressed in AGV research. However, according to the results of McHaney (1995), the performance of AGV systems with high utilization and hardly any off shift times is influenced by incorporating battery management. These characteristics belong specially to AGV systems in transportation and transshipment areas. Thus, in future researches, for large AGV systems, it is greatly important to incorporate battery management decisions. These decisions should be integrated with decisions on routing, scheduling, and dispatching of full and empty AGVs.

In another paper, Takehito Kawakami and ShozoTakata (2012) developed a battery management strategy that considers the appropriate time intervals and the cost of charging. They proposed a battery management simulation to solve this problem with respect to the battery related costs under various AGV operation modes.

Zhai Jun-Jie (2007) introduced a battery monitoring system with smart battery monitoring chip. This presented system can include the on-line monitor pressure, current, temperature, remaining capacity, and process of charge/discharge. It can be also used to improve maintenance effect of storage battery and enhance the battery life.

Watch arinPinlam et al. (2002) provided an AGV system with automatic recharging and a central processor for control. The authors described the application and the role of central processor and automatic recharging in this paper. In addition, some kinds of central processors together with theirs application for an AGV system are stated.

Despite the importance and role of battery management founded in previous papers developed by researchers in this area of knowledge, they have not paid much attention to location of battery charge where the full and healthy batteries are maintained. It can be a challenging decision faced by managers to determine the optimal location, especially when AGVs had been employed in the manufacturing systems. As a result, endeavor was made to determine the optimal location for BSC in this paper. This optimal location is the place where the costs associated with transportation between BSC are minimized and where the AGVs have been stopped.

Herein, the proposed model by Saidi-Mehrabad et al. (2015) is revised where the AGVs transfer the parts from one machine to another in a job shop environment. Since, in their paper, the selected routes for each AGV are not pre-determined, it is possible that the batteries of AGVs are discharged and stop on the guide paths during their movement. In this circumstance, a BSC can be useful to replace the full batteries with empty batteries for the stopped AGVs. Notably, the transportation costs are related to replacing the batteries by BCS depend on the location of the BCS. Certainly, an inappropriate location of the BCS will impose additional costs on manufacturing systems and reduce system efficiency significantly. Thus, our developed model integrated the location of BCS (the best place for establishing the BCS with respect to the costs) with previous papers. The objective function is to minimize the sum of maximum completion time cost (makespan cost) and the transportation cost of changing the discharged batteries (the cost related to transportation between the BCS and stopped AGV).All of manufacturing systems can use the proposed model where AGVs play a key role as a material handling system.

2. Problem Statement

The operational system proposed by Saidi-Mehrabad et al. (2015) is also used in this paper in which the number of parts in the warehouse to be processed on machines are given. These parts may require one or more machines so that the processing routes for each part may be various. Moreover, all AGVs are at the starting point of the warehouse at the beginning of the planning horizon. The AGVs transfer the parts from the starting point of the warehouse to the first P/D (Pickup and Delivery) point of required machine through network guide paths. They stop at that P/D point to terminate their part processing on the first machine in order to receive and transfer that part to subsequent machine if necessary. Otherwise, the AGVs move to the ending point of the warehouse. Indeed, in our problem, an AGV is not assigned to another part, while that AGV delivers assigned part to the warehouse at the ending point. However, it is possible that the AGVs stop along their routes due to batteries discharging. As a result, a BCS should be established on a point of network to charge or change the discharged batteries. The other assumption is that the AGVs should not collide with each other during their routing which is *called conflict-free* *routing* in literature. The job shop environment described above is represented in Fig.1. The other assumptions considered in this paper are as follows:

- All AGVs have unit-part capacity
- AGV and machines operate continuously without breakdown.
- AGVs loading and unloading times are fixed and considered in travel times
- Machines are not identical
- Starting and ending points are on the network.
- No machine can process more than one part at a time
- The processing of the operations cannot be interrupted
- All parts and all machines are available from time 0
- AGVs cannot be located on the BCS point at considered horizon. In other words, it is impossible that AGVs are located at the BCS point at any time of the horizon planning. In other words, because the BCS has a physical structure (like a room), AGVs are not able to pass this physical structure throughput the horizon planning and BSC is as an obstacle for AVGs. As an example, when the BCS in the red point in Fig.1 is established, AGVs are not allowed to be located on the red point throughout the planning horizon.
- The time unit of discharging the batteries is fixed for all of AGVs
- The transportation and operation times relevant to changing the batteries of AGVs have not been considered in the makespan.

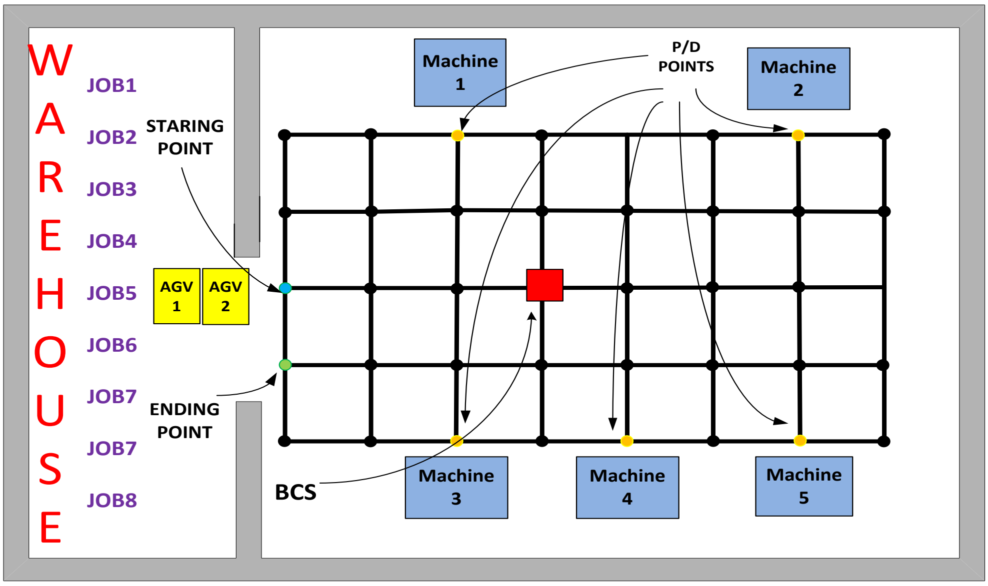

Fig. 1.The production environment under study

3. The Mathematical Model

In this section, the integrated mathematical model of problem under study is represented. The sets, parameters, and decision variables are as follows:

Sets

(i,j):The set of coordinates of points on the network
K:The set of AGVs
S:The set of parts in automatic warehouse
H: The set of considered times in horizon

Parameters

$\boldsymbol{b_{ijs}}$: 1 If point *(i,j)* is a P.D point for part*s*; 0 otherwise

$\boldsymbol{z_{iji'j'}}$: 1 If P.D point *(i,j)* precedes P.D point *(i′,j′)* for part*s*; 0 otherwise

$\boldsymbol{a_{ijs}}$: The sequence of P.D point *(i,j)* for part*s*

$\boldsymbol{t_{ijs}}$: The operation time for part*s* in the P.D point *(i,j)*

$\boldsymbol{cht}$ *:* The time unit that the battery of AGV is discharged

C.MS: The unit cost of makespan

C.TR: The unit cost of transportation between BCS and stopped AGV

$(\boldsymbol{a}, \boldsymbol{b})$: The starting point where AGVs receive the parts from warehouse

$(\boldsymbol{a'}, \boldsymbol{b'})$: The ending point where AGVs deliver the parts to the warehouse

h: The available time (The planning horizon)

M: A big number

In addition, the following relations should be between some parameters of the model. It should be noted that the following relations are not part of problem constraints; however, these have to be respected when the problem parameters are determined.

$$z_{iji'j's} + z_{i'j'ijs} = b_{ijs} \times b_{i'j's} \quad \forall (i,j),(i',j') \in (I,J), s \in S \quad (1)$$

$$b_{ijs} \times a_{i'j's} - \left(b_{i'j's} \times a_{ijs}\right) \leq M \times z_{iji'j's} \quad \forall (i,j),(i',j') \in (I,J), s \in S \quad (2)$$

$$b_{ijs} \times a_{i'j's} - \left(b_{i'j's} \times a_{ijs}\right) \geq -M \times z_{iji'j's} \quad \forall (i,j),(i',j') \in (I,J), s \in S \quad (3)$$

Relation(1) states that if two points *(i,j)* and *(i′,j′)* are P/D points for part*s*, then either *(i,j)*precedes*(i′,j′)*,or vice versa. In other words, even if one of two points*(i,j)*and*(i′,j′)*is not P/D points for part*s*, there are no relations between two points. Relations (2) and (3) determine precedency of points. For example, if sequence of P/D point*(i,j)*is greater than sequence of P/D point*(i′,j′)*, then$z_{i'j'ijs} = 1$ and$z_{iji'j's} = 0$.

Variables

x_{ijkst}: 1 If AGV *k* which transfersparts in time *t* is in point *(i,j)*; 0 otherwise

y_{kst}: 1 If part*s* is received by AGV *k* in time *t*; 0 otherwise

g_{ij}: 1 If BSC is established on point *(i,j)*; 0 otherwise

CT_s: The completion time of part*s*

T: The maximum completion time

Model

$$Min \quad C.MS \times T + \sum_{i\in I}\sum_{j\in J}\sum_{i'\in I}\sum_{j'\in J}\sum_{k\in K}\sum_{s\in S}\sum_{t=1}^{\left\lfloor \frac{h}{cht} \right\rfloor} C.TR \times (|i'-i| + |j'-j|) \times g_{i'j'} \times x_{ijks(t\times cht)} \quad (4)$$

$$T \geq CT_s \quad \forall s \in S \quad (5)$$

$$CT_s = \sum_{t\in H}\sum_{k\in K} t \times x_{a'b'kst} \quad \forall s \in S \quad (6)$$

$$\sum_{t\in H}\sum_{k\in K} x_{ijkst} \geq b_{ijs} \quad \forall (i,j) \in (I,J),\ s \in S \quad (7)$$

$$\sum_{t\in H}\sum_{k\in K} t \times x_{ijkst} \leq \sum_{t\in H}\sum_{k\in K} t \times x_{i'j'kst} + M\left(1 - z_{iji'j's}\right) \quad \forall (i,j),(i',j') \in (I,J), s \in S \quad (8)$$

$$\sum_{k\in K}\sum_{s\in S} x_{ijkst} \leq 1 \quad \forall (i,j) \in \{(I,J) - (a,b)\}, t \in H \quad (9)$$

$$x_{ij-1kst+1} + x_{ijk's't+1} \leq 3 - \left(x_{ijkst} + x_{ij-1k's't}\right) \quad \forall (i,j) \in (I,J), k,k' \in K(k' \neq k), s,s' \in S(s' \neq s) \quad (10)$$

$$x_{i-1jkst+1} + x_{ijk's't+1} \leq 3 - \left(x_{ijkst} + x_{i-1jk's't}\right) \quad \forall (i,j) \in (I,J), k,k' \in K(k' \neq k), s,s' \in S(s' \neq s) \quad (11)$$

$$\sum_{i\in I}\sum_{j\in J} x_{ijkst} \leq 1 \quad \forall k \in K, s \in S, t \in H \quad (12)$$

$$x_{ijkst} \leq x_{i+1jks+1} + x_{i-1jkst+1} + x_{ij+1kst} + x_{ij-1kst+1} + x_{ijkst} + M \times y_{kst} \quad \forall (i,j) \in (I,J), s \in S, k \in K, t \in H \quad (13)$$

$$y_{kst} \leq x_{abkst} \quad \forall k \in K, s \in S, t \in H \quad (14)$$

$$y_{kst} \leq \sum_{\substack{s'\in S \\ s'\neq s}} x_{a'b'ks't-1} \quad \forall k \in K, s \in S, t \in H(t > 0) \quad (15)$$

$$\sum_{s\in S} y_{ks0} = 1 \quad \forall k \in K \quad (16)$$

$$\sum_{t\in H}\sum_{k\in K} y_{kst} = 1 \quad \forall s \in S \quad (17)$$

$$\sum_{s\in S}\sum_{i\in I}\sum_{j\in J} x_{ijkst} \leq 1 \quad \forall k \in K, t \in H \quad (18)$$

$$\sum_{t'=t}^{t+t_{ijs}} x_{ijkst'} \geq (t_{ijs}+1) \times x_{ijkst} \times b_{ijs} \qquad \forall (i,j) \in (I,J), k \in K, s \in S, t \in H \tag{19}$$

$$\sum_{i \in I} \sum_{j \in J} g_{ij} = 1 \tag{20}$$

$$\sum_{k \in K} \sum_{s \in S} \sum_{t \in H} x_{ijkst} \leq M \times (1 - g_{ij}) \qquad \forall (i,j) \in (I,J) \tag{21}$$

$$x_{ijkst}, y_{kst}, g_{ij} \in \{0,1\} \ and \ CT_s, T \geq 0 \tag{22}$$

The first term in objective function (4) minimizes the sum of the maximum completion time costs. The second term also minimizes the transportation costs between BCS and the stopped AGVs. It should be noted that this transportation costs are incurred into objective function only when batteries of AGVs have been discharged. For this reason, index t starts from 1 to $\left[\frac{h}{cht}\right]$ which is equal to number of times that each AGV stops over the planning horizon. In addition, index of t in variable x_{ijkst} is changed to $(t \times cht)$, because this index shows only times that AGVs stop. As a result, the second term becomes active in times that AGVs stop and required to new batteries. For example, suppose that battery of each AGV is discharged in every 500 minutes (cht=500 min). The planning horizon is also equal to 5000 minutes (h=500 min).Therefore, each AGV stops $\left[\frac{h}{cht}\right]=\left[\frac{5000}{500}\right]=10$ times and locations of stopped AGVs are x_{ijkst} for t= 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, and 5000. Constraint (5) assures that the maximum completion time is greater than all of completion times for set of parts. Constraint (6) calculates the completion time for each part that is equal to the time that a part is delivered to the ending point *(a',b')*. Constraint (7) states that each AGV must meet each required P/D point for each part*s* if that part is assigned to that AGV. Constraints (8) ensure that if P/D point*(i,j)*precedes P/D point*(i',j')* for part*s*, then arrival time of AGV to*(i,j)* is earlier than arrival time to*(i',j')*. Constraint (9) ensures that there can only be one AGV in each point except the starting point at the same time. In other words, this constraint prevents collision of AGVs on the nodes of network. Constraints (10) and (11) assure that AGVs have no conflicts on the horizontal and vertical edges of the network. Constraint (12) says that each AGV can be only located in one point at the same time. Constraint (13) ensures that each AGV that is in point*(i,j)*can either go to four adjacent points including *(i+1,j)*, *(i-1,j)*,*(i,j+1)*, and*(i,j-1)*or stay at the same point in the next time unit. Constraint (14) states that an AGV can deliver a part only when that AGV is in starting point*(a,b)*. Constraint (15) states that when a new part can be assigned to an AGV, apart would be delivered to warehouse by the same AGV at the last time unit. Constraint (16) states that all of AGVs should certainly receive a part at time 0. Constraint (17) indicates that each part can be assigned to only one AGV. In other words, if an AGV receives a part, AGV follows that part to be delivered to the warehouse. Constraint (18) says that each AGV can be only responsible for transferring one part. Constraint (19) states that an AGV waits t_{ijs} time unit (operation time unit) for part*s* in P/D point*(i,j)*.Constraint (20) states that only a BCS must be established on one of the network points, and constraint (21) guaranties that AGVs cannot be located on the BCS point through the considered horizon. Constraint (22) determines the variable bounds.

As seen in the above model, two variables $x_{ijkst}$and $g_{i'j'}$ are multiplied in the second section; therefore, the objective function is in a nonlinear form. To linearize the objective function, the developed method by Glover and Woolsey (1974) is used. This method is such that the following new binary variable set is defined:

$$xg_{iji'j'kst} = x_{ijkst} \times g_{i'j'} \quad \forall (i,j),(i',j') \in (I,J), k \in K, s \in S, t \in H \tag{22}$$

Consequently, the objective function becomes:

$$Min \quad C.MS \times T + \sum_{i \in I} \sum_{j \in J} \sum_{i' \in I} \sum_{j' \in J} \sum_{k \in K} \sum_{s \in S} \sum_{t=1}^{\left[\frac{h}{cht}\right]} C.TR \times (|i'-i| + |j'-j|) \times xg_{iji'j'ks(t \times cht)} \tag{23}$$

The below linear constraints should be added to the model to enforce Eq. (22).

$$xg_{iji'j'kst} \leq x_{ijkst} \quad \forall (i,j),(i',j') \in (I,J), k \in K, s \in S, t \in H \tag{24}$$

$$xg_{iji'j'kst} \leq g_{i'j'} \quad \forall (i,j),(i',j') \in (I,J), k \in K, s \in S, t \in H \tag{25}$$

$$xg_{iji'j'kst} \geq x_{ijkst} + g_{i'j'} - 1 \quad \forall (i,j),(i',j') \in (I,J), k \in K, s \in S, t \in H \tag{26}$$

Now, with replacing Eq. (23) into Eq. (4) and adding Eqs. (24-26) to the model, the nonlinear model is transformed into a linear form. As a result, the GAMS commercial software can attain a global optimal solution rapidly.

4. Numerical Sample

4.1. The computational example description

A computational example for three parts, two AGVs, three machines in Fig. 2is represented. The sequence of required machines with processing times for three parts is shown in Table 1. Herein, there are 24 rails between sixteen points whose coordinates are *(i,j)*(*i*=0,1,2,3 and *j*=0,1,2,3). The travel time between two adjacent points on the network is also assumed equal to 1 (**Δ**=1) in this computational experiment. Since the proposed model has been written for **Δ**=1, if the travel time between two adjacent points is equal to a number greater than 1 (**Δ**=*n*, *n*>1), all processing times should be the integer multiple for *n*. In such conditions, all times are divided into *n* and **Δ** is changed to 1. The starting and ending points are (0,1) and (0,2),respectively. Moreover, machines1, 2, and 3 are located with points (1,3), (2,0),and (3,3), respectively.

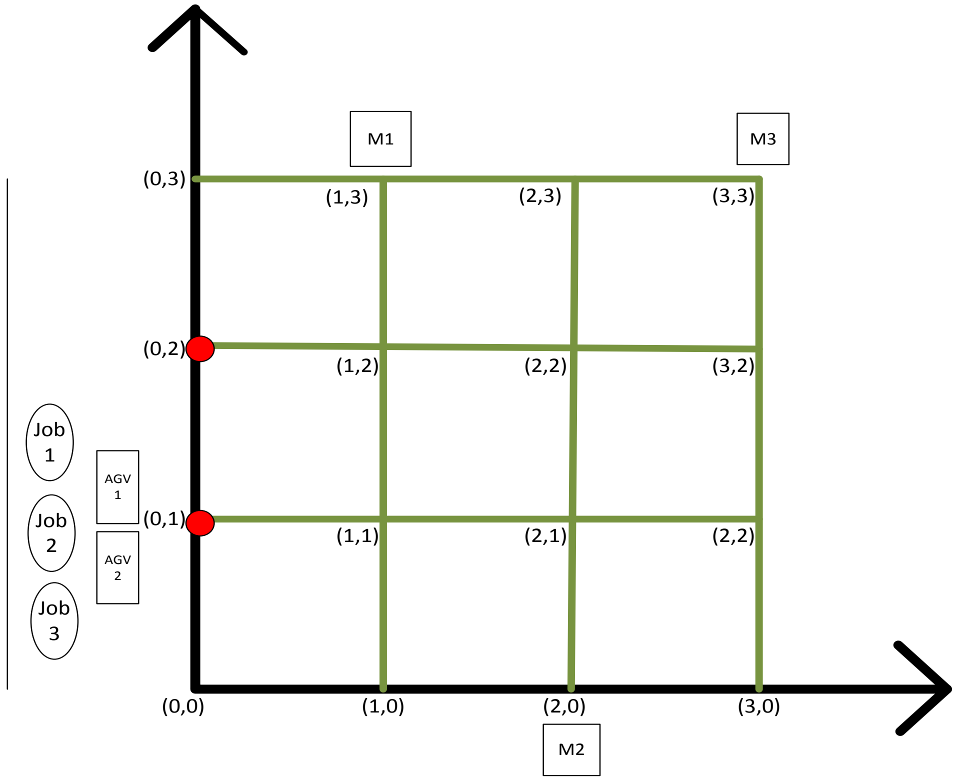

Fig. 2. Illustrative example

In addition, *cht* is equal to 7 time units. This means that each AGV after 7 time unit is discharged and needs a BCS to change its battery. *C.MS* and *C.TR* equal 100$ and 80$, respectively.

Table 1
Required machines and process sequence and time for illustrative example

part	Machine Sequence and process time: *machine sequence (process time(second))*		
1	***M2 (3)***	***M3 (4)*** →	***M1 (2)*** →
2	***M1 (3)***	***M3(1)*** →	***M2(3)*** →
3	***M3 (4)***	***M1(3)*** →	

4.2. The obtained results from above example

The above-mentioned example was solved by CPLEX in GAMS software on a personal computer Pentium4 (Intel (R) Core TM i7- 2670QM CPU@2.2GHz) and Microsoft Windows 7. The objective function equal to 4560 was obtained so that the makespan cost and transportation cost of changing the batteries are 3600 and 960, respectively. In addition, parts 1, 2, and 3 were assigned to AGVs 2, 2, and 1. The AGVs stopped for 5 times in the considered horizon. The main conclusion is the location of BCS can be the point (2,2) an optimal location for the above example. Notably, this solution has been obtained after 8 hours by GAMS; consequently, an efficient algorithm in terms of times is needed. For example, the meta-heuristic algorithms, such as genetic algorithm, simulated annealing, tabu search, ant colony algorithm, and particle swarm optimization, can be developed to solve the proposed model here.

Several other small-sized examples also are generated according to Table 2,and their results in terms of optimal cost (objective function) and location of the BCS are represented. In all of examples, it is assumed that *C.MS* and *C.TR* are equal to 100$ and 80$, respectively; moreover,=1 and *cht* is equal to 7. In addition, *i*j* represents the number of points on *X* and *Y* axes of coordinates (for example, 3*3 is a network including points (0,0),(0,1),(0,2),(0,3),(1,0),(1,1),(1,2),(1,3),(2,0),(2,1),(2,2),(2,3),(3,0),(3,1),(3,2), and (3,3)).

Table 2
The generated examples together optimal costs and BCS points

No. of example	Number of Part/AGV/machine/i*j	Machine sequence and processing time (part): machine(machine location point)(process time)	Optimal cost	Optimal BCS point
1	2/2/2/2*2	(1): 1(2,2)(2)-2(1,1)(1) (2): 2(1,1)(3)	2730	(1,2)
2	2/3/3/3*3	(1): 2(2,0)(2)-3(3,3)(3) (2): 1(2,3)(1)-2(2,0)(1)-3(3,3)(2)	3990	(2,2)
3	3/3/3/3*3	(1): 1(2,3)(2)-2(2,0)(3) (2): 2(2,0)(3)-3(3,3)(1) (3): 2(2,0)(4)	4600	(2,2)
4	3/3/4/3*3	(1): 2(2,0)(2)-3(3,3)(2) (2): 1(2,3)(3)-2(2,0)(2)-4(3,0)(3) (3): 2(2,0)(3)-4(3,0)(3)	6470	(3,1)
5	4/2/4/3*3	(1): 1(2,3)(3)-4(3,0)(2) (2): 1(2,3)(2)-4(3,0)(3) (3): 2(2,0)(1)-3(3,3)(4) (4): 3(3,3)(2)-4(3,0)(2)	8760	(1,2)
6	4/2/4/4*4	(1): 2(2,4)(2)-3(4,0)(2)-4(4,4)(1) (2): 3(4,0)(3)-4(4,4)(1) (3): 1(2,0)(1)-3(4,0)(4)-4(4,4)(1) (4): 1(2,0)(4)-2(2,4)(5)	8930	(2,3)
7	4/3/4/4*4	(1): 1(2,0)(3)-3(4,0)(3) (2): 3(4,0)(5) (3): 2(2,4)(2)-4(4,4)(3) (4): 1(2,0)(2)-2(2,4)(2)-4(4,4)(1)	8220	(3,2)

4.3. Sensitivity analysis

The effects of two important parameters, including number of AGVs and number of parts, in a manufacturing system on the objective function must be seen as sensitivity analysis. Fig. 3 show these effects in some above-generated examples. As observed, with the increase of the number of AGVs in Figs. 3.(*a*) and (*b*),a minimum point on the diagram appeared. Therefore, this minimum point together with economic analysis can help us to determine the optimal number of AGVs in order to minimize the completion time in the considered production environment. Further, the objective function has an ascending trend with the increase of number of parts according to Figs. 3. *(c)*and*(e)*. The result is obvious since more parts at warehouse need more time to be processed on machines.

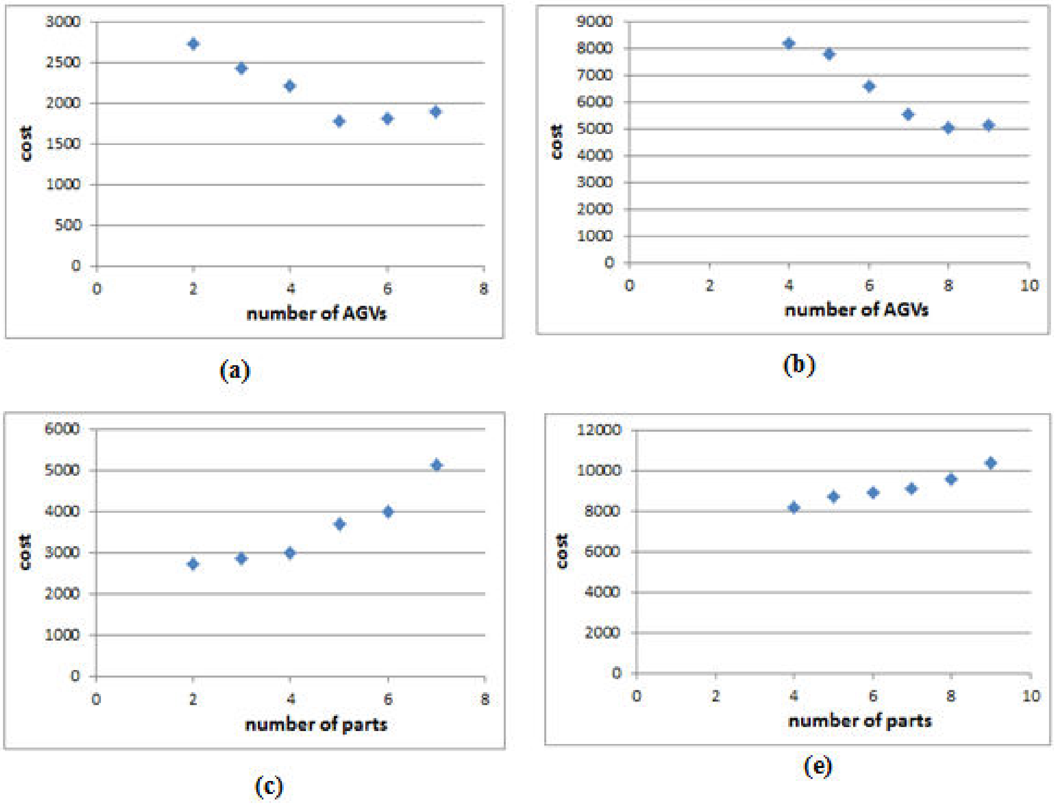

Fig. 3. The sensitivity analysis on number of AGVs and parts (a),(c) for example 1 and (b),(e)for example 7

The obtained results can help managers handle the robotic vehicles in a manufacturing environment and to obtain the best routes and scheduling for them so that the makespan can be minimized. In addition, this point is important that if the numbers of robotic material handling systems, such as AGVs, increase in a manufacturing environment to transfer the parts among different stations, it is possible that the makespan and costs do not decrease necessarily.

5. Conclusion

This paper developed an integrated model of scheduling of parts, routing of Automated Guided Vehicles (AGVs), and location of Battery Charging Storage (BCS) in a job shop environment. Since the proposed model was nonlinear, it could not achieve an optimal, global solution. As a result, the nonlinear model was transformed into a linear form to be efficiently solved in GAMS software. Afterwards, a numerical example was presented to illustrate the model and algorithm efficiency. It was observed that the optimal scheduling, routing and location of BSC were obtained by CPLEX in GAMS during 8 hours. Finally, a meta-heuristic algorithm was suggested to solve the proposed problem efficiently in terms of the time. To determine the optimal number of AGVs in a manufacturing system, our proposed model can be an open search.

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