APEM journal

Advances in Production Engineering & Management
Volume 15 | Number 1 | March 2020 | pp 69–80
https://doi.org/10.14743/apem2020.1.350

ISSN 1854-6250
Journal home: apem-journal.org
Original scientific paper

Assembly transport optimization for a reconfigurable flow shop based on a discrete event simulation

Yang, S.L.[a,b,c,d,*], **Xu, Z.G.**[a,b,c], **Li, G.Z.**[e], **Wang, J.Y.**[a,b,c]

[a]Key Laboratory of Networked Control Systems, Chinese Academy of Sciences, Shenyang, P.R. China
[b]Shenyang Institute of Automation, Chinese Academy of Sciences, Shenyang, P.R. China
[c]Institutes for Robotics and Intelligent Manufacturing, Chinese Academy of Sciences, Shenyang, P.R. China
[d]University of Chinese Academy of Sciences, Beijing, P.R. China
[e]School of Mechanical Engineering and Automation, Northeastern University, Shenyang, P.R. China

A B S T R A C T

Reconfigurable Manufacturing Systems (RMSs) are widely used to produce small batches of customized products in the current manufacturing environment. We comprehensively optimized the assembly transport strategy, production process, and production configuration of a reconfigurable flow shop (RFS). Firstly, three assembly transfer strategies, one-to-one, one-to-many, and many-to-many, are proposed for an RFS, given the specific process limitations. In addition, a production simulation model of the RFS is established by the Plant Simulation software to verify and compare those three strategies with realistic production constraints considered. Moreover, the production processes are optimized, and the optimal buffer configuration and vehicle configuration are optimized by the design of experiment (DOE) method. After the optimization processes, the throughput and facility utilization under each strategy increases significantly. Additionally, the optimal buffer size and vehicle quantity under each strategy are determined and compared. The one-to-one strategy can maximize the production output, but it requires the most production resources. In addition, the many-to-many strategy is more efficient than the one-to-many strategy. Our study provides a variety of assembly transport strategies for an RFS and offers an efficient optimization method for production performance and production configuration.

A R T I C L E I N F O

Keywords:
Reconfigurable manufacturing systems (RMS);
Discrete event simulation;
Assembly transport strategy;
Optimization;
Plant Simulation;
Reconfigurable flow shop;
Production configuration;
Production performance;
Simulation modelling

**Corresponding author:*
yangshengluo@sia.cn
(Yang, S.L.)

Article history:
Received 13 December 2019
Revised 16 March 2020
Accepted 18 March 2020

1. Introduction

The current manufacturing environment aims at getting an increasing variety of customized, high-quality products in flexible batches [1]. Reconfigurable Manufacturing Systems (RMSs) can rapidly change its structure, hardware, and software configuration to adapt to a dynamic market demand [2, 3]. With flexibility, the RMSs have been studied extensively [4-6].

For an RMSs, due to its frequent changes, the production performance and production configuration need to be optimized frequently and efficiently. Various methods have been proposed to optimize the RMSs. Amiri and Mohtashami optimized the buffer allocation using a genetic algorithm and line search method. They presented a multi-objective formulation and determined the optimal buffer size [7]. Many algorithms, such as the Simulated Annealing (SA) [8] and Genetic Algorithm (GA) [9, 10], are also used to optimize production performance. However, it is hard for algorithms to solve the problems that are closer to reality, and the convergence speed and efficiency of algorithms are usually slow for complex optimization problems [11].

Discrete event simulation (DES) is one of the most commonly used techniques for optimizing and analyzing manufacturing systems. It can be used to evaluate and optimize different alternatives of production configurations and operating strategies [12]. Because of its high flexibility, DES has been widely used in the design and operations of manufacturing systems [13-17]. Gyulai *et al*. evaluated different modular cell configurations using the DES [18]. Gironimo *et al*. optimized the scheduling problems of a high-speed train using the DES [19]. Leitão2012 *et al*. used the Delmia software and Petri net based service-oriented frameworks to design, analyze, simulate, and control manufacturing systems in a virtual environment [20]. Rifai *et al*. studied the scheduling problem of a flexible manufacturing system (FMS) and evaluated the part dispatching sequence and the routing options using the FlexSim [21]. Subulan and Cakmakci determined the major influential parameters that affect the performance criteria of a storage system, using the ARENA 3.0 program and MINITAB15 [22]. Renna and Ambrico developed three simulation models for the design, reconfiguration, and scheduling of a manufacturing system using the LINGO package [23].

In addition to those DES studies, the Plant Simulation software is widely used to optimize production performance and production configuration due to its powerful logistics simulation functionality. Andrade-Gutierrez *et al*. optimized a flexible die-casting plant using the Plant Simulation software. They evaluated several numerical models, identified the bottlenecks, and adjusted the production line components [24]. Ištoković *et al*. determined the size and entry order of the product batches, using the GA model implemented in the Plant Simulation software [25]. Yang *et al*. optimized the production process and main production configurations, including the equipment allocation, worker allocation, buffer allocation, and logistics vehicle allocation of an assembly shop [26]. Supsomboon and Varodhomwathana used the Plant Simulation software for production planning design for an automotive part production process to fulfill the desired capacity and customer needs with the minimum number of workers [27]. García-Montalvo *et al*. evaluated two different scenarios of the sand recovery in a pilot plant using the Plant Simulation software [28]. Malega *et al*. improved the production efficiency of a tapered roller bearing using the Plant Simulation [29]. Fedorko *et al*. identified critical points of failure within a specific delivery process for a Milk Run system with the help of Plant Simulation [30].

From the above literature review, we can know that production performance and production configuration have been studied extensively for the RMSs and other types of workshops using the DES. However, as one of the widely used RMSs, the reconfigurable flow shop (RFS) has not received much attention. Little literature has been published on it. Besides, for an RFS, due to its variability, an efficient and adaptable assembly transport strategy is also crucial. Nevertheless, to the best of our knowledge, no research efforts have been studied the assembly transport strategy for an RFS.

This study comprehensively optimized the assembly transport strategy, production performance, and production configuration of an RFS using the DES. Considering the specific characteristics of an RFS, we proposed three assembly transport strategies, which were one-to-one, one-to-many, and many-to-many. For each strategy, we illustrated the scheduling strategy, optimized the production performance, and determined the optimal vehicle configuration. The results show that the one-to-one strategy produced the most output, but its vehicle utilization was the lowest. In addition, the many-to-many strategy produces a relatively large output with a moderate number of vehicles. Our study provides and compares a variety of assembly transport strategies for the RFS and offers an efficient optimization method for production performance and production configuration.

The paper is organized as follows. Section 2 presents the workshop layout and process flow of an RFS. Section 3 illustrates the three proposed assembly transport strategies. Section 4 establishes the simulation model of the RFS, optimizes the production processes and vehicle configuration. Sections 5 compares the three assembly transport strategies. Finally, Section 6 summarizes conclusions and provides suggestions for future work.

2. Workshop layout and process flow

An RFS is used as an optimization case study. The workshop layout in Fig. 1 shows that this workshop consists of an automated storage and retrieval system (ASRS), denoted as AS00, and 13 assembly or detection workstations, denoted as AS01-AS13. All workstations are moveable so that the assembly line can be reconstructed in future production adjustments. Besides, the Automated Guided Vehicle (AGV) is used to transport products between workstations. Considering the workshop layout and process flow, we divide the workshop into two workshops, i.e., front workshop (from AS00 to AS10) and rear workshop (from AS11 to AS13). Two types of AGV vehicles, AGV1, and AGV2, are used for the two workshops, respectively. And the speed of the AGV vehicle is 0.34 m/s.

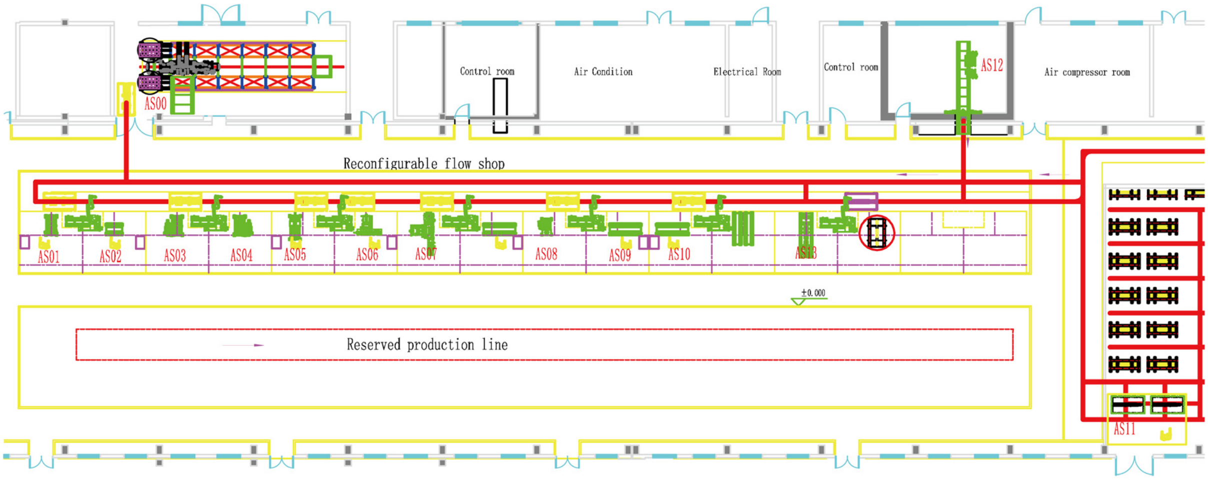

Fig. 1 Workshop layout of the reconfigurable flow shop

The workshop assembles a certain type of product. This product is mainly assembled by a main part and three sections (S1, S2, and S3). The main part and the three sections are first matched in the ASRS, i.e., AS00, and then transported by the same vehicle to workstations to ensure the corresponding relationship between the four parts. The three sections (S1, S2, and S3) are assembled to the main part in workstation AS01, AS02, and AS05, respectively. After AS05, all these three sections are assembled into the main part. Thus the product can be transported by other vehicles. Then some other assembly and detection operations are carried out in the following workstations (AS06-AS13). The operation time of each workstation is shown in Table 1. Moreover, some realistic constraints are considered. In the workstation AS00, the vehicle waits for 426 s to load all the three sections. In the workstation AS12, the vehicle maintains occupied before the operation finished.

Table 1 The operation time of each workstation

Workstation	AS00	AS01	AS02	AS03	AS04	AS05	AS06	AS07	AS08	AS09	AS10	AS11	AS12	AS13
Time/s	426	420	365	305	307	418	363	357	309	305	311	366	421	358

3. Proposed assembly transport strategies

As mentioned above, this workshop is divided into two workshops. In the front workshop, the three sections of the product are transported by the same AGV before those sections are assembled into the main part. According to the corresponding relationship between vehicles and workstations, three assembly transport strategies, one-to-one, one-to-many, and many-to-many, are proposed for the front workshop.

3.1 One-to-one

To ensure the corresponding relationship between the main part and three sections, we restrict it in the first assembly transport strategy that a vehicle can only transport the product away, which is processing on the current workstation. Therefore, one vehicle corresponds to one workstation, denoted as one-to-one. Every vehicle, AGV1, transports the main part and three sections of a product from the ASRS and transports them to the following workstations until AS10. After AS10, the product is transport by AGV2 to the rear workshop, and the AGV1 goes back to ASRS to transport parts of another product.

Two sensors for loading and unloading are set on the AGV route beside each workstation. When an AGV goes through the sensor, the operation for loading or unloading is triggered. Every running AGV has its destination information, which is Target Track and Target Workstation. If the current workstation is the target one, and the AGV is occupied, the product will be unloaded from the AGV to the Target Workstation. Then the AGV waits until a new transportation request is assigned to it and moves to the new destination. A new transportation request will be produced by a workstation when its operation is finished, and its next workstation is idle. For the one-to-one strategy, a vehicle can only fulfill the transportation request of the current workstation. The pseudocode of Unload is given in Fig. 2.

Procedure 1 Unload

```
if the current workstation is the Target Workstation and the vehicle is occupied then
    Stop the vehicle
    Unload the product from the vehicle to the Target Workstation
    Delete the destination of the vehicle
    Record the current time, t2
    Calculate the transportation time t, t = t2 − t1
    Waituntil a new request is assigned to the vehicle
    Get the Target Workstation and Target Track of the new request for the vehicle
    Move the vehicle to the destination using the shortest path principle
    Record the current time, t1
else
    Continue to move
end if
```

Fig. 2 The procedure of Unload

If the current workstation is the Target Workstation and the AGV is empty, an operation for loading is performed. The product is loaded from the Target Workstation to the AGV. Every product has its process information, including the Target Track and Target Workstation for all processes. The AGV will get the Target Track and Target Workstation for the next operation. Then, the AGV moves to the Target Track using the shortest path principle, which automatically plan the shortest route from the current location to the destination. The procedure is shown in Fig. 3.

Procedure 2 Load

```
if the current workstation is the Target Workstation and the vehicle is empty then
    Stop the vehicle
    Load the product from the Target Workstation to the vehicle
    Get the Target Workstation and Target Track from the product
    Move the vehicle to the Target Track by the shortest path principle
else
    Continue to move
end if
```

Fig. 3 The procedure for loading

3.2 One-to-many

The first transport strategy is simple, but it requires too many AGV vehicles. Hence we adopt the strategy to that one vehicle corresponds to many workstations, denoted as one-to-many. This means that a vehicle can fulfill the transport request of many workstations within a certain area. Under this strategy, six skip cars are introduced for AS00-AS05. A skip car carries the three sections (A1-A3) and the main part of a product at the same time, and the skip car is transported by an AGV to workstations. Therefore, the AGV can fulfill the transport request of other workstations without breaking the corresponding relationship between the four parts of a product. If one AGV is responsible for 5, 4, 3, and 2 workstations, the number of vehicles required for the 11 workstations in the front workshop is 2, 3, 4, and 5, respectively. The scope of workstations for each AGV under different number of AGVs is shown in Fig. 4. One vehicle is responsible for all the transportation tasks of all workstations within its scope. For example, if the number of vehicles is 3, the first AGV1 is responsible for workstations AS00-AS03. The second AGV1 is responsible for workstations AS04-AS06, and the last AGV1 is responsible for workstations AS07-AS10.

The procedure for loading and unloading is similar to those in the one-to-one strategy. However, for the one-to-many strategy, a vehicle can fulfill the transportation request of all the workstations within its scope.

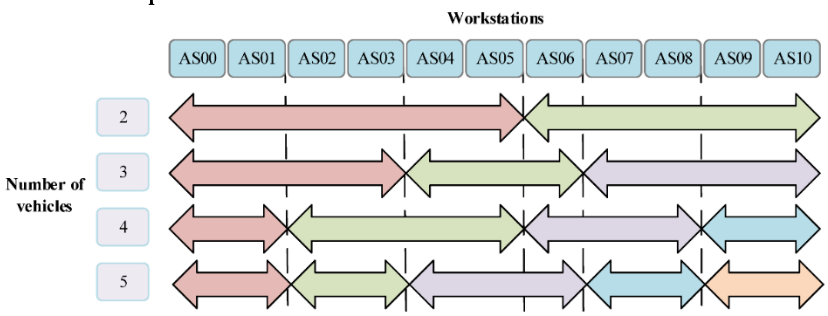

Fig. 4 Scopes of workstations for each AGV under different number of AGVs

3.3 Many-to-many

The last strategy is that many vehicles fulfill the transport request of many workstations within an area, and is denoted as many-to-many. Under this strategy, the front workshop is divided into two areas. The first area contains the workstations from AS00 to AS05, and the second one contains the workstations from AS06 to AS10. The first and second area is equipped with AGV1 and AGV3, respectively. And products in the rear workshop is still transported by the AGV2. For the first area, similar to the one-to-many strategy, six skip cars are used to carry the four parts of a product, and the skip cars are transported by an AGV. For the two areas of the front factory, the many-to-many strategy is used. Under this strategy, a certain area, which contains many workstations, is equipped with many AGV vehicles. When a vehicle finished its current transportation, it becomes available and can be used by all other workstations within this area.

When a workstation *a* finishes its operation, and its next workstation is idle, the workstation *a* generates a transport request and writes the request to the Distribution Table. Then, a method is accessed every 5 s to allocate the requests of the Distribution Table to a vehicle selected from the Available Vehicles. The Available Vehicles is the vehicle set of available vehicles within an area. If both the number of requests and the Available Vehicles are greater than 0, the first transport request is removed from the Distribution Table and assigned to an available vehicle. The vehicle is selected by the shortest distance principle, which first selects the vehicle closest to the workstation. Then the vehicle moves to its destination for loading or unloading. The pseudocode for allocating is shown in Fig. 5.

Procedure 3 Allocate requests to vehicles

```
m=sizeof(Distribution Table)
n=sizeof(Available Vehicles)
while m >0 and n >0 do
    Remove the first transport request from the Distribution Table
    Remove a vehicle from the Available Vehicles by the shortest distance principle
    Get the Target Workstation and Target Track of the request
    Move the vehicle to the Target Track by the shortest path principle
    Record the current time t1
    Update the Distribution Table and Available Vehicles
    m=sizeof(Distribution Table)
    n=sizeof(Available Vehicles)
end while
```

Fig. 5 The procedure for allocating

A sensor for loading and unloading is set beside every workstation. When a vehicle passed by the sensor, the sensor is triggered. If the current workstation is the Target Workstation, the vehicle stops. Furthermore, if the vehicle is occupied, the vehicle unloads its product to the Target Workstation. Then, the vehicle becomes available and waits for a new transport request. If an empty vehicle reaches to its Target Workstation, the vehicle first loads the product from the Target Workstation and then moves to its destination by the shortest path principle. The pseudocode for loading and unloading is shown in Fig. 6.

In summary, three assembly transport strategies, which are one-to-one, one-to-many, and many-to-many, are proposed for the front workshop. Moreover, for the rear workshop, only the many-to-many strategy is used.

Procedure 4 Load or unload

if the current workstation is the Target Workstation **then**
    Stop the vehicle
    if the vehicle is occupied **then**
        Unload the product from the vehicle to the target workstation
        Delete the destination of the vehicle
        Record the current time, t_2
        Calculate the transportation time t, $t = t_2 - t_1$
        Append the vehicle to the Available Vehicles
        Waituntil a new request is assigned to the vehicle
    else
        Load the product from the Target Workstation to the vehicle
        Get the Target Workstation and Target Track of the product
        Move the vehicle to the Target Track by the shortest path principle
    end if
end if

Fig. 6 The procedure for loading and unloading

4. Modelling and optimization of the proposed transport strategies

This section establishes a production simulation model for the RFS. The three assembly transport strategies are implemented and verified in the model. Besides, production process and vehicle configuration of each strategy are optimized.

4.1 Establishment of the simulation model

The Plant Simulation software is used to establish the simulation model of the RFS. The simulation model mainly contains the ASRS, workstations, vehicles, scheduling strategies, experiment module, and statistical analysis. For more modelling information about the workshop logistics processes, please refer to [26]. Finally, the simulation model of the RFS is shown in Fig. 7.

The production is operated 7 hours a day and lasts for 10 days. The throughput, facility utilization, and vehicle quantity of those three transport strategies are evaluated and optimized.

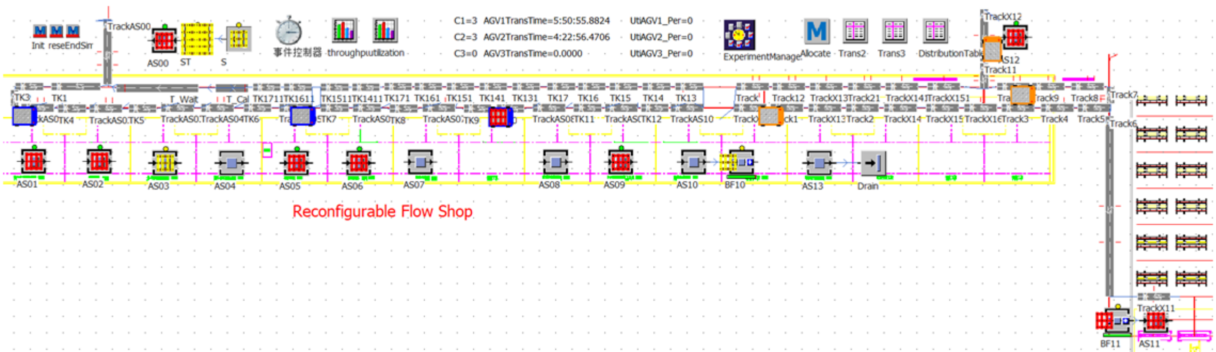

Fig. 7 Simulation model of the reconfigurable flow shop

4.2 Optimization of the one-to-one strategy

Recall that the front workshop contains 10 workshops and an ASRS, and the rear workshop contains four workstations. Firstly, sufficient vehicles (11 AGV1 and 5 AGV2) are provided for the two workshops to evaluate production performance. After 10 days of production, the throughput is 390, and the facility utilization is shown in Fig. 8A. Fig. 8A shows that the overall facility utilization is relatively low, and many workstations are blocked. The blockage appeared in AS10 and its front workstations. This is because the finished product in AS10 is to be transported away by the vehicles of the rear workshop. The rear workshop uses the many-to-many transport strategy, which may wait for a long time before a vehicle is available. Moreover, there is a long distance between the AS10 and the AS11. Thus, the finished product in the AS10 may wait for a long time before transported away, which results in a blockage in AS10. When AS10 is blocked, the workstations in front of it will also be blocked. To lessen the blockage, we set buffers after AS10 and before AS11, namely BF10 and BF11, respectively.

Buffer sizes are optimized by the design of experiment (DOE) method. The buffer size of BF10 and BF11 are increased from 0 to 3 and from 0 to 5, respectively. A total of 24 experiments are carried out, and the output is shown in Fig. 9A. Fig. 9A shows that when buffers are set, the throughput increases significantly. The maximum output is 566, which is 45.1 % higher than the output before the buffer optimization.

Among the experiments reaching the maximum output, the 10th experiment uses the least buffer size. In this experiment, the buffer size for BF10 and BF11 are 1 and 3, and this buffer configuration is chosen as the best one. The facility utilization under this buffer configuration is shown in Fig. 8B. It shows that after the buffer optimization, facility utilization of all workstations increases obviously, and blockages reduce significantly. However, workstations AS04 and AS11 still have some blockages. This is because the next workstation of AS04 and AS11 have more operation time, and no extra space exists besides the two workstations.

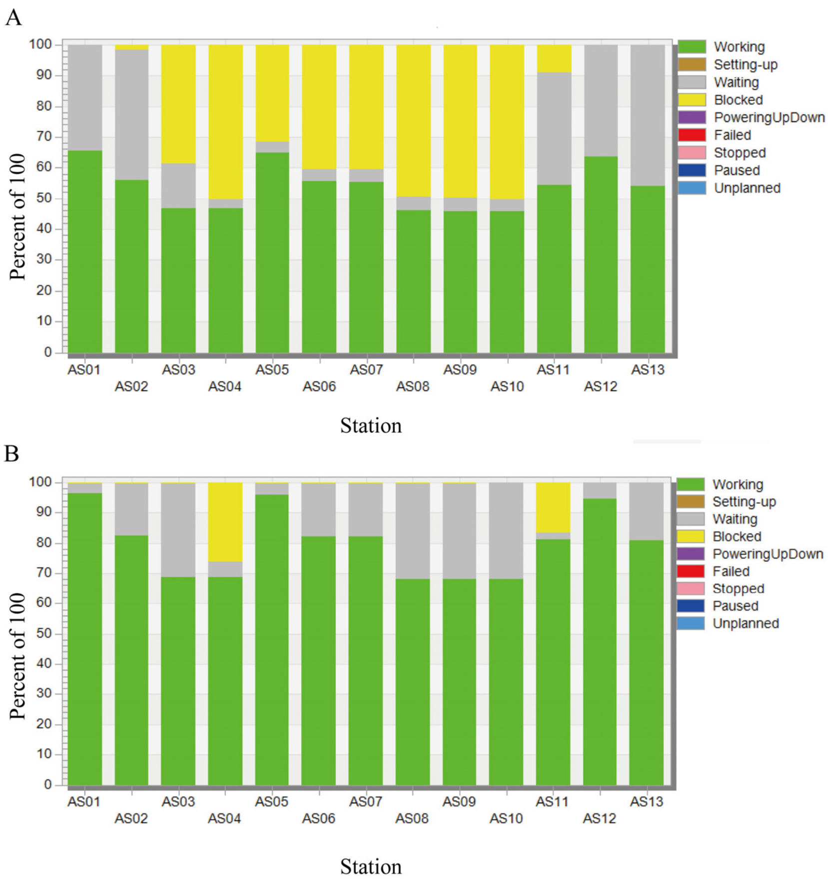

Fig. 8 Comparison of the facility utilization before and after the buffer optimization: (A) Before the buffer optimization, (B) After the buffer optimization

Under the optimal buffer configuration, vehicle quantity is optimized by the DOE method. The number of AGV1 and AGV2 are increased from 5 to 11 and from 1 to 5, respectively. Thus, a total of 35 experiments are carried out, and the output of those experiments are shown in Fig. 9B. Fig. 9B shows that when the vehicle configuration changes, the output varies greatly, from 304 to 566. In the 23rd experiment, the maximum output is reached for the first time. In this experiment, the number of AGV1 and AGV2 are 9 and 3, respectively.

Further analysis is carried out to find the relationship between the number of vehicles and the maximum output and vehicle utilization. The maximum output for a certain configuration of a type of AGV is the maximum output obtained when other types of AGV are equipped with the maximum number. Fig. 9C shows that with the increases in the number of AGV1, the maximum output increases. When the number of AGV1 increases to 9, the maximum output is reached for the first time. Before the maximum output, with the increase of AGV1, the output increases accordingly, and there are no significant changes for vehicle utilization. After the maximum output is reached, with the increase of AGV1, the output does not increase, but vehicle utilization decreases significantly. Fig. 9D also shows a similar trend for the AGV2. The maximum output is reached for the first time when the AGV2 increased to 3. Besides, the utilization of the AGV2 is obviously higher than that of AGV1. Finally, considering the output and vehicle utilization, we set the number of AGV1 and AGV2 to 9 and 3, respectively.

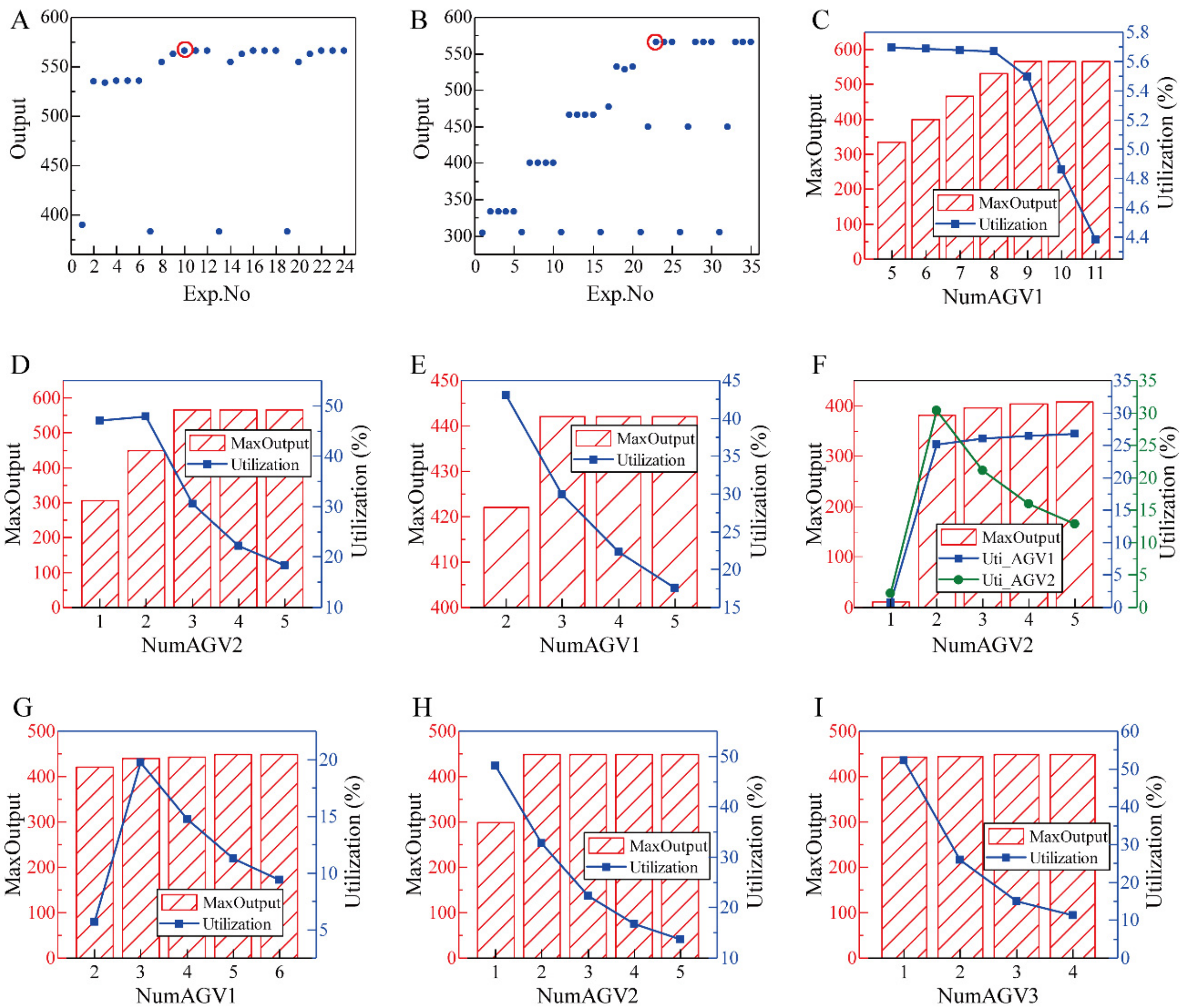

Fig. 9 The output and vehicle utilization of the optimization experiments for all three strategies: (A) The output of experiments in buffer optimization, (B) The output of experiments in vehicle configuration optimization for the one-to-one, (C-D) The output and vehicle utilization for the AGV1 and AGV2 under the one-to-one strategy, (E-F) The output and vehicle utilization for the AGV1 and AGV2 under the one-to-many strategy, (G-I) The output and vehicle utilization for the AGV1 and AGV2 under the many-to-many strategy

4.3 Optimization of the one-to-many strategy

As mentioned above, six skip cars are introduced in the front workshop. Firstly, to determine the best number of AGV1, the front workshop is considered separately, i.e., the production is finished after AS10. The number of AGV1 increased from 2 to 5. The maximum output and the vehicle utilization of all the four configurations are shown in Fig. 9E. Fig. 9E shows that when the number of AGV1 increased to 3, the maximum output (422) is reached for the first time. And vehicle utilization is relatively high. Therefore, the number of AGV1 is set to 3.

Under the optimal number of the AGV1 and sufficient number of AGV2 (AGV2=5), we optimized the buffer size of BF10 and BF11 using the same procedure for buffer optimization illustrated in the one-to-one strategy. After the optimization process, the optimal buffer size of BF10 and BF11 are set to 1 and 0, respectively.

Finally, the number of AGV2 is optimized under the optimal configuration of AGV1 and buffers. When the quantity of AGV2 increases from 1 to 5, the maximum output and the vehicle utilization of AGV1 and AGV2 are shown in Fig. 9F. As shown in Fig. 9F, the output is very low when there is only one AGV2. And when the number of AGV2 increases from 1 to 2, the output surges. However, when the quality increases from 2 to 5, the output increases slowly and reaches the maximum output (408) at 5.

The vehicle utilization for both AGV1 and AGV2 is very low when the number of AGV2 is set to 1 because of the low output. When the number of AGV2 increases from 2 to 5, the vehicle utilization of AGV1 increases slightly; however, the utilization of AGV2 decreased significantly. This is because the number of AGV1 is fixed at 3; its utilization increases slowly with a small increase in output. For AGV2, with the increase of vehicles, the output does not increase considerably; thus, the vehicle utilization decreases significantly. When the number of AGV2 is 3, the output is 396, which is close to the maximum output 408. Moreover, the utilization rate of AGV2 is relatively high, which is 21.1 %. Therefore, the number of AGV2 is set to 3.

4.4 Optimization of the many-to-many strategy

Six skip cars are used for the workstations from AS00 to AS05. Moreover, for the workstations from AS06 to AS10, AGV3 is introduced for transportation. We carry out a similar optimization procedure, as illustrated in the buffer size optimization for the one-to-one strategy. After the optimization, the optimal buffer size for BF10 and BF11 are 1 and 2, respectively.

The quantity of the three types of AGV is optimized by the DOE method. And the specific number of those AGVs is as follows: AGV1: 2-6, AGV2: 1-5, and AGV3: 1-4. Thus, a total of 100 experiments are performed. As shown in Fig. 9G, with the number of AGV1 increases, the output shows a slight increase. When the number of AGV1 is 3, the output is close to the maximum output, and vehicle utilization is the highest, which is 18.4 %. Fig. 9H shows that the maximum output can be achieved when the number of AGV2 is 2, and the vehicle utilization decreases markedly with the increase of vehicle quantity. Fig. 9I shows that for the AGV3, one vehicle can meet the production requirement. Finally, the number of three types AGV is set to 3, 2, and 1.

5. Comparison of the results and discussion

Three assembly transfer strategies are proposed for an RFS. For each strategy, the optimal vehicle configuration, buffer configuration, and vehicle utilization are shown in Table 2. As shown in Table 2, the output of the one-to-one strategy is significantly larger than the other two strategies. However, the vehicle utilization of AGV1 in the one-to-one is very low, which is 5.5 %, and the buffer size is large. This indicates that the one-to-one strategy can maximize the production output, but it requires more investment costs. Additionally, the one-to-many strategy generates the least output and requires the least buffer size. Moreover, the total number of AGVs used in the many-to-many strategy is equal to those of the one-to-many, but the many-to-many strategy produces 12.4 % more output than those of the one-to-many strategy. And the average vehicle utilization in the many-to-many strategy is also higher. It shows that the many-to-many strategy is more efficient than the one-to-many strategy.

Table 2 The optimal production configuration and its maximum output of the three strategies

	Max output	Number of vehicles			Vehicle utilization			Buffer size	
		AGV1	AGV2	AGV3	AGV1	AGV2	AGV3	BF10	BF11
one-to-one	566	9	3	-	5.50 %	30.50 %	-	1	3
one-to-many	396	3	3	-	26.30 %	21.10 %	-	1	0
many-to-many	445	3	2	1	18.40 %	32.20 %	53.30 %	1	2

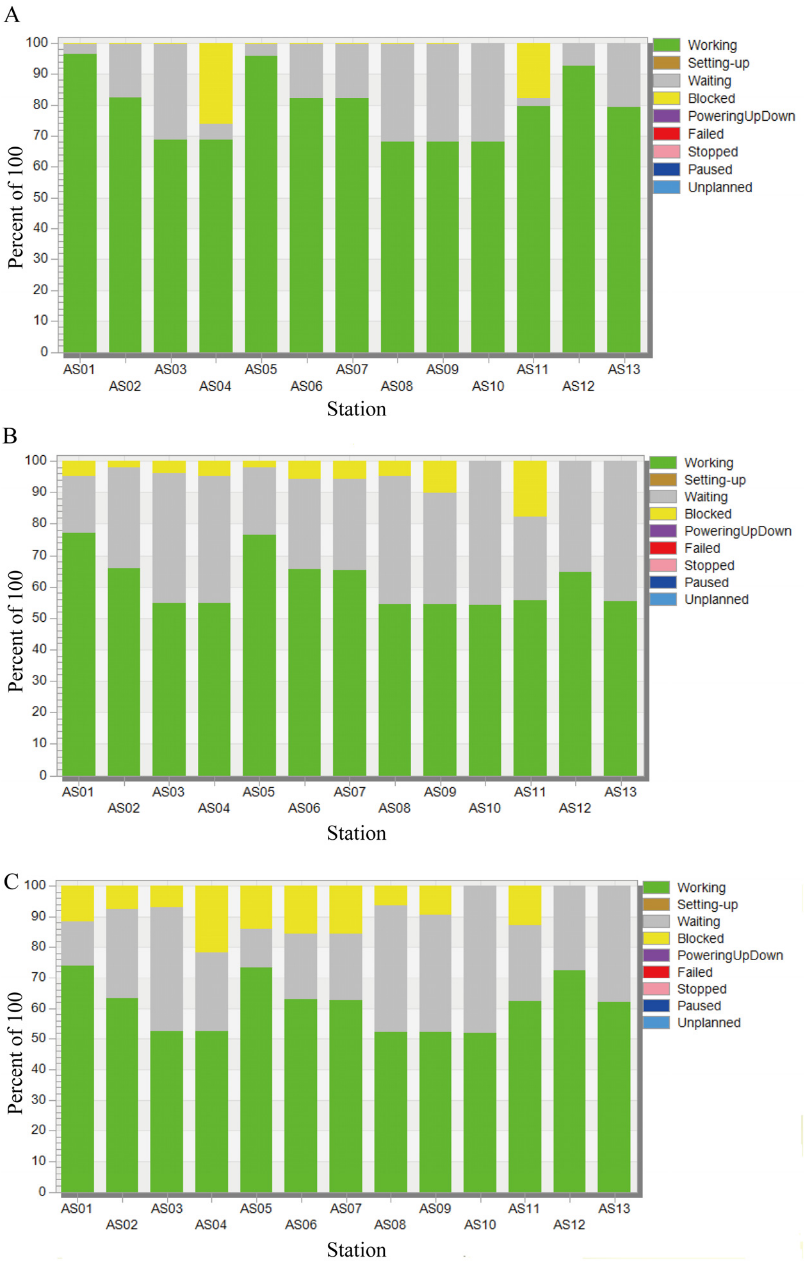

Fig. 10 The facility utilization of the three strategies under their optimal production configuration: (A) one-to-one, (B) one-to-many, (C) many-to-many

The facility utilization of those three strategies under their optimal vehicle configuration and buffer configuration is shown in Fig. 10. As shown in Fig. 10, the facility utilization in the one-to-one strategy is the highest, which is basically over 70 %, and the highest is 96.2 %. And there is no significant difference between the other two strategies. Considering the output, facility utilization, and production configuration provided, decision-makers can select a transfer strategy according to the market demand and investment cost.

6. Conclusion

We proposed three assembly transport strategies for a reconfigurable flow shop (RFS). We compared the three strategies using the DES, optimized the production performance, and determined the optimal buffer configuration and vehicle configuration of each strategy. Buffers are set at critical workstations to improve production performance. After the buffer optimization, the output and facility utilization increased significantly. The optimal vehicle quantity for each strategy is determined by the DOE method. Moreover, production performance and production configuration of those three strategies are compared. The results show that the one-to-one strategy obtains the maximum output and facility utilization, but it requires the largest number of vehicles. The many-to-many strategy generates relatively large output with a moderate number of vehicles. This study provides three assembly transport strategies for an RFS and shows that we can verify and optimize various scenarios using the DES. Our work has important implications for the reconfigurable workshop, which requires considerable simulation, verification, and optimization. However, the assembly transport strategy was designed for a flow shop. If the strategy was to be used for other types of workshops, vehicle scheduling must be adjusted accordingly.

Future research could be conducted to apply this assembly transport strategy to other types of reconfigurable workshops. Moreover, more production configurations, such as worker configuration and machine configuration, should be considered.

Acknowledgement

This work was supported by the Science and Technology Planning Projects of Shenyang under Project No. Z17-7-002.

References

[1] Bortolini, M., Galizia, F.G., Mora, C. (2018). Reconfigurable manufacturing systems: Literature review and research trend, *Journal of Manufacturing Systems*, Vol. 49, 93-106, doi: 10.1016/j.jmsy.2018.09.005.

[2] Esmaeilian, B., Behdad, S., Wang, B. (2016). The evolution and future of manufacturing: A review, *Journal of Manufacturing Systems*, Vol. 39, 79-100, doi: 10.1016/j.jmsy.2016.03.001.

[3] Koren, Y., Heisel, U., Jovane, F., Moriwaki, T., Pritschow, G., Ulsoy, G., Van Brussel, H. (1999). Reconfigurable manufacturing systems, *CIRP Annals*, Vol. 48, No. 2, 527-540, doi: 10.1016/S0007-8506(07)63232-6.

[4] Dou, J.-P., Dai, X.-Z., Meng, Z.-D. (2007). Configuration selection of reconfigurable manufacturing system based on hybrid analytical hierarchy process, *Computer Integrated Manufacturing Systems,* Vol. 13, No. 7, 1360-1366.

[5] Gupta, A., Jain, P.K., Kumar, D. (2015). Configuration selection of reconfigurable manufacturing system based on performance, *International Journal of Industrial and Systems Engineering*, Vol. 20, No. 2, 209-230, doi: 10.1504/IJISE.2015.069543.

[6] Rehman, A.-U., Subash Babu, A. (2009). Evaluation of reconfigured manufacturing systems: An AHP framework, *International Journal of Productivity and Quality Management*, Vol. 4, No. 2, 228-246, doi: 10.1504/IJPQM.2009.023189.

[7] Amiri, M., Mohtashami, A. (2012). Buffer allocation in unreliable production lines based on design of experiments, simulation, and genetic algorithm, *The International Journal of Advanced Manufacturing Technology*, Vol. 62, No. 1-4, 371-383, doi: 10.1007/s00170-011-3802-8.

[8] Huang, L., Gao, Y., Qian, F., Tang, S., Wang, D. (2011). Configuration selection for reconfigurable manufacturing systems by means of characteristic state space, *Chinese Journal of Mechanical Engineering*, Vol. 24, No. 1, 23-32, doi: 10.3901/CJME.2011.01.023.

[9] Youssef, A.M.A., ElMaraghy, H.A. (2008). Availability consideration in the optimal selection of multiple-aspect RMS configurations, *International Journal of Production Research*, Vol. 46, No. 21, 5849-5882, doi: 10.1080/00207540701261626.

[10] Youssef, A.M.A., ElMaraghy, H.A. (2007). Optimal configuration selection for reconfigurable manufacturing systems, *International Journal of Flexible Manufacturing Systems*, Vol. 19, No. 2, 67-106, doi: 10.1007/s10696-007-9020-x.

[11] Zhang, Z., Wang, X., Wang, X., Cui, F., Cheng, H. (2019). A simulation-based approach for plant layout design and production planning, *Journal of Ambient Intelligence and Humanized Computing*, Vol. 10, No. 3, 1217-1230, doi: 10.1007/s12652-018-0687-5.

[12] Negahban, A., Smith, J.S. (2014). Simulation for manufacturing system design and operation: Literature review and analysis, *Journal of Manufacturing Systems*, Vol. 33, No. 2, 241-261, doi: 10.1016/j.jmsy.2013.12.007.

[13] Azadeh, A., Nokhandan, B.P., Asadzadeh, S.M., Fathi, E. (2011). Optimal allocation of operators in a cellular manufacturing system by an integrated computer simulation-genetic algorithm approach, *International Journal of Operational Research*, Vol. 10, No. 3, 333-360, doi: 10.1504/IJOR.2011.038905.

[14] Huang, C.-J., Chang, K.-H., Lin, J.T. (2012). Optimal vehicle allocation for an automated materials handling system using simulation optimisation, *International Journal of Production Research*, Vol. 50, No. 20, 5734-5746, doi: 10.1080/00207543.2011.622311.

[15] Michalos, G., Makris, S., Mourtzis, D. (2012). An intelligent search algorithm-based method to derive assembly line design alternatives, *International Journal of Computer Integrated Manufacturing*, Vol. 25, No. 3, 211-229, doi: 10.1080/0951192X.2011.627949.

[16] Staley, D.R., Kim, D.S. (2012). Experimental results for the allocation of buffers in closed serial production lines, *International Journal of Production Economics*, Vol. 137, No. 2, 284-291, doi: 10.1016/j.ijpe.2012.02.011.

[17] Um, I., Cheon, H., Lee, H. (2009). The simulation design and analysis of a flexible manufacturing system with automated guided vehicle system, *Journal of Manufacturing Systems*, Vol. 28, No. 4, 115-122, doi: 10.1016/j.jmsy.2010.06.001.

[18] Gyulai, D., Pfeiffer, A., Kádár, B., Monostori, L. (2016). Simulation-based production planning and execution control for reconfigurable assembly cells, *Procedia CIRP*, Vol. 57, 445-450, doi: 10.1016/j.procir.2016.11.077.

[19] Di Gironimo, G., Lanzotti, A., Peluso, F., Renno, F. (2015). Virtual production planning of a high-speed train using a discrete event simulation based approach, *International Journal on Interactive Design and Manufacturing*, Vol. 9, No. 1, 65-75, doi: 10.1007/s12008-013-0193-0.

[20] Leitão, P., Mendes, J.M., Bepperling, A., Cachapa, D., Colombo, A.W., Restivo, F. (2012). Integration of virtual and real environments for engineering service-oriented manufacturing systems, *Journal of Intelligent Manufacturing*, Vol. 23, 2551-2563, doi: 10.1007/s10845-011-0591-8.

[21] Rifai, A.P., Dawal, S.Z.M., Zuhdi, A., Aoyama, H., Case, K. (2016). Reentrant FMS scheduling in loop layout with consideration of multi loading-unloading stations and shortcuts, *The International Journal of Advanced Manufacturing Technology*, Vol. 82, No. 9-12, 1527-1545, doi: 10.1007/s00170-015-7395-5.

[22] Subulan, K., Cakmakci, M. (2012). A feasibility study using simulation-based optimization and Taguchi experimental design method for material handling – Transfer system in the automobile industry, *The International Journal of Advanced Manufacturing Technology*, Vol. 59, No. 5-8, 433-443, doi: 10.1007/s00170-011-3514-0.

[23] Renna, P., Ambrico, M. (2015). Design and reconfiguration models for dynamic cellular manufacturing to handle market changes, *International Journal of Computer Integrated Manufacturing*, Vol. 28, No. 2, 170-186, doi: 10.1080/0951192X.2013.874590.

[24] Andrade-Gutierrez, E.S., Carranza-Bernal, S.Y., Hernandez-Sandoval, J., Gonzalez-Villarreal, A.J., Berber-Solano, T.P. (2018). Optimization in a flexible die-casting engine-head plant via discrete event simulation, *The International Journal of Advanced Manufacturing Technology*, Vol. 95, No. 9-12, 4459-4468, doi: 10.1007/s00170-017-1562-9.

[25] Ištoković, D., Perinić, M., Dobovišek, S., Bazina, T. (2019). Simulation framework for determining the order and size of the product batches in the flow shop: A case study, *Advances in Production Engineering & Management*, Vol. 14, No. 2, 166-176, doi: 10.14743/apem2019.2.319.

[26] Yang, S.L., Xu, Z.G., Wang, J.Y. (2019). Modelling and production configuration optimization for an assembly shop, *International Journal of Simulation Modelling*, Vol. 18, No. 2, 366-377, doi: 10.2507/IJSIMM18(2)CO10.

[27] Supsomboon, S., Varodhomwathana, T. (2017). Robot and plant simulation for automotive part production process design: A case study, *International Journal of Simulation Modelling*, Vol. 16, No. 4, 617-629, doi: 10.2507/IJSIMM16(4)5.397.

[28] García-Montalvo, O., Hernández-Sandoval, J., Haro-Rodríguez, S., Berber-Solano, T.P., Bello-Gómez, M.A., Salas-Zamarripa, A., Sáenz-Valdez, A.A., Talamantes-Silva, J. (2019). Discrete-event modeling for the design of a sand recovery flexible pilot plant in the casting process, *The International Journal of Advanced Manufacturing Technology*, Vol. 103, No. 9-12, 4703-4711, doi: 10.1007/s00170-019-03957-y.

[29] Malega, P., Kadarova, J., Kobulnicky, J. (2017). Improvement of production efficiency of tapered roller bearing by using plant simulation, *International Journal of Simulation Modelling*, Vol. 16, No. 4, 682-693, doi: 10.2507/IJSIMM16(4)10.405.

[30] Fedorko, G., Molnár, V., Honus, S., Neradilová, H., Kampf, R. (2018). The application of simulation model of a milk run to identify the occurrence of failures, *International Journal of Simulation Modelling*, Vol. 17, No. 3, 444-457, doi: 10.2507/IJSIMM17(3)440.