TOWARDS JOB-SHOP SCHEDULING WITH THE USE OF VIRTUAL MANUFACTURING CELLS

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Abstract The article presents the possibility to modify finding solutions when job-shop scheduling is conducted based on the idea of virtual cellular manufacturing. It is demonstrated that creation of virtual manufacturing cells for defined production orders and exploiting them in the process of job-shop scheduling allows to reduce makespan. In a virtual manufacturing cell, machines are dedicated to produce for selected production orders as in a regular manufacturing cell, but machines are not physically allocated in designated area. Virtual cell configurations are therefore temporary, and assignments are made to optimize the scheduling objective under changing demand conditions. In this research, an example of job-shop scheduling problem with embedded virtual cellular manufacturing is presented. The conditions of application of virtual manufacturing cells in terms of production flow modification are described.

Paper type: Research Paper

Published online: 30 October 2014
Vol. 4, No. 4, pp. 331-339

ISSN 2083-4942 (Print)
ISSN 2083-4950 (Online)

Keywords: *virtual manufacturing cell, job-shop scheduling*

1. INTRODUCTION

Today's constantly growing competitiveness enforces manufacturing firms to improve their manufacturing abilities. Adaptation to changing business environment is the only way to survive on the unpredictable market. Shorter product life cycle, increasing product mix and decreasing production volume result in the volatile market conditions. Kesen, Toksari, Güngör & Güner, (2009) state that $250 billion is annually spent in USA for planning and re-planning because of these changes and this huge cost can be reduced by 10–30% via effective planning. Thus productive and innovative approaches have taken more researchers' attention ever than before.

Several researchers have suggested new configurations of manufacturing systems (e.g., virtual cells, holonic cells, dynamic cells, etc.) to overcome the disadvantages of traditional machine arrangement configured in product layouts, GT-based cellular layout or process layouts. One of these is virtual manufacturing cells (VMCs) which was first proposed by the National Bureau of Standards (Baykasoglu, 2003).

Virtual manufacturing cell is a hybrid form of organizational structure which partially adopts some features of cellular manufacturing in terms of better performance of machines inside the cell as well as process manufacturing with functional layout interms of its flexibility (Habel & Wojakowski, 2010). In a virtual manufacturing cell, machines are dedicated to a part or part family as in a regular cell, but machines are not physically relocated close to each other. Virtual manufacturing cells are predefined by a production control mechanism (Balakrishnan & Cheng, 2007).

In the majority of the literature cases devoted to developing virtual cellular manufacturing, the description concerns either to the design of production systems with the use of virtual cells (Fung, Liang, Jiang & Wong, 2008; Ko & Egbelu, 2003; Slomp, Chowdary & Suresh, 2005) or to performance comparison of virtual cells with other forms of production organizations (Drolet, Marcoux & Abdulnour G, 2008; Nomden & Zee van der, 2008; Rezazadeh, Mahini & Zarei, 2011). These confirms the literature review carried out by Nomden, Slomp & Suresh, 2006, in which the domination of previous approaches to solve the issues of designing the virtual cells was concluded.

However, taking into account the operational aspects of the use of virtual cells it can be seen that it is possible to use this form of production organization in small-batch production conditions. The first mention in this theme can found in Kesen, Das & Güngör, 2010 and was continued in Mahdavi, Aalaei, Paydar & Solimanpur, 2011. The use of virtual cells may be advantageous in phase of job-shop scheduling as shown in the work of Wojakowski, 2012. The employment of virtual cells in the phase of job-shop scheduling supports decision-making on the choice of solutions minimizing the makespan.

The main part of the chapter is devoted to present an example, how to adopt the virtual cellular manufacturing concept into job-shop scheduling problem. It provides detailed description how to create virtual manufacturing cells based on the information about orders execution. Three schedules are depicted, each of different production flow presented for five production orders. Summarizes and directions for further work conclude the part.

2. IMPLEMENTATION OF VIRTUAL MANUFACTURING CELLS INTO JOB-SHOP SCHEDULING PROBLEM

The best way to clarify the concept of job-shop scheduling with embedded virtual cellular environment is to demonstrate an example. In the example, there are five production orders. The following input data, summarized in Table 1, are available for each production order.

The input data are divided into two parts. The first part gives the number of each product to be performed for each order. The size of the order is equal to the production batch. Production batch is transfered between two consecutive operations to complete the order like in job-shop environment. Additionally in some specific cases, virtual cell can be established for some group of orders. The only condition made on creating that cell is that the sequence of operations to complete orders in virtual cell has to be identical. Inside the virtual cell, production flow proceeds in transport batches as evenly divided production batches on smaller entities tranferred between machines. The second part of input data consists of specification of routings selected for each order. The sequence of operations is specified for each routing, machines are aggigned to each operation as well as unit processing time are defined. For simplicity, this example ignores setup considerations.

Table 1 A list of the input data for production orders

No	Content				
No of order	z_1	z_2	z_3	z_4	z_5
Production batch	120	105	150	105	150
Transport batch	20	15	25	35	50
Operation 1	M1 (9)*	M6 (6)	M2 (4)	M1 (8)	M6 (3)
Operation 2	M2 (6)	M7 (5)	M3 (8)	M3 (6)	M2 (5)
Operation 3	M3 (5)	M2 (7)	M4 (8)	M6 (5)	M1 (6)
Operation 4	M4 (9)	M3 (8)	M6 (5)	M4 (6)	M4 (3)
Operation 5	M5 (6)	M4 (7)	M7 (4)		
Operation 6	M6 (8)	M5 (6)			
Operation 7	M7 (8)				

* M1 (9) denotes that operation 1 of order z_1 is performed on machine M1 with the unit processing time 9.

For these five orders, the job-shop schedule without any virtual manufacturing cell is developed initially. The job-shop schedule is created with the use of dispatching rule SPT (*Shortest Processing Time*). Detailed description of the job-shop scheduling based on the SPT dispathing rule is available under request to the author. Figure 1 shows the job-shop schedule without virtual cells. The schedule was set up in the form of a Gantt chart in wich some coding system is assumed to provide identification of number of order (first subsymbol), number of operation (second subsymbol) and number of machine (third subsymbol in the code).

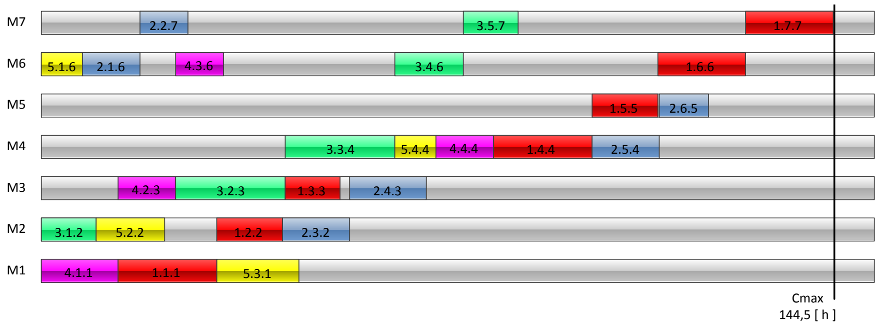

Fig. 1 Job-shop schedule without virtual cells created on the basis of SPT dispatching rule

For the given job-shop schedule depicted on Figure 1, ready time, completion time and flow time for all orders are summarized in Table 2.

Table 2 Results of parameters for all the orders (in hours)

No	Content				
No of order	z_1	z_2	z_3	z_4	z_5
Ready time	14	7,5	0	0	0
Completion Time	144,5	121,75	77	82,5	72
Flow time	130,5	114,25	77	82,5	72
Average flow time	95,25				

It can be noticed that each order is tranferred between machines in production batches. It means that next operation of order can be started until previus operation of this order is fully finished. However, it is the way to speed up starting next operation based on the concept of virtual cellular manufacturing. As mentioned above, the direction of production flow inside the virtual cell is fixed. Thus, it is required to investigate which orders can be grouped together to find the possibilities of virtual cell formation for them. Based on data about routings the chain of operations for each order is built. Chain links are the machines on which sequence of operations are performed. Figure 2 shows the chains of operations for five orders.

The process of orders grouping to decide where virtual cells can be created is to find the longest common substring. The longest common substring consists of sequence of machines on which selected operations are the same for the specific set of orders. There is no limit to the number of orders as well as number of operations that can belong to the longest common substring.

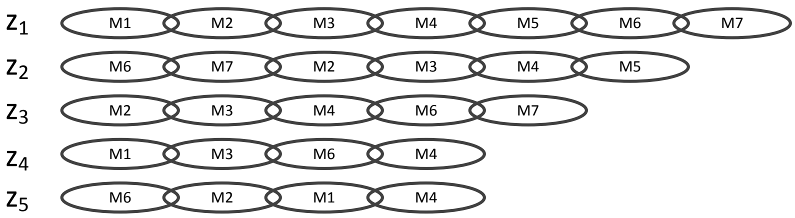

Fig. 2 The chains of operations for five orders

Comparing each pair of chains of operations on Figure 2, the longest common substring have the order z1 and order z2. The longest common substring for these orders are: M2->M3->M4->M5. The length of the longest common substring for orders z_1 and z_2 is equal 4. Figure 3 shows the longest common substring for orders z1 and z2.

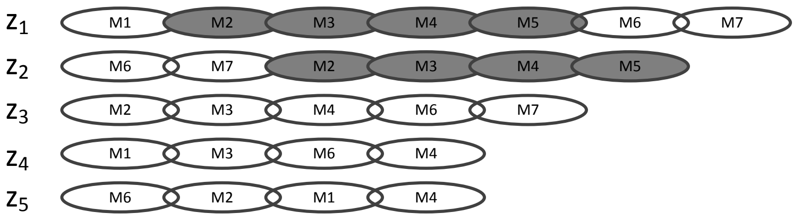

Fig. 3 The longest common substring for orders z_1 and z_2

For the longest common substring for two orders z1 and z2, a virtual manufacturing cell can be created. Production flow of two orders z_1 and z_2 between operations performed on machines M2->M3->M4->M5 is directed, therefore transport batches, smaller than production batches, are transferred between these machines. The flow of transferring transport batches inside virtual cell is called parallel flow. The main assumption is that the virtual cell has precedence when creating the schedule. Other operations outside the virtual cell are treated separately and planned traditionally retaining only the technological limitations (based on already described job-shop conditions). Figure 4 shows the schedule with virtual cell created based on SPT dispatching rule. Please note that during lifetime of the virtual cell the machines M2, M3, M4, M5 are logically separated from the production system (machines are dedicated to the virtual cell). It is not possible to insert other operations on machines dedicated to work for the virtual cells than those contained in the longest common substring.

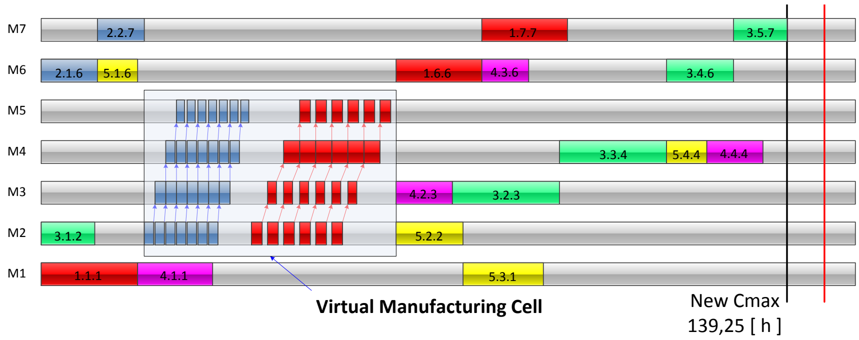

Fig. 4 Job-shop schedule with virtual cell for orders z_1 and z_2

As a result, the job-shop schedule with one virtual manufacturing cell created for oders z_1 and z_2, made by SPT dispatching rule, is characterized by a different distribution of operations throughout the time. It is summarized in Table 3. It can be noticed that althought the makespan is minimized the average flow time increases.

Table 3 Results of parameters job-shop schedule with virtual cell created for two orders (in hours)

No	**Content**				
No of order	z_1	z_2	z_3	z_4	z_5
Ready time	0	0	0	18	10,5
Completion Time	98,25	39,25	139,25	134,75	124,25
Flow time	98,25	39,25	139,25	116,75	113,75
Average flow time					101,45

The main assumption of job-shop scheduling with embedded virtual manufacturing cells is that orders that flow through the virtual cell are scheduled as first. Such assumption results in creating the schedule (using the same SPT dispatching rule) with minized makespan, at the expense of increasing the average flow time of the set of production orders. The reason for increasing the average flow time of production orders involves certain operations expectation to release the machines dedicated to virtual cell.

Seeking opportunities for further grouping of orders to find other virtual manufacturing cells the length of the longest common substring can be reduced. For example, it is possible to create virtual manufacturing cell consisting of the orders z_1, z_2 and z_3, for which the longest common substring is: M2-> M3-> M4. The set of operations belongs to the virtual manufacturing cell in this sense is de-picted in Figure 5. Figure 5 shows at the same time the longest common substring for orders z_1, z_2 and z_3.

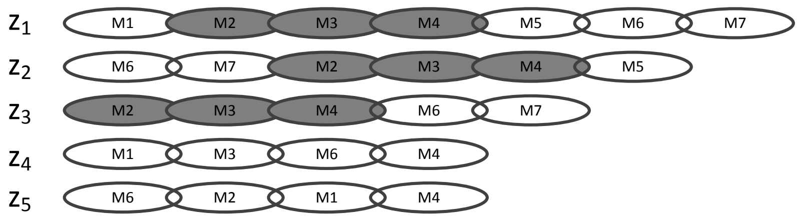

Fig. 5 The longest common substring for orders z_1, z_2 and z_3

Again, for the set of five orders, the job-shop schedule with virtual manufacturing cell is built. This time, the virtual cell emerges for three orders, namely, z_1, z_2 and z_3. Since the following machines: M2, M3 and M4 belong to longest common substring of orders z_1, z_2 and z_3, these machines are dedicated to the virtual manufacturing cell. Figure 6 shows the modified job-shop schedule with a virtual manufacturing cell for orders z_1, z_2 and z_3.

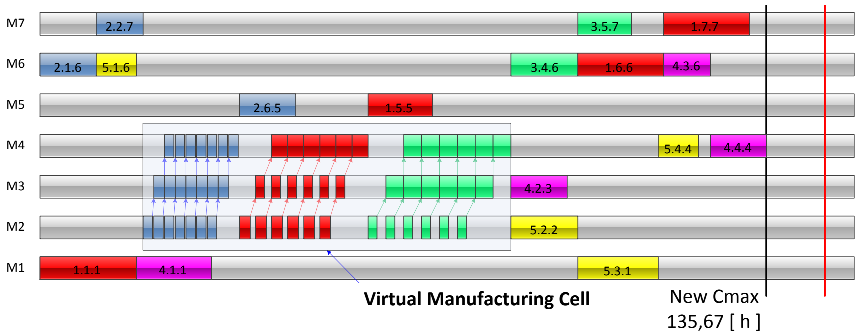

Fig. 6 Job-shop schedule with virtual cell for orders z_1, z_2 and z_3

Table 4 Results of parameters job-shop schedule with virtual cell created for three orders (in hours)

No	Content				
No of order	z_1	z_2	z_3	z_4	z_5
Ready time	0	0	61,25	18	10,5
Completion Time	132,42	47,75	110,42	135,67	122,92
Flow time	132,42	47,75	49,17	117,67	112,42
Average flow time					91,88

The job-shop schedule with wirtual manufacturing cell for orders z_1, z_2 and z_3 was built based on SPT dispatching rule. A detailed description of the method of job-shop scheduling with embedded virtual manufacturing cells is available under request to the author. Again, for the given job-shop schedule depicted on Figure 6, ready time, completion time and flow time for all the orders are summarized in Table 4.

The use of virtual manufacturing cell for orders z_1, z_2 and z_3 allows further to reduce the makespan. Average time flow of five orders is also reduced. Reduction of average flow time might be achieved bacause the majority of operations of order z_3 is performed inside virtual cell. It considerably condense the time of producing parts of order z_3 when taking into account production flow between machines.

3. CONCLUSION

The part is devoted to show possibility of reducing the makespan through the use of the idea of virtual cellular manufacturing in conjunction with the process of job-shop scheduling. This approach focuses on seeking of formation of grouped production orders for which the longest common substring is determined. The longest common substring consists of operations to be executed inside a virtual cell created on dedicated set of machines. As a result, the values of makespan and the average flow time are affected what was presented above on an example of five production orders.

From the standpoint of the management of lot production, mainly in small-lot production environment, this approach seems to be a powerful tool to achieve measurable benefits from reducing the production time while maintaining a high level of workload inside created virtual manufacturing cells. As shown in the chapter, the formation of these virtual cells is a combinatorial task in which there are many additional solutions when trying to create a modified job-shop schedule with virtual manufacturing cells. The job-shop scheduling problem with embedded virtual cellular manufacturing should be treated as optimization problem by following adopted optimization criterion or criteria.

The example presented in the chapter can be considered as a trivial task. Attempt to create a job-shop schedule with virtual manufacturing cells for five orders based on SPT dispatching rule does not cause major problems. For larger issues, however, there will be the problem of combinatorial explosion resulting in difficulty in finding the optimum solution. Further work should therefore be focused on developing optimization method based on metaheuristics to seek a rational solution from the point of view of the decision of when and how to organize the batch production by forming presented virtual manufacturing cells.

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BIOGRAPHICAL NOTES

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