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Robust Design of Dynamic Cell Formation Problem Considering the Workers Interest

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ABSTRACT

To enhance agility and quick responding to customers' demand, manufacturing processes are rearrenged according to different systems. The efficient execution of a manufacturing system depends on various factors. Among them, cell design and human issue are the pivotal ones. The proposed model designs cellular manufacturing systems using three objective functions from three different perspectives, to reflect a more realistic picture of the cell formation problem. This paper presents a model with the goals of maximizing the total value of grouping efficacy and minimizing the total costs and total non-interest workers in cells in a dynamic environment for several consecutive periods. The main idea of the proposed model is enhancing cell efficiency through an assigning the group of workers who have a mutual interest in working with each other. For solving the current model, the revised multi-choice goal programming method has been employed. Finally, computational results and sensitivity analysis are discussed.

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1. INTRODUCTION

Manufacturing companies upgrade their process continuously regarding maintaining their share survival in growing global markets. Group technology (GT) by concentrating on cellular manufacturing (CM) is an approach that helps manufacturers to enhance agility and quick responding to customers' demands. Cellular manufacturing (CM) systems give practitioners an exceptional opportunity to take the advantage of the cost-effectiveness of mass production approach and flexibility of job shop manufacturing by classifying similar parts and dissimilar machines into part families and machines cells, respectively.

There are many preponderances concerned with cellular manufacturing systems including diminished material handling, setup time, expedition, in-process inventory, part makespan, promoted human relations, and operator proficiency and also some disservices including boosted capital investment and lower machine usage. Throughout the literature on CM, there are several surveys and review-based articles which have provided a wide perspective about the research achievements and future research directions.

Many scholars attempted to enhance the synergy among the various aspects of the cellular manufacturing system by relying on one of the most strong optimization tools, mathematical modeling, which has had prominent application in cell formation problem. In CMS, operators play a crucial role in exploiting productive resources. In order to guarantee optimization of CM executions, a complementary match between social and technical systems is required. Team-related approaches [1, 2] in the workforce is an efficient avenue for improving the workers' productivity and consequently the manufacturing systems. One approach to elevate system productivity is assigning a suitable operator to suitable machinery. In this regard, by utilizing mathematical modeling tools, many scholars tried to incorporate the human factor in cell formation problem. Table 1 provided a brief overview of the literature on the worker assignment problem in cellular manufacturing systems. Since more than one operator is assigned to a cell, employing the interest-based relationship concept in worker assignment problem could help operators to create a friendly atmosphere among themselves. Increasing participation, synergy, interchange experiences and self-education are the consequences of

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the mentioned condition and in the long run, manufacturers will reach to more profit. As it is shown in Table 1, there is no previous study that incorporates the mutual interest among workers concerned with worker assignment problem.

This paper presents a multi-objective mathematical model for the multi-period cell formation problem in a dynamic environment. The proposed considered multi-period period, system reconfiguration, the availability of workers, worker assignment considering the mutual interest among operators, machine assignment, and machine capacity. The intention of the proposed model are maximizing the total value of grouping efficacy, minimizing the total costs and total noninterest workers in each cell. The cost function includes machine overhead cost, machine processing, hiring, firing, and salary costs. To solve the proposed multi-objective mathematical model, a revised multi-choice goal programming is utilized. The rest of the paper is arranged as follows: Sections 2 and 3 provide problem formulation and methodology, respectively. Problem validation using experimental results presents in section 4. In section 5, the sensitivity analysis is carried out. The conclusion is provided in section 6. The paper ends with some directions for future works.

2. PROBLEM FORMULATION

In this section, The proposed model with the goals of maximizing the total value of grouping efficacy (TVGE), and minimizing the total costs (TC) and total noninterest (TNI) workers in cells is described. The momentous notion of the proposed model is enhancing cell efficiency through an assigning the group of workers who have a mutual interest in working with each other.

2. 1. Sets

Q	Number of part types.
W	Number of worker types.
M	Number of machine types.
C	Number of cells.
H	Number of periods.
I	Index for part type (i=1, …, Q)
W	Index for worker type (w=1,…,W)
M	Index for machine type (m=1,…,M)
K	Index for cell (c=1,…,C)
T	Index for period (h=1,…,H)

2. 2. Input Parameters

r_{imw}	1 if machine type *m* is capable to process part type *i* with worker *w*; 0 otherwise.
a_{im}	1 if part type *i* requires machine type *m*; 0 otherwise.
$b_{ww'}$	1 if there is mutual interest between worker *w* and w' ; 0 otherwise
LM_k	Minimum number of machines assigned to cell *k*
LW_k	Minimum number of workers assigned to cell *k*

TABLE 1. An overview of literature on the worker assignment

Considered factors in worker assignment	Goals					Ref.
	Cell Layout	Production Planning	Worker Assignment	Machine Assignment	Part Assignment	
Technical skill, Worker conative tendencies			■			[3]
Technical skill, change in worker skill level/ Training, General Cognitive Ability level		■	■			[4]
Technical skill,workers' multi-functionality		■	■			[5]
Available number of workers			■		■	[6]
Available time and number of workers		■	■	■	■	[7]
Technical skill, available time and number of workers		■	■	■	■	[8]
Technical skill, change in worker skill level/ Training, workers' multi-functionality	■	■	■	■		[9]
Technical skill			■	■	■	[10]
Technical skill, change in worker skill level/ Training and forgetting		■	■	■	■	[11]
Technical skill, change in worker skill level/ Training	■	■	■	■	■	[12]
Technical skill, available time and number of workers		■	■	■	■	[13]
Technical skill, change in worker skill level/ Training, available time and number of workers		■	■	■	■	[14]
Technical skill, change in worker skill level/ Training, available time and number of workers	■	■	■	■	■	[15]
Technical skill, available time and number of workers, the interest level- matrix among operators		■	■	■	■	Current work

LP_k	Minimum the number of parts assigned to cell *k*
AM_m	The number of available machines of type *m*
AW_w	The number of available workers of type *w*
RW_{wt}	Available time for worker type *w* in period *t*
RM_{mt}	Available time for machine type *m* in period *t*
Ti_{imw}	Processing time of part type *i* on machine type *m* with worker type *w*
D_{it}	Demand of part type *i* in period *t*
α_m	Maintenance and overhead expenses of machine type *m*.
β_m	Operation expense of machine type *m* in unit time
HI_{wt}	Hiring expense of worker type *w* within period *t*
FI_{wt}	Firing expense of worker type *w* in period *t*
Sa_{wt}	Salary expense of worker type *w* in period *t*.
NP	Number of periods
A	An arbitrary big positive number

2. 3. Decision Variables

$\boldsymbol{Y_{ikt}}$	1 if part type *i* is operated in cell *k* in period *t*, 0 if not.
Z_{wkt}	1 if worker w is allocated to cell *k* in period *t*, 0 if not.
X_{mk}	1 if machine m is assigned to cell *k* in period *t*, 0 if not.
G_{imwkt}	1 if part type *i* is to be operated on machine type *m* with worker *w* in cell *k* in period *t*, 0 if not.
NW_{wt}	A number of workers of type *w* assigned period *t*.
L^+_{wt}	A number of workers of type *w* hired system during period *t*.
L^-_{wt}	A number of workers of type *w* fired during period *t*.

2. 4. Mathematical Model

$$MaxTVGE = \sum_{t=1}^{T}\sum_{i=1}^{p} D_{it}\left(\frac{Numerator}{Deno\min ator}\right)$$
$$Numerator: \sum_{m=1}^{M}\sum_{w=1}^{W} r_{imw} - \sum_{k=1}^{C}\sum_{m=1}^{M}\sum_{w=1}^{W}[X_{mk}(2 - Y_{ikt} - Z_{wkt})G_{imwkt}] \; Deno\min a\,tor: \sum_{m=1}^{M}\sum_{w=1}^{W} r_{imw} + \sum_{k=1}^{C}[\sum_{m=1}^{M}\sum_{w=1}^{W} X_{mk} Y_{ikt}.Z_{wkt} - \sum_{m=1}^{M}\sum_{w=1}^{W} X_{mk}.Y_{ikt}.Z_{wkt}.G_{imwkt}] \quad (1)$$

$$MinTC = \left[\left(\sum_{k=1}^{C}\sum_{m=1}^{M}\alpha_m . X_{mk}\right).NP\right] + \sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{k=1}^{C}\sum_{w=1}^{W}\sum_{m=1}^{M} B_m.Ti_{imw}.G_{imwkt}.D_{it} + \sum_{t=1}^{T}\sum_{w=1}^{W} HI_{wt}.L^+_{wt} + \sum_{t=1}^{T}\sum_{w=1}^{W} FI_{wt}.L^-_{wt} + \sum_{t=1}^{T}\sum_{w=1}^{W} Sa_{wt}.NW_{wt} \quad (2)$$

$$MinTNI = \sum_{k=1}^{K}\sum_{t=1}^{T}\sum_{w=1}^{W-1}\sum_{w'=w+1}^{W} z_{wkt}.z_{w'kt}(1 - b_{ww'}) \quad (3)$$

Subject to:

$$\sum_{w=1}^{W}\sum_{i=1}^{I} G_{imwkt}.Ti_{imw}.D_{it} \le X_{mk}.RM_{mt} \quad \forall m,k,t \quad (4)$$

$$\sum_{m=1}^{M}\sum_{i=1}^{I} G_{imwkt}.Ti_{imw}.D_{it} \le NW_{wt}.RW_{wt} \quad \forall w,k,t \quad (5)$$

$$NW_{wt} = NW_{w(t-1)} + L^+_{wt} - L^-_{wt} \quad \forall w,t \quad (6)$$

$$\sum_{k=1}^{C} X_{mk} \le AM_m \quad \forall m \quad (7)$$

$$\sum_{k=1}^{C} Z_{wkt} \le AW_w \quad \forall w,t \quad (8)$$

$$\sum_{w=1}^{W} Z_{wkt} \ge LW_k \quad \forall k,t \quad (9)$$

$$\sum_{m=1}^{M} X_{mk} \ge LM_k \quad \forall k \quad (10)$$

$$\sum_{i=1}^{I} Y_{ikt} \ge LP_k \quad \forall k,t \quad (11)$$

$$\sum_{k=1}^{C} Z_{wkt} = NW_{wt} \quad \forall w,t \quad (12)$$

$$\sum_{k=1}^{C} Y_{ikt} = \min(1, D_{it}) \quad \forall i,t \quad (13)$$

$$G_{imwkt} \le r_{imw}.X_{mk} \quad \forall i,m,w,k,t \quad (14)$$

$$\sum_{k=1}^{C}\sum_{w=1}^{W} G_{imwkt} = a_{im}.\sum_{k=1}^{C} Y_{ikt} \quad \forall i,m,t \quad (15)$$

$$X_{mk}, Z_{wkt}, Y_{ikt}, G_{imwkt} \in \{0,1\} \quad \forall i,m,w,k,t \quad (16)$$

$$L^+_{wt}, L^-_{wt}, NW_{kt} \ge 0 \quad \forall w,k,t \quad (17)$$

The first objective function (TVGE) attempts to maximize the total value of grouping efficacy. TC minimizes several costs. The third objective function minimizes total noninterest (TNI) workers in cells.

Constraints (4) and (5) guarantee that the available time for machines and the number of workers does not overstep from defined value, respectively. Constraint (6) ensures that the workers balance in different periods. Constraint (7) controls the available machines which can be allocated to each cell. Constraint (8) controls the available workers of type *w* which can be allocated to each cell. The lower bounds for availabe resources are given in Constraints (9), (10) and (11). Constraint (12) ensures that the balance of workers in all cells. Constraint (13) represents that part *i* is assigned only a cell or not. Constraint (14) indicates that when part type *i* could be processed in cell *k* if required machine and required worker were assigned to cell *k* previously. Constraint (15) controls the allocation of one worker, if one part requires to be processed by machine type *m*. Constraints (16) and (17) define the variable type. For the sake of brevity, the linearization of proposed nonlinear model is not given.

In the way of solving multi- objective optimization model, advantages associated with the goal programming (GP) approach [16] have made it as an attractive approach [17] for scholars. Chang et al. [18] imposed some revisions on GP and proposed the revised multi-choice goal programming (RMCGP) approach which is more flexible speedy than the original version of GP.

Here, the revised multi-choice goal programming (RMCGP) model for the proposed problem is formulated.
Variables and Parameters:

w_i	weight of positive and negative deviation of the *i-th* goal
$f_{i.min}$	Lower bound of the *i-th* goal expectation level
$f_{i.max}$	Upper bound of *i-th* goal expectation level
ρ_i	The weight attached to the sum of the positive and negative deviations from level R_i
f_1	TVGE objective function
f_2	TC objective function
f_3	TNI objective function
e_i^+, e_i^-	Positive and negative deviations attached to $\lvert y_{i-} g_{i\,max}\rvert$, the more the better strategy- based
e_i^+, e_i^-	Positive and negative deviations attached to $\lvert y_{i-} g_{i\,min}\rvert$, the less the better strategy- based
R_i	Expected level for objective function *i*

Mathematical model:

$$Minz=\left(\frac{w_1}{f_{1.\max}-f_{1.\min}}\right)(d_1^+ + d_1^-)+\left(\frac{\rho_1}{f_{1.\max}-f_{1.\min}}\right)(e_1^+ + e_1^-) +\left(\frac{w_2}{f_{2.\max}-f_{2.\min}}\right)(d_2^+ + d_2^-)+\left(\frac{\rho_2}{f_{2.\max}-f_{2.\min}}\right)(e_2^+ + e_2^-)+ \left(\frac{w_3}{f_{3.\max}-f_{3.\min}}\right)(d_3^+ + d_3^-)+\left(\frac{\rho_3}{f_{3.\max}-f_{3.\min}}\right)(e_3^+ + e_3^-) \quad (18)$$

S.t:

Constraints (4)-(17)

$$f_1 - d_1^+ + d_1^- = R_1 \quad (19)$$

$$R_1 - e_1^+ + e_1^- = f_{1.max} \quad (20)$$

$$f1_{1.max_{1.min}} \quad (21)$$

$$f_2 - d_2^+ + d_2^- = R_2 \quad (22)$$

$$R_2 - e_2^+ + e_2^- = f_{2.min} \quad (23)$$

$$f2_{2.max_{2.min}} \quad (24)$$

$$f_3 - d_3^+ + d_3^- = R_3 \quad (25)$$

$$R_3 - e_3^+ + e_3^- = f_{3.min} \quad (26)$$

$$f3_{3.max_{3.min}} \quad (27)$$

$$f_1 \le f_{1.max} \quad (28)$$

$$f_1 \ge f_{1.min} \quad (29)$$

$$f_2 \le f_{2.max} \quad (30)$$

$$f_2 \ge f_{2.min} \quad (31)$$

$$f_3 \le f_{3.max} \quad (32)$$

$$f_3 \ge f_{3.min} \quad (33)$$

$$d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^-, e_1^+, e_1^-, e_2^+, e_2^-, e_3^+, e_3^- \ge 0 \quad (34)$$

3. COMPUTATIONAL RESULT

To elucidate the credibility of the proposed model, some instances are solved using RMCGP by LINGO 9.0. The first example consists of two cells, four machines, four parts, and three workers. The data set associated with are given in Tables 1 to 3, respectively.

The workers data, processing time of each part, and machine data set are presented in Tables 4 to 6, respectively. The results are pesented in Table 7. This

TABLE 1. Example #1 input data of machine -part matrix

		Machine type				Demand Quantity		
		1	2	3	4	D_{i1}	D_{i2}	D_{i3}
Part type	1	1	0	1	0	300	1500	150
	2	0	1	0	0	20	0	500
	3	1	0	1	0	400	980	0
	4	0	0	0	1	700	750	300

TABLE 2. Example #1 input data of machine- worker

		Machine type			
		1	2	3	4
Worker type	1	1	0	1	0
	2	0	1	0	0
	3	1	0	1	1

TABLE 3. Example #1 input data of worker_worker incidence matrix

		Worker type		
		1	2	3
Worker type	1	1	0	1
	2	0	1	0
	3	1	0	1

Table shows the machine assignment, part assignment and worker assignment to cells during three consecutive periods. Moreover, the obtained results of large instances, example numbers 2 and 3, through proposing model and RMCGP method are summarized in Table 8. For brevity, the related data of examples 2 and 3 are not given.

TABLE 4. Example #1 input data about workers

		Workers' data			
		AW_w	Sa_{w1}	Sa_{w2}	Sa_{w3}
	1	2	435	440	500
	2	2	460	485	490
	3	2	450	465	500
		HI_{w1}	HI_{w2}	HI_{w3}	FI_{w1}
	1	240	260	285	145
Workers	2	260	290	295	145
	3	265	270	285	155
		FI_{w2}	RW_{w1}	RW_{w2}	RW_{w3}
	1	150	30	30	30
	2	150	30	30	30
	3	160	30	30	30

TABLE 5. Example #1, the processing time

		Part 1			Part 2		
		W_1	W_2	W_3	W_1	W_2	W_3
Machine	M_1	0.04		0.02			
	M_2					0.03	
	M_3	0.01		0.02			
	M_4						
		Part 3			**Part 4**		
		W_1	W_2	W_3	W_1	W_2	W_3
Machine	M_1	0.02		0.03			
	M_2						
	M_3				0.03		0.04
	M_4		0.03	0.04		0.02	0.04

TABLE 6. Example #1, input data about machines

Machine type	Data of machines					
	AM_M	α_m	B_m	RM_{m1}	RM_{m2}	RM_{m3}
1	2	620	20	30	30	30
2	2	810	30	30	30	30
3	2	730	25	30	30	30
4	2	670	28	30	30	30

TABLE 7. The results of Example #1

P	Part Assignment		Machine Assignment		Workers Assignment	
	Cell 1	Cell 2	Cell 1	Cell 2	Cell 1	Cell 2
1	2	1 & 3			2	3
2	4	1 & 3	2& 4	3 & 1	3	3
3	2	1 & 4			2	3

TABLE 8. The result of example number 1, 2, and 3

Exp. No.	P	W	M	K	T	No. of constraint	No. of the decision variable	CPU (S)	TC	TVGE	TNI
1	4	3	4	2	3	469	383	50	16206	3980	0
2	7	5	6	2	2	1050	948	2380	16372	1248	0
3	9	5	6	2	2	1318	1196	28800	17208	1587	0

As can be seen in Table 8, with an increase in the size of the problem, the CPU usage will also increase. It means that the proposed algorithm for solving the large size problem is too time-consuming.

4. SENSITIVITY ANALYSIS

We implemented the sensitivity analysis from three different perspectives on model features: (1) hiring and firing workers, (2) the weight of objective functions in goal programming and (3) workers interest perspective.

4. 1. Hiring and Firing Scenarios

The owners of various industries, depending on their policies, proceed to hire and fire the workers. Two opposing policies for hiring and firing the workers in the period can be carried out. In this paper, hiring and firing workers occurs at the initiation of a period. However, the production plan can be initiated with fixed workers in all periods. Here, this case is called the opposite scenario. Table 9 shows the value of three objective functions for both flexible and fixed workers scenarios for example 2. Figures 1 and 2 compare the result of these opposing scenarios.

As can be seen in Table 9, Figures 1 and 2, in fixed scenario, the cost of production systems will be significantly increased and also system efficiency will improve because this policy compels the system to continue its process with the current workers. However, due to the high amount of workers salary than firing and hiring cost, the system will face increased production costs during each period.

TABLE 9. The value of objective functions in different scenarios

	Instance Size	Objective Function		
		TC	TVGE	TNI
flexible workers	Small	16206	3980	0
	Medium	16372	1248	0
	large	17208	1587	0
fixed workers	Small	16458	4030	0
	Medium	16635	1483	0
	large	17434	1595	0

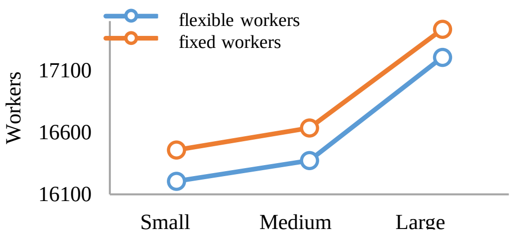

Figure 1. TC in different scenarios – Example 2

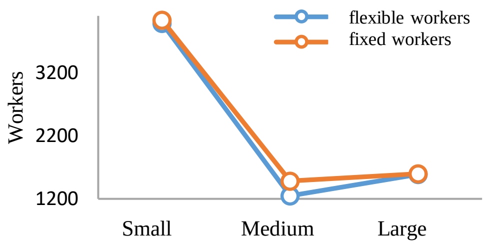

Figure 2. TVEG in different scenarios – Example 2

4. 2. Weight of Objective Functions The behavior of objective functions will be examined in this section in the presence of assigning various weights in RMCGP algorithm. In this paper, 8 different weight is assigned to each objective functions. The obtained results have been presented in Table 10 and Figures 3, 4, and 5. Variable *Z* in Table 10 represents the final value of objective function in RMCGP algorithm.

4. 3. Workers Interet In this section, the behavior of objective functions will be examined in the presence of two opposing situation, when it affects the workers interest and when it assumes that workers are indifferent to each other.

As can be seen in Figure 6 and 7, although the better value for TC and TVGE functions when the interest of the workers is not considered, according to the Liemhetcharat et al.'s research work [19], increasing the synergy among workers has long-term benefits for system and in this regard, when the system could reach the maximum level of synergy that imposes the workers interest.

TABLE 10. The behavior of objective functions in the presence of assigning various weights

State	Weight			Z	Value		
	TVGE	TC	TNI		TVGE	TC	TNI
1	0.8	0.1	0.1	0.155	1394	17771	2
2	0.7	0.2	0.1	0.302	1376	18828	1
3	0.6	0.3	0.1	0.471	1303	17533	1
4	0.6	0.2	0.2	0.426	1315	17379	1
5	0.5	0.2	0.3	0.426	1663	18956	1
6	0.3	0.6	0.1	0.256	1448	16391	0
7	0.2	0.7	0.1	0.219	1207	16356	0
8	0.1	0.8	0.1	0.110	1248	16372	0

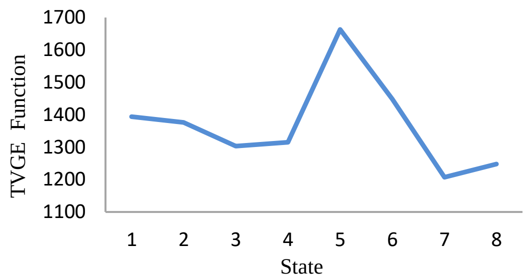

Figure 3. The behavior of TVGE function

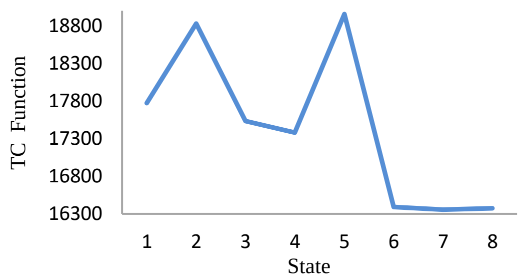

Figure 4. The behavior of TC function

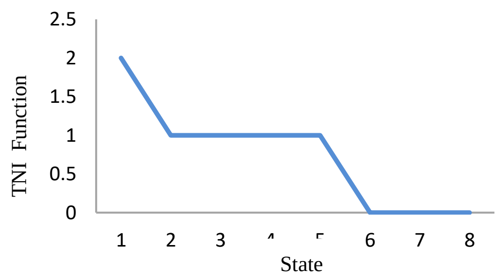

Figure 5. The behavior of TNI function

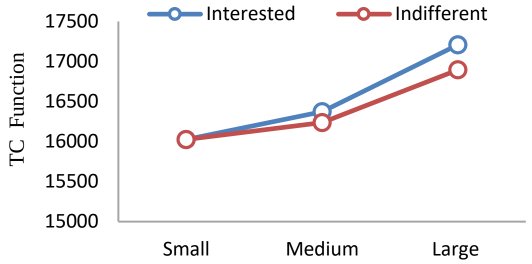

Figure 6. The behavior of TC function

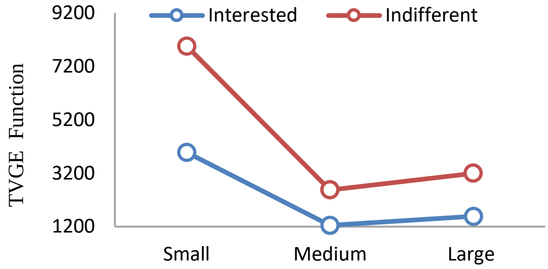

Figure 7. The behavior of TVGE function

5. CONCLUSION

This paper presented a multi-period cell formation problem in a dynamic environment with the goals of maximizing the total value of grouping efficacy and minimizing the total costs and total noninterest workers. The interest-based relationship notion for the worker assignment problem allows workers to establish a friendly atmosphere among themselves. The proposed model designs cellular manufacturing systems using three objective functions from three different perspectives, to reflect a more realistic picture of the cell formation problem.

The sensitivity analysis is executed to figure out the model in the presence of fixed and flexible workers in the system. The model behavior under these two opposing strategies indicates that with the fixed number of workers, the cost of the production system will be significantly increased and also system efficiency will improve. In the second attempt, we tried to evaluate the behavior of objective functions under assigning various weights to them. The question about which objective function should receive more priority is completely depended to company policy and finally, the model behavior was assessed when the workers interest is overlooked.

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Robust Design of Dynamic Cell Formation Problem Considering the Workers Interest

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چکیده

برای پیاده‌سازی موفق تولید سلولی، دو عامل طراحی سلول و مسائل انسانی فاکتور مهم و قابل توجه‌ای به حساب می‌آیند. در این مقاله، مدل ریاضی چند هدفه برای مساله آرایش سلولی با در نظر گرفتن برنامه‌ریزی چند دوره‌ای در محیط پویا با هدف حداکثرسازی بهره‌وری گروهی و حداقل‌سازی هزینه‌ی کل و سطح عدم علاقه‌مندی کارگران سلول‌های کاری ارائه شده است. ایده‌ی اصلی مدل پیشنهادی، افزایش بهره‌وری سلول به وسیله تخصیص گروهی کارگرانی که علاقه‌ی متقابل در کار کردن با یکدیگر دارند. برای حل مدل پیشنهادی، روش برنامه‌ریزی آرمانی چند گزینه‌ای اصلاح شده به کار گرفته شده است. نتایج محاسباتی همراه با آنالیز حساسیت بر روی چند مساله نمونه ارائه شده است.

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