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Resource selection and allocation in dynamic multi-period formation of virtual cell with consideration of multiple processing routes

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ABSTRACT: To enhance the production continuity and optimal utilization of the Shipbuilding enterprises during multi-period, a multi-object dynamic mixed integer programming model of virtual cell is proposed to complete the resource selection and batch assignment of routes by minimizing the processing cost, transportation cost, scheduling factors and load balance. The factors including constraints on the processing capacity equipment redundancy and the influences of batch processing and cellular formation on scheduling are considered in the model design. This paper proposed improved multi-object genetic algorithm to obtain optimal pareto solution set and introduced TOPSIS to determine the best resource group. The model and algorithm presented is applied in a job shop of pipe in a shipyard. The robust resource selection strategy during multi-period can greatly balance the working load of all shops, and achieve more superior structure of virtual cell formation.

Keywords: VCMS; source selection; robust strategy; schedule factor; adaptive genetic algorithm

1 INTRODUCTION

Shipbuilding is a complex, dynamic and large-scale system. As the processing objectives are of high complexity, large varieties, strict standards of specialization and the physical location of the processing equipment is difficult to move, it can easily cause low utilization rate of equipment and personnel, disorganization and poor production flexibility. The production efficiency still can be improved by forming manufacturing cell and transforming the original single, small batch production into mass production because of the similarity of processing technology. Virtual cell manufacturing system [1] introduced the concept of “equipment sharing” and “logical reconfiguration”, which not only significantly improve the production flexibility and equipment utilization, but also quickly integrate the manufacturing resources by logical reconfiguration in response to changes of production tasks, thus avoiding drastic change of plant layout caused by the cell reconfiguration [2]. Because the manufacturing resource is located in different places and the production exist multiple routes, the optimization of manufacturing resources is one of the key factors that determine the performance of manufacturing system. Therefore, Leng Sheng et al. [3] presented a mathematical model with the least production cost and workpiece delivery time to deal with the resource selection and allocation problem considering the flexible process routes in virtual cell reconfiguration. Guo et al. [4] developed a manufacturing resources organization model based on virtual manufacturing cell, which aimed to maximize the sum of processing routes similarity coefficient (minimize its reciprocal), minimize the total cost, transportation time, and balance the working load of the machine. Zeng et al.[5] pointed out that the formation strategy of traditional cells mostly apply to long-term production plan without considering the multi-route of the processing and overemphasize the integrity of the processing cell, which will lead to low equipment utilization rate. Hence, they proposed a dynamic reconfiguration framework to order production based on virtual manufacturing cell system.

In response to the demand of varied parts, deficiency of capacity and unexpected equipment failures in actual production, Javadian et al. [6] decomposed the original plan into a plurality of small continuous pro-

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duction plans with different types of parts and demand, and then constantly adjusted the internal resource production systems. The current studies on the resource selection problem are mostly available for a single period. Some scholars [7-8] analyzed the problem of the optimization of batch production and the resource allocation during the multi-period formation. It showed that periodical cell reconfiguration will interrupt regular production; in order to reduce the cost and time consumption, it is necessary to consider some robust strategies for cell reconfiguration [9]. Meanwhile, cell formation and scheduling are interrelated decisions [10], so the possible scheduling conflicts should be considered in resource selection, which may be of great significance to the overall optimization of the production system. However, some researches still discuss the cell formation and the scheduling problem independently.

From the perspective of short-term job, this study presented an extended problem of resource selection and allocation for dynamic part production, which is capable of producing part families during the multi-period virtual cell formation. The design of robust cell configurations is based on the best part processing route selected from using specified multiple process routes for each part type considering average product demand during the planning horizon. The concept of scheduling factor is the consideration of avoiding conflict during resource selection. It must balance the four objectives of processing cost, transportation cost, load balance of equipment and scheduling factor. The adaptive multi-objective genetic algorithm is developed to obtain pareto optimal solutions of resource selection, with introducing TOPSIS to evaluate and propose the best solution of resource selection and batch distribution.

2 THE MATHEMATICAL MODEL OF RESOURCE SELECTION IN MULTI-PERIOD FORMATION OF VITURAL CELL

The resource selection based on VCMS is not only the distribution of internal workshop equipment to the cell, but also organize the scattered manufacturing resources directly managed by the production system to virtual manufacturing cell; it is the basis of entire manufacturing process and production scheduling system. So the selection of resources emphasizes the completion of the processing and the overall optimal output exported by the entire VCMS including cell reconfiguration and scheduling as well. So, during resource selection, the processing and transportation cost, load balance of equipment and conflict avoidance should be taken into consideration, thus it can form a more robust VMC on the premise of balancing the demand of each part during all periods.

2.1 *Problem description*

The resource selection problem of VMC multi-phase formation can be described as: simultaneously consider the production plans in h periods, and list the orders of i kinds of products. And then sorts out the equipment needed in one or more processing procedures from the shared resource repository and constitute a candidate set $Cm=\{Cm_1,Cm_2\ldots Cm_M\}$. In actual production, there is only one piece of some equipment and others are more than one piece. The number of various types of equipment is n_m. Number the same equipment in the same place, as for the equipment in different place, it needs to number them separately even for the same types. Each product has more than one processing route due to the versatility and flexible of equipment, so the resource selection also includes the choice of processing route and the distribution of the processing batch. To complete the product processing, we need select a certain amount of resources Sm= {Sm1, Sm2…Smk} from Cm to form the corresponding processing route.

The study in this paper is based on the following assumptions:

(1) The processing of each product of any route in any procedures can only and must be finished with one piece of equipment.

(2) Products can have multiple processing routes, but the processing routes and the equipment can finish each route are already known.

(3) The probability of each route being selected is the same.

(4) The distance between each two pieces of equipment is measurable and already known.

(5) The processing time for each product of all equipment in every procedure is settled and already known.

(6) The production demand in each period is already known.

2.2 *The mathematical model of resource selection*

2.2.1 *Indices*

i (i=1,…,I), part index;
j (j=1,…,J_i), process index of part I;
m (m=1,…,M), equipment index;
n (n=1,…,n_m), the number of equipment m;
h(h=1,…,H), period index;
r_i (r_i=1,…,R_i), route index.

2.2.2 *Parameters*

TP_h, the time span of period h;
O_m, the unit cost of equipment m;
C_{hm}, the capacity of any equipment m in period h;
$P_{ir_i jm}$, The processing time of equipment m of route j with equipment m;

tr_{xy} (x =1,2,…,m; y =1,2,…,m), The transport distance between equipment x and equipment y.

B_i (i=1,…,I), The transportation capacity of part i.

2.2.3 *Decision variables*

D_{hr_i} , The processing number of part i in route r_i in period h.

$M_{hir_i jm}$, if operation j of part i in route r_i is done at period h, it is 1; otherwise it is 0.

d_{mr_i} , the number of equipment m in the processing j of part i in route r_i.

2.2.4 *Scheduling factor*

If it needs more than one piece of the equipment for one procedure, and the processing of different products choose the same equipment, the subsequent processing are very likely to cause conflict and bottleneck, resulting in the processing being prolonged. In order to take the possibility of the appearance of bottleneck into consideration, this paper puts forward the concept of scheduling factor (SF).

$$SF = \frac{N_m}{N_0} \times \frac{T_m}{TP_h}$$

The first item in SF refers to the ratio of the equipment being selected in current period and the number of all required procedures; the second item means the ratio of the time needed to finish the processing with the equipment in current period and the planned time for current period.

2.2.5 *Mathematical model and constraints*

$$\min\left\{ f_1(D), f_2(D), f_3(D,M), f_4(D,M) \right\}$$

$$f_1(D) = \sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{r_i}^{R_i} D_{hr_i} \times C_{r_i} \tag{1}$$

$$f_2(D) = \sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{r_i}^{R_i} \left\lceil \frac{D_{hr_i}}{B_i} \right\rceil \times tr_{r_i} \tag{2}$$

$$f_3(D,M) = \sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{m}^{M}\sum_{n}^{N_m} \frac{\left|L_{hmn} - L_h\right| + \left|L_{hmn} - L_{mn}\right|}{\sum_{m}^{M} N_m} \tag{3}$$

$$f_4(D,M) = \max\left(\frac{\sum_{i}^{I}\sum_{r}^{R_i} M_{hijr_i m}}{\sum_{i}^{I} J_i} \times \frac{\sum_{i}^{I}\sum_{r}^{R_i} M_{hijr_i m} D_{hr_i} P_{ir_i jm}}{TP_h} \right) \tag{4}$$

Subject to:

$$C_{r_i} = \sum_{j=1}^{J_{R_i}} P_{jm} O_m \tag{5}$$

$$tr_{r_i} = \sum_{j=1}^{J_{R_i}} tr_{r_i j \to r_i (j+1)} = \sum_{j=1}^{J_{R_i}}\sum_{x=1}^{M}\sum_{y=1}^{M} tr_{xy} \left(M_{hir_i jx} \times M_{hir_i jy} \right) \tag{6}$$

$$\forall d_{mr_i} C_{hm} \geq P_{hir_i jm} D_{hr_i} \tag{7}$$

$$\max\left(\sum_{j=1}^{J_i} D_{hr_i} P_{ir_i jm} \right) \leq \sum_{h}^{H} TP_h \tag{8}$$

$$\sum_{m}^{M}\sum_{n}^{N_m} M_{ir_i jm} = 1 \tag{9}$$

$$M_{hir_i jm} = 0,1 \quad \forall i, j, m, n \tag{10}$$

$$D_{hri} \geq 0 \text{ , and interger} \tag{11}$$

The first objective function refers to the total processing cost. The second one refers to the total transportation distance for the completion of all processing, in which $\left\lceil D_{hr_i} / B_i \right\rceil$ refers to the delivery times needed in route ri in period h and the bracket means to set the time as integer greater than the actual number. The third one refers to load balance ratio of all equipment, and $L_{hmn} = \sum_{i=1}^{I}\sum_{r_i=1}^{R_i} \frac{\sum_{j=1}^{Ji} D_{hr_i} P_{ir_i jm} M_{hir_i jm}}{d_{mr_i}}$ denotes the load of the n-th equipment m in period h; $L_h = \sum_{M}^{M}\sum_{n}^{n_m} L_{hmn} \Big/ \sum_{m}^{M} n_m$ refers to the average load of the n-th equipment m in period h; $L_{mn} = \sum_{h}^{H}\sum_{n}^{n_m} L_{hmn} \Big/ H\sum_{n}^{n_m} n_m$ means the average load of the n-th equipment m in all periods. The former item means the whole load deviation of one piece of equipment with others in one period and the latter item means the load deviation of one piece of equipment is different periods. Reasonable resource selection can balance the load deviation of all equipment. The fourth one denotes the maximum scheduling factor of all equipment. Function (5) refers to the whole processing cost in route r_i. Function (6) refers to the whole transportation distance in route r_i. Function (7) refers to the number of equipment assigned can satisfy any processing tasks. Function (8) refers to the maximum completion time of all routes does not exceed the lead time. Function (9) refers to each procedure can only choose one piece of equipment. Function (10) refers to status of the equipment can only be empty or occupied. Function (11) refers to the processing quantity assigned in each route are all positive integers.

3 ALGORITHM DESIGN

As for the resource selection model, genetic algorithm can better describe the decision variables with complex structure, and obtain more pareto non-dominated solutions. This paper adopts the Adaptive Multi-objective Genetic Algorithm (AMOGA) to realize the optimal pareto solution set. In order to improve the poor iterative search ability in early stage and solve the problem of being easily trapped in the local optimum in late stage, this paper adopt adaptive crossover

$$cross\_rate = \begin{cases} cross\_\max - \left(\dfrac{cross\_\max - cross\_\min}{maxgen} \right) \times iter & , f' \le f_{avg} \\ cross\_\max & , f' > f_{avg} \end{cases} \tag{12}$$

$$mutate\_rate = \begin{cases} mutate\_\max - \left(\dfrac{mutate\_\max - mutate\_\min}{maxgen} \right) \times iter & , f < f_{avg} \\ mutate\_\min & , f \ge f_{avg} \end{cases} \tag{13}$$

and mutation strategy; it can ensure the efficiency and convergence of the algorithm. As four objectives cannot be compared directly, the combination of external elite retention and internal random selection is applied to produce new offspring, which have a negative effect on time efficiency, but can get better pareto non-dominated solutions.

The main steps of algorithm are as follows:

Step 1: as the resource selection need to determine the assignment of equipment, and the production batch assigned to each processing route as well. Therefore, the hybrid coding strategy is adopted with equipment selection module using the 0-1 encoding and batch and equipment distribution using integer coding.

Step 2: Generate initial random population P_0.

Step 3: Calculate the fitness value of initial population, select all non-dominated solutions to construct the external pareto non-dominated solution set and start the iteration.

Step 4: Calculate the fitness value of current population, put together with the external pareto solution set, remove the solutions of repetitive or dominated and update the external pareto solution set.

Step 5: Determine the probability of crossover and mutation based on the fitness value of current population and iteration counter and perform the adaptive crossover or mutation to generate the new offspring.

Step 6: Eliminate invalid individuals, and retrieve some elite individuals from the external non-dominated solutions and form the temporary parent to select new individuals randomly.

Step 7: Let the new offspring be current generation, add 1 with iteration counter until it reaches maximum iteration or meets the termination conditions.

In Step 5 and Step 6, the new individuals are mainly generated from genetic operation. To find the optimal pareto solution set of the resource selection problem, the following improvements of the three operators are performed in this paper.

3.1.1 *Selection strategy*

In order to ensure high quality of new individuals, it adopts the elite retention strategy: the external pareto solution will be chosen as the parent generation of individuals in priority, and it must strictly limit the selected number so as to guarantee uniformity of individuals. Also it applies the random selection to ensure the equal probability of each individual, and thus it can guarantee the offspring's diversity.

3.1.2 *Adaptive crossover and mutation strategy*

The whole evolution in traditional genetic algorithm used fixed crossover an mutation probability. In the beginning, the algorithm cannot produce enough new individuals ; whereas it will produce a large number individuals of poor quality in late times. It does not benefit to the convergence of the algorithm. Therefore, the adaptive crossover and mutation strategy are adopted to set the upper and lower limitation of crossover and mutation probability in advance, and gradually adjust the probability of each iteration according to the fitness value of current population and evolution iteration.

In the equation (12) and (13), *cross_rate* and *mutate_rate* denote the adaptive crossover and mutation probability of current iteration. *cross_max*, *cross_min*, *mutate_max* and *mutate_min* denote the upper and lower limitations of crossover and mutation probability. *maxgen* is the maximum iteration，*iter* means the current iteration counter. *f'* means a fitness vector composed of maximum value of four objectives in two selected individuals which are used to perform crossover operation, f_{avg} means the fitness vector composed of average value of four objectives in the current population, *f* means the fitness value needed to perform mutation operation.

The pseudo code of the whole algorithm as following shows the entire implementation process of the algorithm.

```
Begin
Initialize P0;
Calculate the fitness of P0;
Generate Initialize pareto;
t=1; //iteration counter
While t<maxgen do
Calculate the fitness of Pt;
        update pareto;
        Qt= select(Pt);
Rt=select(Pareto_indiv);
        Qt+1= Qt ∪Rt;
        Calculate Cross-rate&mutate-rate
Qt+1=crossover(Qt+1);
        Qt+1=mutation(Qt+1);
        Pt=Qt+1;
end while
end
```

4 CASE STUDY

4.1 *Background of the case*

Shipbuilding is always the customization production due to its specialty. To a certain degree, some production of its parts can be stadardized and thus it can realize batch production. Pipe is an indispensable part for ship and it can be divided into many kinds of products according to the features and requirements. Our study is based on a whole production data of one shift assignment. The equipment information of the workplace is in Table 1; the transportation distances between each equipment are presented in Table 2; the specific processing and route information of the parts, and the requirements of each cycle are shown in Table 3. The transportation batch (pieces) of three pipe jobs P1, P2, P3 are prsesented as B1 = 25, B2 = 20, B3 = 30 respectively; the delivery time (minutes) are set as 1500, 1860, 570.

Table 1. Equipment information

Process	Equipment/quantity/capability (minute)
cut	M1/2/2600, M4/1/1350
bend	M2/2/2000
hydraulic test	M3/2/750, M7/1/2000
weld	M5/1/6000, M6/2/2000
surface treatment	M8/1/4000

Table 2. Transportation distance between equipment (m)

	M1	M2	M3	M4	M5	M6	M7	M8
M1	0	6	15	20	9	12	19	30
M2		0	8	23	12	8	11	29
M3			0	28	15	11	3	14
M4				0	22	26	28	37
M5					0	5	13	25
M6						0	9	21
M7							0	12
M8								0

Table 3. Processing information of the parts

Part	Route	Equipment/processing time(minute)	Demand h1	h2	h3
P1	1-1	M1/10-M2/10- M3/5	170	0	154
	1-2	M4/6-M2/10-M3/5			
P2	2-1	M1/25-M5/31-M2/15- M3/5	75	87	83
	2-2	M4/19-M5/31-M2/15- M3/5			
	2-3	M1/25-M6/26-M2/15-M3/5			
	2-4	M4/19-M6/26-M2/15- M3/5			
P3	3-1	M5/38- M3/9- M8/32	30	94	65
	3-2	M6/41- M7/12- M8/32			

4.2 *The model solution and analysis*

In order to simultaneously complete the processing of 3 kinds of products in three periods, the resource selection module adopts the 8 * 8 type with 0-1 coding structure, and as for the route of batch distribution in three periods, it adopts 3 * 8 integer coding structure. The population size is 100, the maximum iteration is 500 and the probability of the external elite retention is under 50%. The maximum number of external non-dominated solution must be less than 300 to ensure the calculation efficiency of AMOGA. All calculation coding of fitness value and AMOGA are implemented in Matlab 7.11. Due to randomness of the initial population, the AMOGA need to be performed 10 times and gather the whole pareto non-dominated solutions are gathered and the ones of repetitive or dominated should be eliminated and 90 pareto solutions are obtained finally.

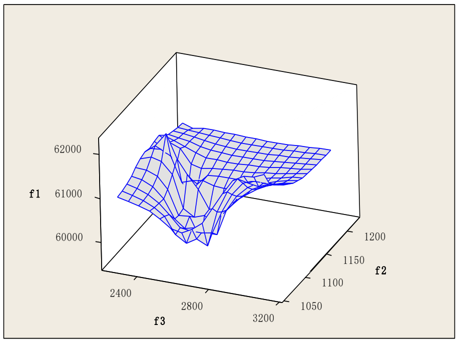

Figure 1. The 3D distribution figure of f1, f2, f3

As shown in Figure 1, the pareto non-dominated solutions obtained by AMOGA can cover the optimal front of pareto solution well and are equally distributed, and the optimal value of each target can be obtained. However, there exists inherent conflicts between the four objectives, especially the limits of f1 and f2 caused by f3, which is determined by the meaning of the objective itself. In order to obtain the best solution, the impact of different dimensions in four objectives must be rule out first, and then the 90 pareto solutions should be standardized by equation (14).

$$y = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \tag{14}$$

After standardization, the virtual positive and negative ideal points will be determined based on TOPSIS, and then it need to calculate the close degree of each solution. Finally, the best solution of resource selection and allocation can be obtained.

As the same processing of different parts may involve the adjustment of molds, jigs or tools and other auxiliary production tooling, it will need more time for adjustment. In order to reduce the time for adjustment, some processing routes with small production batch will be merged into other suitable ones. The original optimal solution “Rh” and modified

"Rh*" can be seen in Table 4. The solution "Sh" can be obtained by putting the part demand of three periods into the model respectively.

The objective values of "Sh" are (40189, 899, 1540.528, 0.1614). However, the objective values of "Rh" of robust strategy are (38046, 979, 1265.833, 0.0672). We can see that the load balance rate of equipment and the value of the scheduling factor decreased. Therefore, to some extent the conflicts in the scheduling stage will be reduced. The production plan will be more reasonable by merging the routes with small processing batch to other routes. The modified value of objectives are (37904, 958, 1426.5, 0.0474) ; although the value of objectives of the corrected solution have little change, euipment M7 can be released completely.

Table 4. Resource selection and allocation solution

	R1	R2	R3	R4	R5	R6	R7	R8
Rh1	65	43	0	0	38	37	63	0
Rh2	71	37	18	0	19	38	52	11
Rh3	62	46	6	0	33	36	59	4
Rh1*	65	43	0	0	38	37	63	0
Rh2*	71	37	18	0	19	38	63	0
Rh3*	62	46	0	0	36	39	63	0
Sh1	170	0	0	20	36	19	14	16
Sh2	0	0	0	0	87	0	85	9
Sh3	154	0	0	31	0	52	50	15

Table 5. Load distribution of equipment (10^2 minutes)

	m1	m2	m3	m4	m5	m6	m7	m8
Rh1*	16	22.1	14.8	9.6	23.9	19.5	0	20.2
Rh2*	21.8	13.1	12	0	32.3	26.3	1.1	30.1
Rh3*	15.4	27.9	16.4	15.8	28.6	19.7	1.8	20.8
Sh1	16	22.1	14.8	9.6	23.9	19.5	0	20.2
Sh2	16.4	22.1	14.8	9.4	29.5	14.8	0	20.2
Sh3	15.2	22.1	14.8	10.2	23.9	19.5	0	20.2

The 2th to 4th column of Table 5 represent the equipment load in single period, and the 5th to 7th column of Table 5 represent the equipment load based on the robust strategy. As we can see in Table 5, the resource selection based on the robust strategy can balance the load of every equipment in each period, and the balace can be performed according to the processing capacity of the equipment and the requirements of the parts. From the perspective of resource selection, due to fluctuations of the parts, the choice of resources will be changed frequently to realize good production performance. This situation will not only make the production management chaos and bring a large amount of waste in production process, but also increase the preparation cost of equipment and generate more frequent changes of production tasks and workplaces. With considering the resource selection in robust strategy, the cell formation can achieve a good production balance, and greatly avoid the conflicts between resources in production and relatively stablize the processing status of the euipment and workers.

5 CONCLUSION

The dynamic formation of virtual cell has always been a hot topic in the study of virtual cellular manufacturing system: the effect of the cell largely determines the efficiency of the whole system, and the resource selected by cell is the premise of cell formation. So this paper studies the problem of resource selection in the process of dynamic virtual manufacturing cell formation with considering the parts demand in multi-periods. The four objectives of production, transportation cost, equipment load balance and scheduling factor must be taken into full consideration; the cycle processing demands need to be balanced, thus obtaining more robust resource combination. Based on the newest optimal pareto techniques and random elite retention strategy, the genetic algorithm can be developed to solve practical problem. Also, it shows good application ability of the model from two aspects of the optimization objectives and actual production effect.

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REFERENCES

[1] Mak L.K., Lau S.K.J. & Wang X. X. 2005. A genetic scheduling methodology for virtual cellular manufacturing systems: an industrial application. *International Journal of Production Research*, 43(12): 2423-2450.

[2] Iraj Mahdavi, Amin Aalaei, Mohammad Mahdi Paydar & Maghsud Solimanpur. 2012. Multi-objective cell formation and production planning in dynamic virtual cellular manufacturing systems. *International Journal of Production Research*, pp : 6517–6537.

[3] Sheng Leng, Xiaobin Wei, Ningsheng Wang & Wenyi Zhang. 2007. Resouce slection in virtual manufacturing cell reconfiguration. *Computer Integrated Manufacturing Systems*, 12(11): 1814-1820.

[4] Ning Guo, Tianguo Jing & Wenjian Liu. Formation of a new manufacturing resource model based on virtual manufacturing cell. 2009. *Computational Intelligence and Software Engineering*, pp : 1-4.

[5] Wenming Hang, Liyi Zeng & Yunde Wei. 2011. Study on dynamic reconfiguration approach of manufacturing cell for make-to-order. *Process Automation Instrumentation*. 32(3): 29-32.

[6] Javadian N, Aghajani A & Rezaeian J, et al. 2011. A multi-objective integrated cellular manufacturing systems design with dynamic system reconfiguration. *The International Journal of Advanced Manufacturing Technology*, 56(1-4): 307-317.

[7] Defersha M.F. & Chen M. 2008. A linear programming embedded genetic algorithm for an integrated cell formation and lot sizing considering product quality.

Europe Journal of Operations Research, 187 (1): 46–69.
[8] Kia R., Baboli A. & Javadian N., et al. 2012. Solving a group layout design model of a dynamic cellular manufacturing system with alternative process routings, lot splitting and flexible reconfiguration by simulated annealing. *Computers & Operations Research*, (39): 2642-2658.
[9] Deep K & Singh P.K. 2015. Design of robust cellular manufacturing system for dynamic part population considering multiple processing routes using genetic algorithm. *Journal of Manufacturing Systems*, 35: 155-163.
[10] Mak L.K. & Ma J. 2011. A Novel Hybrid Algorithm for Multi-period Production Scheduling of Jobs in Virtual Cellular Manufacturing Systems. *Proceeding of the Word Congress on Engineerin*g, 1: 978-988.