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A New Part Routing-Based Decisional Algorithm for Urgent Fabrication through a Cost-Time Model in a Flexible Manufacturing System

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Abstract

This paper provides an efficient algorithm for decision makers concerning the incoming commands within the context of flexible fabrication. It deals with a specific case of a factory which is fully occupied treating other customer demands. When it receives a new fabrication request, it has either to accept or refuse it based on many factors. Admitting the new command means a cost and time rescheduling of all of its tasks. This may cause delays for the existing commands resulting in a damage on the reputation of the factory as well as additional penalties. The algorithm searches for the optimal part routing based on the overall duration and cost of the production in order to provide a final decision. It was tested with a numerical example and succeeded to prove its ability to provide optimal decisional solutions.

Keywords
Flexible manufacturing system, cost, time, urgent fabrication, customer demand.

1. Introduction

An urgent fabrication command is a one which is requested by a customer who is rushed to get it completed within a specified cost and delay. When a factory receives a request for such a command, it needs sometimes a tool to help it decide whether to accept or refuse it. This case happens mainly when the factory is fully occupied and consequently, it has to reschedule all of its tasks in order to implement the urgent one. This rescheduling involves critical factors such as the new overall fabrication costs and durations. Among the possible negative consequences of accepting such a command are the intolerable resulting delays on the ongoing fabrication. These delays may result in damages on the reputation of the factory as well as penalty charges. In addition to the manufacturing costs, the required design changes within the factory's flexible manufacturing system will cause additional charges. In order to ensure that the acceptation of the new demand will not cause side problems, the factory has to specify upper limitations for the duration and cost of the treatment of the new command. This paper presents a new algorithm which inputs the number of operations required onto each part of the new command as well as the relevant costs and durations. Thereafter, it searches for the optimal parts routing which is able to respect the maximum allowable overall cost and time for the fabrication of the new demand. Afterwards, it uses another algorithm for designing the manufacturing cells. The resulting exceptional elements, if there are any, will cause in turn the increase in both the fabrication cost and time. The new algorithm will then provide a re-routing of the parts only if the maximum allowable cost or duration have been surpassed. The procedure continues in this manner until the algorithm tells whether the situation is or not realizable and the best found solution will be considered as the final one. Some authors worked on the routing of manufacturing parts through different methodologies without taking necessarily into consideration the combo of the two parameters; namely, the cost and duration. H. Joseph Wen detailed the dynamic part routing [1]; M. Souier et al. used a meta-heuristic method for real-time routing [2] whereas J. Fenchel et al. introduced a distributed routing policy for flexible manufacturing systems [3].

2. The new algorithm

The first step consists of constructing a matrix which contains the information about the processing cost and time for each part. Let o_n be the number of operations required on the part number n, c_{nm} and d_{nm} are consecutively the cost and the duration required for processing the part number n on the machine number m. The factory specifies C as the maximum allowable cost for treating all of the parts and D as the maximum acceptable duration. The total processing cost and duration must be re-calculated after designing the manufacturing cells because some exceptional elements may result and increase them. For a better understanding, we are going to describe the algorithm step by step through the numerical example, as shown below:

A factory receives a fabrication request of 5 parts (n = 5). It needs 4 different machines (m = 4) in order to complete the request. The following matrix specifies the fabrication cost (c_{ij}) and duration (d_{ij}) of each part on each of the 4 machines:

m \ n	1	2	3	4	5
1	(c11,d11) = (2,5)	(c12,d12) = (5,3)	(c13,d13) = (5,3)	(c14,d14) = (9,8)	(c15,d15) = (6,8)
2	(c21,d21) = (5,9)	(c22,d22) = (6,4)	(c23,d23) = (4,2)	(c24,d24) = (8,2)	(c25,d25) = (4,7)
3	(c31,d31) = (4,9)	(c32,d32) = (4,6)	(c33,d33) = (7,4)	(c34,d34) = (7,2)	(c35,d35) = (4,6)
4	(c41,d41) = (6,8)	(c42,d42) = (2,3)	(c43,d43) = (7,9)	(c44,d44) = (2,2)	(c45,d45) = (8,2)

The parts number 1, 2, 3 and 4 require 2 operations whereas 3 operations are needed for the part number 5. After making a case study, the factory decides that the maximum allowable cost for accepting this command is 50 and the maximum duration is 55.

2.1 Let O be the total number of required operations i.e. $O = \sum_{i=1}^{n} O_i$

In this example, O = 11

2.2 Let x_1 be the weight of the processing cost with respect to the duration where $0 <= x_1 <= 1$

Let us begin with $x_1 = 0.65$

2.3 Let x_2 be the weight of the processing duration with respect to the cost where $x_1 + x_2 = 1$

$x_2 = 0.35$

2.4 $c_{2nm} = x_1 \times c_{nm}$ is the weighed cost

2.5 $d_{2nm} = x_2 \times d_{nm}$ is the weighed duration

After applying the steps *2.3* and *2.4* on the numerical example, we obtain the following matrix:

m/n	1	2	3	4	5
1	(1.3,1.75)	(3.25,1.05)	(3.25,1.05)	(5.85,2.8)	(3.9,2.8)
2	(3.25,3.15)	(3.9,1.4)	(2.6,0.7)	(5.2,0.7)	(2.6,2.45)
3	(2.6,3.15)	(2.6,2.1)	(4.55,1.4)	(4.55,0.7)	(2.6,2.1)
4	(3.9,2.8)	(1.3,1.05)	(4.55,3.15)	(1.3,0.7)	(5.2,0.7)

2.6 Assign a single value v_{nm} for each operation where $v_{nm} = c_{2nm} + d_{2nm}$

2.7 Build a new matrix M_N which contains the v_{nm} values:

m/n	1	2	3	4	5
1	3.05	4.3	4.3	8.65	6.7
2	6.4	5.3	3.3	5.9	5.05
3	5.75	4.7	5.95	5.25	4.7
4	6.7	2.35	7.7	2	5.9

2.8 Select the lowest O values of v_{nm}

m/n	1	2	3	4	5
1	3.05	4.3	4.3	8.65	6.7
2	6.4	5.3	3.3	5.9	5.05
3	5.75	4.7	5.95	5.25	4.7
4	6.7	2.35	7.7	2	5.9

2.9 Begin with the first column, if the number of selected operations is not greater than the required number, do nothing and go to the next column.

2.10 If the number of selected operations is greater than the required number, do the following:

a. Make a one by one subtraction between each selected element and all of the unselected elements in the same row.
In this example, the subtraction procedure gives the following results (coloured in green):

m/n	1	2	3	4	5
1	3.05	4.3	4.3	-4.35	-2.4
2	-1.1	5.3	3.3	-0.6	5.05
3	-1.05	4.7	-1.25	5.25	4.7
4	-4.35	2.35	-5.35	2	-3.55

b. Begin with the greatest resulting value from the previous step, check the number of selections in the relevant column:

i. If it is greater than or equal to the required number, do nothing.

ii. Otherwise, swap the selection between the new and the selected element.

iii. Repeat the steps a., b.i. and b.ii. with the next element until decreasing the number of the selected operations in the column to the required number which is o_n.
Thus, the new selection becomes:

m/n	1	2	3	4	5
1	3.05	4.3	4.3	8.65	6.7
2	6.4	5.3	3.3	5.9	5.05
3	5.75	4.7	5.95	5.25	4.7
4	6.7	2.35	7.7	2	5.9

2.11 Repeat the steps *2.9* and *2.10* Until completing the treatment of all the columns.

2.12 Revert the matrix to its original form and include the elements in the form of ones and zeros.

m/n	1	2	3	4	5
1	1	0	1	0	1
2	0	1	1	0	1
3	1	0	0	1	1
4	0	1	0	1	0

2.13 At this stage, the routing of the parts is completed, we make the sum of the costs as well as of the durations of the selected operations in order to obtain the total resulting cost C_{ti} and Duration D_{ti} where i is the iteration number.
The calculations give $C_{t1} = 49$ and $D_{t1} = 51$.

2.14 Use another algorithm in order to form the manufacturing cells.
We obtain 2 cells as follows:

m/n	4	2	1	3	5
1	0	0	1	1	1
2	0	1	0	1	1
3	1	0	1	0	1
4	1	1	0	0	0

2.15 If there are resulting manufacturing elements, we calculate the sum of the additional processing cost C_{ai} and time D_{ai}. Let us assume that the 2 exceptional elements located at (3,4) and at (2,2) cause successively additional costs of 2 and 1 as well additional durations of 2 and 2. Thus, $C_{a1} = 4$ and $D_{a1} = 3$.

2.16 Let C_{fi} and D_{fi} and be successively the final operational cost and time for the iteration number i where $C_{fi} = C_{ti} + C_{ai}$ and $D_{fi} = D_{ti} + D_{ai}$. So $Cf_1 = 49 + 4 = 53$ and $D_{f1} = 51 + 3 = 54$.

a. If $C_{fi} <= C$ and $D_{fi} <= D$; stop and consider the resulting solution as the final one.
b. If $C_{fi} <= C$ and $D_{fi} > D$; increase x_1 by a small value Δx_1 and decrease x_2 by the same amount and go to step 4 in order to begin the next iteration.
c. If $C_{fi} > C$ and $D_{fi} <= D$; decrease x_1 by a small value Δx_1 and increase x_2 by the same amount and go to step 4 in order to begin the next iteration.
d. Else, stop and consider that no solution can be found.

2.17 In our example, $C_{f1} = 53 > C = 50$ and $D_{f1} = 54 < 55$; that is why, we decrease x1 by 0.05 and we increase x_2 by the same value. We repeat the steps 4 to 12 for the second iteration and we obtain a new routing for the elements as follows:

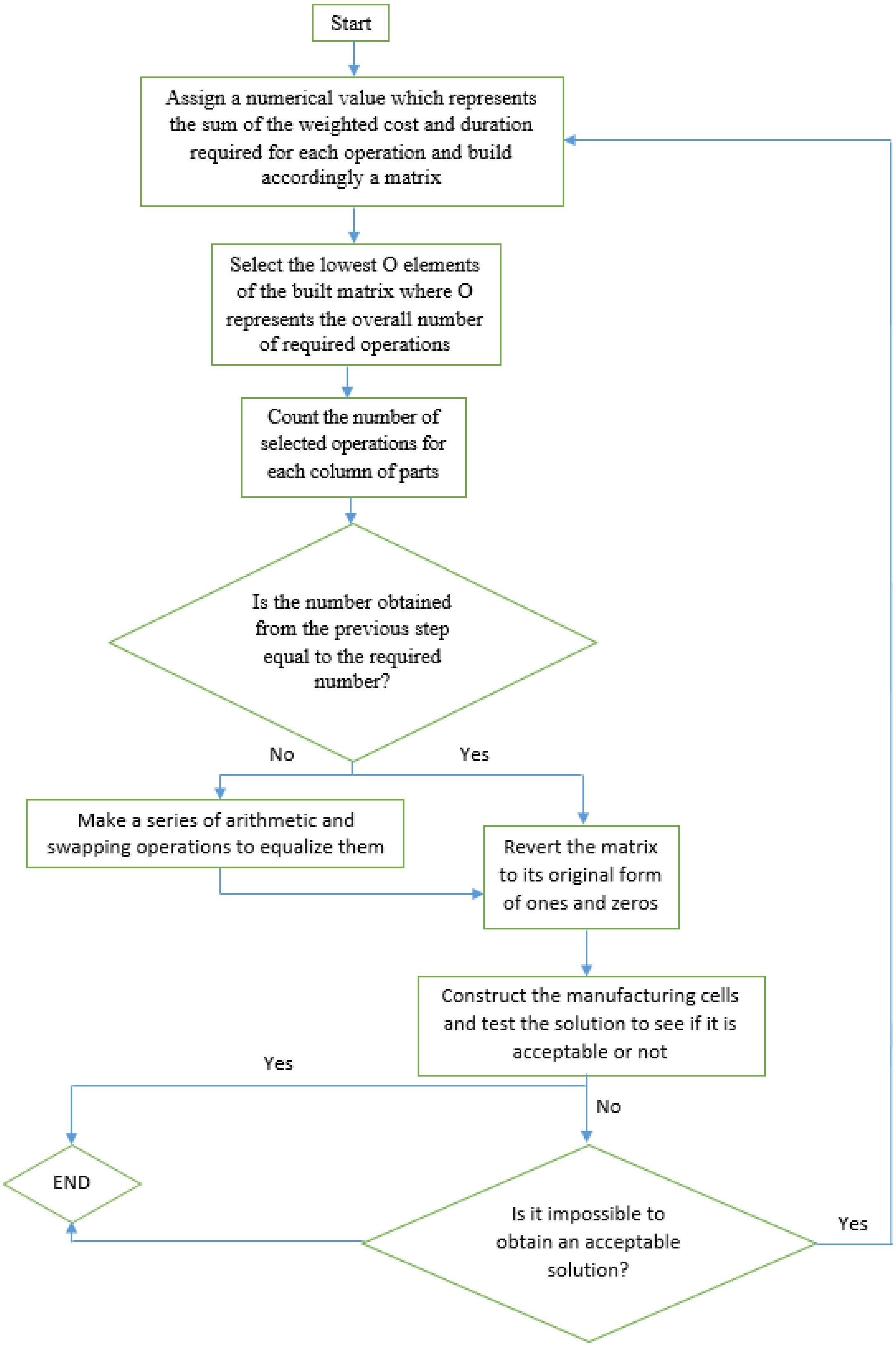
m/n	1	2	3	4	5
1	1	0	1	0	1
2	1	0	1	0	1
3	0	1	0	1	1
4	0	1	0	1	0

We make the relevant calculations for the second iteration in order to obtain $C_{t2} = 45$ and $D_{t2} = 53$. Thereafter, we repeat the step 14 in order to form the new manufacturing cells:

m/n	1	3	5	4	2
1	1	1	1	0	0
2	1	1	1	0	0
3	0	0	1	1	1
4	0	0	0	1	1

A single exceptional element was obtained at (3,5). It causes an additional cost of 1, and an additional processing time of 2. $C_{f2} = 45 + 1 = 46 < C = 50$ and $D_{f2} = 53 + 2 = 55$ which is equal to D. That is why, this solution is acceptable, there is no need for additional iterations and the factory admits accordingly the new command.

The proposed algorithm can be illustrated in a diagram as follows:



Start
Assign a numerical value which represents the sum of the weighted cost and duration required for each operation and build accordingly a matrix
Select the lowest O elements of the built matrix where O represents the overall number of required operations
Count the number of selected operations for each column of parts
Is the number obtained from the previous step equal to the required number?
No
Yes
Make a series of arithmetic and swapping operations to equalize them
Revert the matrix to its original form of ones and zeros
Construct the manufacturing cells and test the solution to see if it is acceptable or not
Yes
No
END
Is it impossible to obtain an acceptable solution?
Yes

3. Conclusion

A new algorithm was developed and presented in this paper. It routes the parts within the context of flexible manufacturing based on the cost and processing time information. The algorithm is mostly efficient in the sense of providing a decisional tool for an enterprise which receives a new command when it is fully occupied treating other customer's demands. It was tested also for a big problem (15 machines x 30 parts) and the satisfactory results have been obtained.

4. References

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Biographies

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