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Optimization of production scheduling with RC-Filter approach: A case study

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Abstract–

Production scheduling is the central of factory's planning and control system. One of attractive production scheduling systems is the cellular manufacturing systems (CMS). The CMS is a structure system based on the group theory. Several advantages of the CMS concept include principally the makespan and flew time reduction. The CMS is an NP-hard optimization problem. Depending on the size of the problem, the number of machine and the number of parts, the calculation time needed to get the optimal solution increases exponentially. To resolve NP-hard optimization problems, metaheuristic algorithms are the greatest solution to get good solutions in reasonable time.

In this work, we propose a new methodology to optimize the sequence of parts in each manufacturing cell including exceptional elements. This technique is based on RC-Filter algorithm. The proposed methodology was used to optimize the sequence of parts including exceptional elements to minimize the makespan. The proposed approach was validated using 12 problems taken from literature and the results were compared with that given by the extended great deluge algorithm.

Keywords: Cellular Manufacturing, Metaheuristics Algorithm, RC-filter, Makespan.

INTRODUCTION

The CMS is a model for workplace architecture, and became an integral part of lean manufacturing systems. The CMS allows machines and parts to be grouped in manufacturing cells. These cells are sharing the same required production process route which means the parts are going to be processed on the same machines within the cell [19]. The CMS have several advantages such as, the reduce costs of the material handling, the reduce number of the processing setups undertaking, the reduce work in process inventories, simplified production planning and control and also improve space utilization.

Moreover, CMS provides a production infrastructure that facilitates successful implementation of modern manufacturing technologies such as just-in-time manufacturing system, flexible manufacturing systems, computer integrated manufacturing, computer aided design system, etc.

The CMS is an excellent manufacturing configuration to optimize the scheduling and minimize the Makespan. The optimization process needed to get the minimum of makespan is very hard & difficult task, it is considered as NP-hard problem therefore, it has been widely known to use metaheuristics algorithms to solve this type of problem in reduce running time.

In the last two decades, many metaheuristic approaches had been used by researchers in engineering, especially in scheduling. For instance, Gaafar[20] found one type of search strategy is an improvement on simple local search algorithms; Metaheuristics of this type include simulated annealing, tabu search, iterated local search, variable neighborhood search, and GRASP [20]. Also, another type of search strategy has a learning component to the search so this type include ant colony optimization, evolutionary computation, and genetic algorithms [21]. Moreover, great deal of the algorithms were developed for group scheduling problem which they usually have two stages. The first stage determines the sequence of parts within the cells and the second stage determines the sequence of cells [22]. Hitomi and Ham [23] define lower bound for the optimum Makespan and propose branch and bound technique to determine the optimum sequence of parts and cells [23]. Since the group scheduling problem is NP-hard Logendran and Nudtasomboon[24] and several researchers have attempted to develop heuristics for the group scheduling problem [24]. Wemmerl and Vakharia [25] compared the performance of eight parts family scheduling procedures and reported that the family-based scheduling approaches perform superior with respect to minimum flow time and lateness [25]. Sridhar and Rajendran [26] introduced a multi-objective model which minimizes the makespan and other performance measurement, yet their model was not able to tackle some exceptional elements that visited other cells [26].

Solimanpur et al. [1] presented a heuristic called the SVS-algorithm to minimize the makespan within cell scheduling including exceptional elements (parts from other cells visited another cells); nonetheless, one of its disadvantages is that not prioritizing the operations order in terms of a high number of inter-cellular movements. The two stages of the SVS-algorithm are Intra-cell scheduling and inter-cell scheduling which is not only determines the sequence parts in the group but also the sequence of cells. Kirkpatrick et al. primarily introduced the simulated annealing algorithm in order to solve hard combinatorial optimization problems[1]. Ben Mosbah and Thien-My [5]developed a metaheuristic called Extended Great Deluge (EGD) to optimize the scheduling of a manufacturing by minimizing the makespan and other performance measurements. The EGD algorithm was able to reduce the setup time of the machines and hence obtained outstanding results [5].

The optimization of scheduling at manufacturing environment is aimed to minimize the makespan or to minimize the total production time. This type of problems were classified NP-hard where the calculation time increase exponentially depending on the size of the problem. For this reason, researchers tried to develop techniques, especially meta-heuristics, which give results in reasonable running time. Sridhar and al.[7] proposed a model to minimize the makespan, the flow time and the idle time in the cell and without introducing the exceptional elements. Abdallah and Dao [2] developed a model to minimise the makespan and the flowtime in cell manufacturing environment including the exceptional elements, the proposed model was based on extended great deluge algorithm. A model based on ant colony optimization proposed by Guo et al. [8] was applied to determine the great sequence of parts in complex Job-shop problems. A methodology was proposed by Bilyk et al. [9] to solve parallel machine scheduling problems.

In this study, we are interested in the manufacturing cell problems including exceptional elements. In the aim to solve this problem, we proposed a hybrid approach based on two metaheuristic algorithms. The first one was the RC-Filter algorithm developed by Nabil and Mustapha [3], and the second one was the Extended Great Deluge algorithm introduced byBurke and al. [4].

Given the importance of this problem, many resolution methods have been developed in scheduling optimization field. Therefore, in this paper a new metaheuristics algorithm called Resistor Capacitor filter (RC-filter) will be applied to tackle the optimization problem in the cellular manufacturing systems scheduling.

METHODOLOGY

The proposed methodology was based on a meta-heuristic algorithm. The used metaheuristic algorithm is called the RC-Filter. This approach was applied in the aim to determine the best sequence of parts which minimizes the makespan.

*A. **RC-Filter algorithm***

The proposed metaheuristic algorithm was introduced by Nabil and Mustapha [3] in the flow-shop scheduling optimization domain. RC-Filter considered as one of the low-pass filter which consists of resistor (R) in series with a capacitor (C). It allows to pass only low-frequency signals. This operation is made by reducing the amplitude of signals with high frequencies. The low-pass filter can be designed in many different forms. For instance, with electronic circuits or digital algorithms for smoothing sets of data, and more [3].

The RC-filter algorithm steps as described by Nabil and Mustapha [3] are as follows:

- ➢ Initialization of parameters:β and β_0
- ➢ Initialization of the maximum number of iteration N and the decreasing rate $\Delta\beta$
- ➢ Select initial solution S_0 and set $S = S_0$
- ➢ While the number of iteration is < N :

1) Randomly select a solution S* from the neighborhood space

- Calculate $G' = f(S) / f(S^*)$
- Calculate $G=1/\sqrt{1+(\beta/\beta 0)^2}$
- If one of the two conditions satisfied $G' \geq 1$ or $G(\beta) > G'$

2) Set $S = S^*$ and $\beta = \beta - \Delta\beta$

- ➢ End while.

*B. **The proposed approach***

In this study, we are interested in the scheduling of manufacturing cells including the exceptional elements. To solve this complex problems, an approach based on the RC-Filter algorithm was proposed in the aim to get the best sequence of parts which provides the minimum makespan. The Flowchart of the proposed RC-Filter approach is shown in Fig. 1.

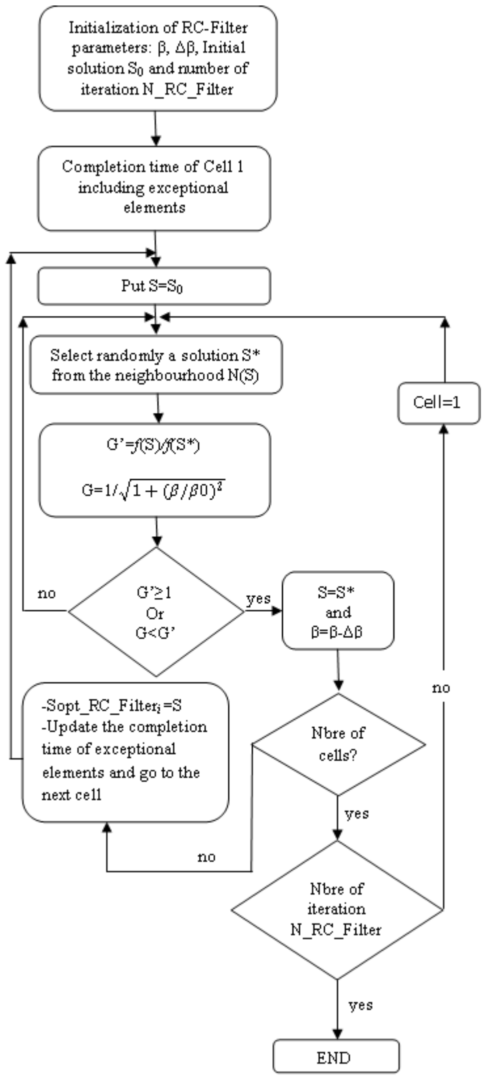


Figure 1. RC-Filter flow chart

The calculation of the makespan (f(S) in Fig. 1) was performed using the model proposed by Sridhar and Rajendran [7], the proposed model is as follows:

n the number of jobs to be scheduled in the cell.

m the number of machines in the cell.

tji the processing time of job j on machine i .

s the set of jobs already scheduled.

$q(s, i)$ the completion time of the partial schedule

s on machine i .

Fs the flow time of all jobs in s .

The formulation of the problem is:

Initialize $T=0$, $Fs=0$ and $Ms=0$

For $j=1$ to n do

$i = 1$ to m do

if $tji > 0$

then

compute the completion time $q(sj,i)$ of partial

schedule sj

$$q(sj,i)=\max[q(s,i); T]+tji \quad (1)$$

update

$$T = q(sj, i) \quad (2)$$

else

$q(sj,i)= q(s,i)$ (3)

the total flowtime of jobs in sj is:

$$Fsj = Fs + T \quad (4)$$

The makespan αsj of the partial schedule sj is:

$Msj = \max(Ms , T)$ (5)

In the Fig. 1, the objective function f is

$fsj = Msj$

The optimization process of the hybrid approach proposed in this work is done as the following steps:

1) Initialization of the RC_Filter parameters: β, Δβ, the initial solution S_0 and the number of iteration N_FC_Filter and give the completion time of the cell 1 including exceptional elements.

2) Put $S=S_0$

3) Define the neighborhood N(S) and select randomly $S^* \in N(S)$

4) Calculate $G' = f(S) / f(S^*)$

Calculate $G=1/\sqrt{1+(\beta/\beta 0)^2}$

5) If $G' \geq 1$ and $G(\beta) > G'$ are not satisfied, go to step 3

6) If : $G' \geq 1$ or $G(\beta) > G'$

7) Put S=S* and decrease $\beta=\beta-\Delta\beta$

8) If the number of cells is not reached:

a. Put Sopt_RC_Filter=S

b. Update the completion time of exceptional elements and go to next cell (Cell =Cell+1).

c. Go to step 2

9) If the number of cells is reached:

a. If the number of iteration < N_RC_Filter

i. Initiate the number of cell (Cell=1)

ii. Go to step 3

b. If the number of iteration is reached:

i. Save the solution $Sopt_i$

ii. END.

COMPUTATIONAL RESULTS

In this section, we present an application of the proposed approach on different problems. The performance of the proposed approach was compared with the extended great deluge algorithm.

A. Illustrative example

To illustrate the performance of the proposed methodology, this meta-heuristic approach was applied to the example shown in table I. The example is composed by ten parts manufactured using nine machines grouped in three cells. The Table I showed the operation times of each part. In this example, they are 5 exceptional elements which require operations outside of their cells where they belong.

The part 1 is manufactured in cell 1 but is requires one operation on machine K in the cell number 2 and one operation on machine G in the cell number 3. The part 5 is manufactured in cell number 2 and requires 2 operations outside of the cell 1, one operation on machine A and one operation on machine C in the cell number 1. The part 7 is affected on cell number 2 but also required 2 operation on machine A and B in the cell number 1. The part 8 and 9 required one operation on machine K and A respectively, outside of their cell (cell 3).

TABLE I
OPERATION TIME

		Parts									
		1	2	3	4	5	6	7	8	9	10
Cells	Machines										
Cell 1	A	6	4	8	9	5		5		8	
	B	9	10		5			13			
	C	1	7	4		6					
Cell 2	K	8				7	7	3	5		
	L					13	8	2			
Cell 3	F								5	13	3
	G	7							15	8	6
	H								8	6	
	R								8	3	7

The operation time was needed to calculate the makespan corresponding to the part sequence. The idea was to add fictive parts and machines in the cells where the exceptional elements are realized. For example, the part 1, 2, 3 and 4 are manufactured on cell 1 but also to realize operations on part 5, 7 and 9. These exceptional elements were added to the family of parts manufactured on cell 1. Fictive machines were added in cell 1, these machines were needed to realize exceptional elements of the part family affected to cell 2 and 3, in this case we added a fictive machines K and G in cell 1. This step help to define the completion time of exceptional elements on the part 1 in the aim to be used in the optimization process of the next part family (on cell 2 and 3).For each iteration, the optimization process was as the following steps:

- Step 1: start with cell 1, the operation time on this cell was presented in Table II. The Gantt diagram of the initial solution is shown in Fig.2. The makespan of in this cell is 50.The optimal sequence given by the proposed method RC-Filter was**7-4-9-3-1-2-5.** The completion time of exceptional elements were calculated to update the operation time of the cell 2 according to the optimal sequence (Table II). The completion time of part 1 on machine K was 36 and was 43 on machine G. The completion time of part 5 on machine A and C were 24 and 38 respectively. The exceptional elements of the part 7 on machine A and B were 5 and 18 respectively. Finally, the exceptional element of part 9 on machine A was done after 45unit time.

TABLE II
OPERATION TIME FOR CELL 1

		Parts						
machines		1	2	3	4	5	7	9
	A	6	4	8	9	5	5	8
	B	9	10	0	5	0	13	0
Cell 1	C	1	7	4	0	6	0	0
	K	8	0	0	0	0	0	0
	G	7	0	0	0	0	0	0

TABLE II
COMPLETION TIME FOR CELL 1

		Parts						
machines		7	1	3	5	2	4	9
	A	5	11	19	24	28	37	45
	B	18	27	27	27	38	43	45
Cell 1	C	18	28	32	38	45	45	45
	K	18	36	36	38	45	45	45
	G	18	43	43	43	45	45	45

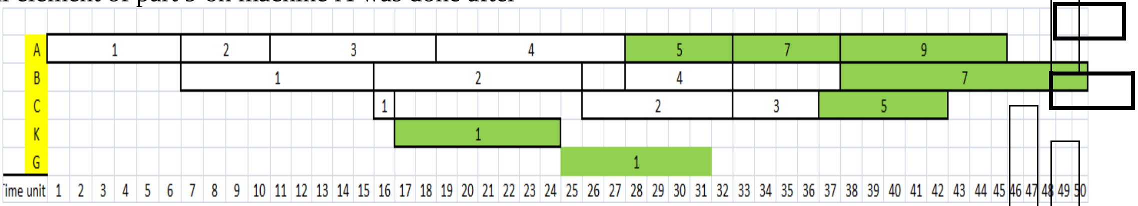


Figure. 2. The Gantt diagram for the initial part sequence in the cell 1

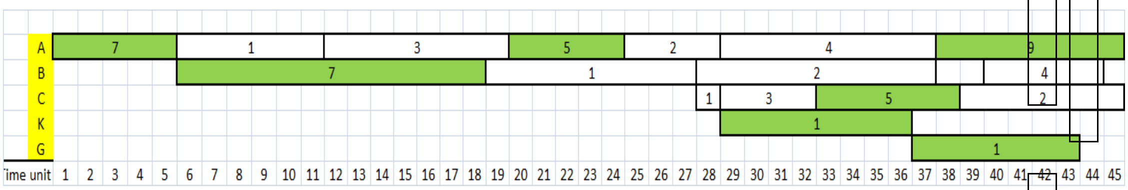


Figure. 3. The proposed solution using RC-Filter in the cell 1

- Step 2: Based on the completion time on cell 1 (Table II), update the operation time (of the exceptional elements) of the second cell and optimize the sequence. The operation time used to optimize the family parts of cell 2 is presented in Table III.

TABLE III
OPERATION TIME FOR CELL 2

		Parts				
machines		1	5	6	7	8
	A	0	24	0	5	0
	B	0	0	0	18	0
Cell 2	C	0	38	0	0	0
	K	36	7	7	3	5
	L	0	13	8	2	0

TABLE IV
COMPLETION TIME FOR CELL 2

		Parts				
machines		8	6	1	5	7
	A	0	0	0	24	29
	B	0	0	0	24	47
Cell 2	C	0	0	0	62	62
	K	5	12	48	69	72
	L	5	20	48	82	84

In this cell the optimal sequence is **8-6-1-5-7**. The completion time of the exceptional elements will be used to optimize the family parts of the third cell.

- Step 3: Based on the completion time on cell 2 (Table IV), update the operation time for the cell 3 used to optimize the sequence of parts.

The Table V present optimal solutions for each cell given by RC-Filter proposed in this work. For this example, the obtained makespan is equal to 108.

TABLE V

OPTIMAL SEQUENCE AND MAKESPAN FOR EACH PART FAMILY

	RC-Filter	
Cells	Optimal sequence	Makespan
1	**7-4-9-3-1-2-5**	45
2	**8-6-1-5-7**	84
3	**3-5-4-1-2**	108

B. Application and results

To validate the performance of the RC-Filter methodology proposed in this study (shown in Fig. 1), 13 problems are selected in the literature and they were resolved using our approach. The Table VI describe the size of these 13 problems (the number of machines m and the number of parts n), the number of cells in each problem and a comparison between the optimal makespan obtained by our approach and that obtained by other techniques. In these problems, the set-up times were not considered. The operation times were generated randomly from distributions ranging between 0 and 100. Each problem was solved 100 times with different data and the average makespan was calculated.

To solve these 13 problems, the proposed RC-Filter approach (Fig. 1) was implemented using MATLAB on a 2.67 GHZ i5 core PC. To solve these problems, the $\Delta\beta$ and the number of iteration were equal to 0.02 and 10^5 respectively. A summary of results were shown in Table VI.

The average makespan obtained by the RC-Filter were compared with those given by the SVS-algorithm and the EGD algorithm. As shown in Table VI, 11 problems were improved with a percentage of error until to 17 % compared to that given using the EGD algorithm, and 10 problems were improved to that obtained by the SVS-algorithm where the percentage of the improvement was until to 44 %.

Table VI. OBTAINED RESULTS

No	Problems	Size			RC-Filter	EGD	SVS-algorithm	Error %	
		m	n	# of cells	Average makespan	Average makespan	Average makespan	E % RC-Filter Vs EGD	E % RC-Filter Vs SVS
1	Kumar and Vannelli [10]	30	41	2	**618.75**	729.43	727.2	15%	15%
2	Chandrasekharan et al. [12]	24	40	7	552.55	555.21	353.8	0%	-56%
3	Chandrasekharan et al. [12]	24	40	7	539.08	516.81	1015.8	-4%	47%
4	Carrie [11]	20	35	4	675.07	633	801.8	-7%	16%
5	Harhalakis et al. [13]	20	20	5	**424.99**	514.1	711.5	17%	40%
6	Seifoddini[16]	11	22	3	**571.17**	602.99	1019.2	5%	44%
7	Seifoddini[17]	5	18	2	**660.37**	675.85	897.1	2%	26%
8	Kusiak and Chow [15]	7	8	3	198.45	205.08	150	3%	-32%
9	King and Nakormchai [14]	5	7	2	230.94	245.18	226.4	6%	-2%
10	Waghodekar and Sahu (1984), Fig.2[18]	5	7	2	**232.23**	273.67	408.3	15%	43%
11	Waghodekar and Sahu (1984), Fig.2[18]	5	7	2	**234.3**	238.98	372.3	2%	37%
12	Waghodekar and Sahu (1984), Fig.2[18]	5	7	2	**312.56**	375.44	425.8	17%	27%
13	Waghodekar and Sahu (1984), Fig.2[18]	5	7	2	**317.15**	369.58	383.7	14%	17%

A. Case study: Application and results

For more illustration of the performance of the proposed approach, a case study was used. The RC-Filter was applied to optimize a big size problem. In this case, there are forty (40) parts and twenty (24) machines. This problem was proposed by Ben Mosbah and Dao [2] and was optimized using EGD approach. These 24 machines proposed in this problem were grouped in 7 cells to makes these 40 parts. The incidence matrix of this problem is shown in Table VII. The cell system design is represented in Table VIII. The processing times represents this case is presented in Table IX. 17 exceptional elements require operations outside where they are affected. Setup times are not considered in this example. To obtain the best solution, the following parameters were used: $\Delta\beta = 0.01$ and the number of iterations were set to 10^5 , these parameters were obtained after several tests. The algorithm was implemented using MATLAB on a 2.67 GHZ i5 core PC.

TABLE VII

INCIDENCE MATRIX [2]

Machines	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
A	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
C	0	1	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
D	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0
E	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
F	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
H	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1
J	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
L	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
M	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
N	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0
P	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	0
Q	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1
R	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1
T	0	1	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
U	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
V	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
W	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
X	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

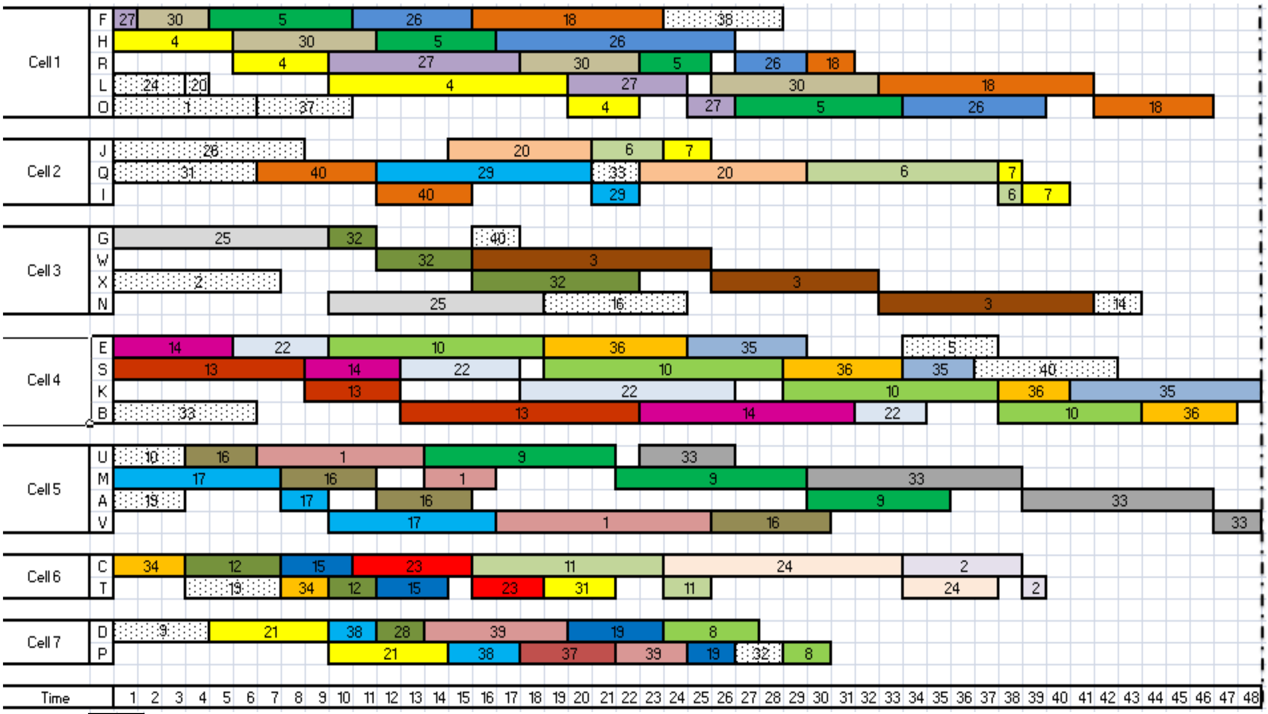
TABLE VIII

THE MANUFACTURING CELLS WITH EXCEPTIONAL ELEMENTS [2]

		Parts																																					
	Machines	30	18	5	26	27	4	20	7	6	29	40	32	3	25	35	36	22	10	14	13	1	33	9	16	17	31	12	24	15	34	23	11	2	28	21	38	8	39	19	37
cell 1	F	1	1	1	1	1	0																														1				
	H	1	0	1	1	1	1																																		
	R	1	1	1	1	1	1																																		
	L	1	1	1	0	1	1	1																					1												
	O	0	1	1	1	1	1															1																			1
cell 2	J				1			1	1	1	0	0																													
	Q							1	1	1	1	1															1														
	I							0	1	1	1	1											1																		
cell 3	G											1	1	0	1																										
	W												1	1	0																										
	X												1	1	0																			1							
	N												0	1	1					1					1																
cell 4	E			1												1	1	1	1	1	0																				
	S											1				1	1	1	1	1	1																				
	K															1	1	1	1	0	1																				
	B															0	1	1	1	1	1		1																		
cell 5	U																		1			1	1	1	1	0															
	M																					1	1	1	1	1															
	A																					0	1	1	1	1														1	
	V																					1	1	0	1	1															
cell 6	C																										0	1	1	1	1	1	1	1							
	T																										1	1	1	1	1	1	1	1						1	
cell 7	D																							1											1	1	1	1	1	1	0
	P												1																						0	1	1	1	1	1	1

TABLE IX
THE PROCESSING TIMES OF CASE STUDY [2]

Machines		30	18	5	26	27	4	20	7	6	29	40	32	3	25	35	36	22	10	14	13	1	33	9	16	17	31	12	24	15	34	23	11	2	28	21	38	8	39	19	37
cel 11	F	3	8	6	5	1	0																														5				
	H	6	0	5	10	3	5																																		
	R	5	2	3	3	8	4																																		
	L	7	9	4	0	5	10	1																					3												
	O	0	5	7	6	2	3															6																			4
cel 12	J				8			6	2	3	0	0																													
	Q							7	1	8	9	5															6														
	I							0	2	1	2	4											2																		
cel 13	G											2	2	0	9																										
	W												4	10	0																										
	X												7	7	0																			7							
	N												0	9	9					2					6																
cel 14	E			4												5	6	4	9	5	0																				
	S											6				3	5	5	10	4	8																				
	K															8	3	9	9	0	4																				
	B															0	4	3	6	9	10		6																		
cel 15	U																		3			7	4	8	3	0															
	M																					3	9	8	4	7															
	A																					0	8	6	4	2														3	
	V																					9	2	0	5	7															
cel 16	C																										0	4	10	3	3	5	8	5							
	T																										3	2	4	3	2	3	2	1						4	
cel 17	D																							4											2	5	2	4	6	4	0
	P												2																						0	5	3	2	3	2	4



: Exceptional elements

Figure. 4 Gantt diagram of the optimal solution given by RC-Filter approach

TABLE IX
Optimal Sequence Of Tasks In Each Cell Given By Rc-Filter Vs Egd

	RC-Filter		**EGD** [2]		Error
Cells	Sequence of parts	Makespan	Sequence of parts	Makespan	
1	24-1-20-37-4-27-30-5-26-18-38	46	20-1-24-38-37-4-5-27-26-18-30	50	8.0
2	31-26-40-29-33-20-6-7	40	33-31-29-7-6-40-20-26	48	16.7
3	2-14-25-16-32-40-3	41	14-16-2-25-3-32-40	35	-17.1
4	33-13-14-22-10-36-35-5-40	48	33-13-22-14-10-36-35-5-40	48	0.0
5	10-19-17-16-1-9-33	48	19-17-16-1-33-9-10	46	-4.3
6	19-34-12-15-23-31-11-24-2	39	19-23-34-31-15-11-12-24-2	39	0.0
7	9-21-38-28-37-39-19-32-8	30	38-37-21-19-39-8-28-32-9	49	38.8

The RC-Filter, presented in figure 1, was applied to solve a large size problem (24 machines, 40 parts) represented in table VII to IX. The makespan given by the proposed approach was improved regards that given by EGD approach proposed by Ben Mosbah and Dao [2]. The obtained makespan was equal to 48 with an improvement of 4 % versus that obtained by the EGD algorithm. The Gantt chart of the feasible solution is shown in Figure 4. The obtained processing sequence for part families and the error compared to that obtained by the EGD approach are summarised in Table IX where the makespan on each cell are calculated.

CONCUSION

In this paper, a new algorithm called RC filter was used to solve the scheduling optimization problem in cellular manufacturing system. A case study was presented to prove its efficiency yet exceptional elements. The proposed algorithm (RC-Filter) was applied to solve 13 optimization problems adopted from previous works. The obtained results were compared with that given by EGD algorithm and SVS-algorithm. 11 problems were improved compared to that given using the EGD algorithm, and 10 problems were improved to that obtained by the SVS-algorithm. Also, the proposed approach was applied on a case study (24x40) where the makespan was improved by 4 % compared to EGD solution.

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