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Effect of Motivation & Learning Curve In Dynamic Cell Formation And The Worker Assignment Problem

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Abstract

The mathematical model presented in this paper considers dynamic cell formation and worker assignment problem simultaneously and also takes into account motivation, learning effect and rewards in cell formation problem's human issues for the first time. In real world problems the available time of workers is not constant and it depends on different items therefore learning curve and motivation effects are noticed to indicate the real available workers time. The model consists of two parts. First part is machine-based such as production cost, inter-cell material handling cost, machine costs in the planning horizon and second part is human-based such as hiring cost, firing cost, training cost, overtime cost, reward cost and salary. Finally a mathematical method and a hybrid solution approach based on simulated annealing (SA) and genetic algorithm (GA) is used in order to solve the problem. Numerical examples are presented to demonstrate the model and compare both solution approaches.

Keywords: Dynamic Cellular Manufacturing; Human Issues; Motivation; Learning Curve.

Introduction

Due to high production variety, short life cycle of production, inconsiderable demand and short delivery times, Cellular Manufacturing Systems (CMSs) are operated under dynamic and uncertain conditions [24]. Moreover, one of the main points in cellular manufacturing is considering human issues because ignoring this factor can reduce cell manufacturing benefits considerably. Bidanda et al. [3] state that, for the successful implementation of cellular manufacturing it is important to focus on both technical issues (cell formation and design) and human issues. However unfortunately, human issues are not examined commonly as technical issues [20]. Min and Shin [17] present a model which assumes that multi workers with different levels of job skills are available for assignment. Because of the difficult computation they divided the problem in two parts. First part is related to the reduction of goal programming formulation for cell formation and the second part is to assign appropriate part-machine values and solving the reduced formulation for worker assignment problem. Deljoo et al. [6] developed Min and Shin's model and notice human costs such as hiring cost, firing cost, training cost and salary.

This paper considers dynamic cellular manufacturing system and worker assignment problem simultaneously and also studies motivation and learning effect in human issues. To do so, Deljoo et al.'s model is developed. In their model motivation, over time cost, reward and also effect of learning curve are not considered. But here we have considered them with also assuming that workers can be trained to promote upper level after spending specific periods. In Deljoo et al.'s model, costs of material handling are independent of distance but it is assumed that cost of material handling depends on where materials are moved in this paper.

The rest of the paper is organized as follows. Section 2 provides a literature review of the dynamic cellular manufacturing and human issues. The development of the model is described in Section 3. In Section 4 solution methodology is explained and experimental results are declared in section 5. Finally conclusions and future research directions are provided in Section 6.

Literature Review

Nowadays manufacturing systems have become very important to global business. Due to the variety of demands, technologies and structure of organization must change. Thus manufacturing systems have to be managed on the basis of low cost and high quality. Also manufacturing systems should be able to respond rapidly to demand changes with low cost. In order to achieve high productivity in an unstable environment, cell manufacturing is one of the solutions used in manufacturing enterprises [4]. CMS is an application of Group Technology (GT) which link both advantage of flexibility and mass production. The aim of CMS is to reduce setup and flow times and therefore to reduce inventory and market response times. Setup times are reduced by using part-family tooling and sequencing, and flow times can reduced by minimizing setup and move times, wait times for moves the cause of reduce wait times for moves is using small transfer batches [20]. As mentioned in [20], the design of CMS has been called Cell Formation (CF).

Rheault et al. [21] introduced assumption of dynamic cellular manufacturing systems (DCMS). Kannan and Ghosh [14] studied scheduling in dynamic cellular manufacturing System (DCMS) and simplified cell scheduling. Drolet et al. [7] presented a four stage methodology to design DCMS and also studied scheduling and operating of DCMS. Marcoux et al. [16] studied and compared the performance of a DCMS with a classical cellular manufacturing system. Kuroda et al. [15] presented a method to design and control a cellular-line system to reduction in production lead times for large-scale manufacturing shops. Balakrishnan and Cheng [2] proposed a two-stage problem that consists of generalized machine assignment problem and dynamic cell formation programming problem under conditions of variable product demand. Tavakkoli-Moghaddam et al. [24] developed the model proposed by Balakrishnan and Cheng by adding some assumptions as: alternative process plans, sequence of operations, machine capacity limitation and machine replication. Safaei et al. [22] developed the model in [24] by adding the cell number flexibility assumption.

One of the important points in cellular manufacturing is considering human issues that can be useful in increasing the benefits of models. In a study by Bidanda et al. [3], In order to find human issues different researches have been done through which 8 factors of human issues important in CM have been found. These factors are: 1) worker assignment strategies, 2) skill identification, 3) training communication, 4) autonomy, 5) reward/compensation system, 6) team work and 7) conflict management. Table 1 summarizes the different factors of human issues. Min and Shin [17] stated the usefulness of human and machine cells in cellular manufacturing simultaneously and assumes that multi-skilled workers with different job levels are available for assignment. Cesani et al. [5] studied flexible labor in cellular manufacturing systems. The special focus of the investigation is to find the impact of using different labor allocation strategies on system performance. Aryanezhad et al. [1] developed the model by Min and Shin's model [17] and studied dynamic cellular manufacturing and worker assignment problem simultaneously. Their objective function consists of two parts one related to machine and operation costs and the other related to worker and human related costs. The objective of the problem is to minimize costs.

Rank	**Respondent Category**			
	Academics	**Managers**	**Workers**	**All Groups**
1	Training	Communication	Communication	Communication
2	Skill Identification	Teamwork	Training	Teamwork
3	Teamwork	Skill Identification	Teamwork	Training
4	Communication	Training	conflict management	Skill Identification
5	Worker Assignment Strategies	Reward/Compensation System	Reward/Compensation System	Reward/Compensation System
6	Reward/Compensation System	conflict management	Skill Identification	conflict management
7	conflict management	Worker Assignment Strategies	Worker Assignment Strategies	Worker Assignment Strategies
8	Autonomy	Autonomy	Autonomy	Autonomy

Most important

Least important

Motivation has an important effect on human productivity and can change productivity of labours by different aspects. Komarraju and Karau [13] studied the relationship between personality characteristics and academic motivation that may be cause of developing more effective teaching strategies. Gilman and Anderman [10] used cluster analysis to combine specific adaptive measures related to mastery motivation (intrinsic motivation, self-adequacy, and locus of control), a total of 654 high school students were placed into distinct adaptive motivation groups. Nakagami et al. [19] proposed examination of the nature of the relationships among Neuro cognition, intrinsic motivation, and psychosocial functioning for schizophrenia patients. Fan and Zhang [8] presents examination of relationships between thinking styles and motivation achievement among Chinese university students. Ishak et al. [12] shows effect of self-motivation and aspiration to learn affect academic performance. According to the reduction of learning curve time of performing a task, the time of action after some iteration is equal to ki^b where k is initial time of job activity, i is number of iteration and b is a negative coefficient [9, 18]. Gu and Takahash [11] investigated learning curves of a so-called ill-disposed learning algorithm that provides useful implications which is regarding the problem of over fitting from a practical. Soderholma and Sundqvist [23] identified and discussed a number of theoretical and econometric issues involved in the estimation of learning curves.

This paper presents a model for dynamic cell formation and worker assignment simultaneously. Motivation and learning effect and rewards also are considered. It is the first time that motivation and learning effect and reward are considered in human issues in cell formation.

Problem Description

This research considers a cell formation environment consisting of several machine groups called machine levels, each with a number of various machine types. Machines in each machine level need the same worker ability to do jobs containing them. Parts move from one machine type to another according to their flexible routing. Routing flexibility means that each operation of parts can be processed on more than one machine and maybe with different process times. Workers are grouped according to their skills and assigned to skill levels. Workers in each skill level have the same skills to do the jobs related to machine types. Newly hired workers are less efficient than experienced ones and have consequently less productivity. By considering learning curve and motivation the productivity of workers changes during periods, while workers perform an action for a long time they get tired and they won't have enough concentration on their work, leading to productivity reduction. In other words newly hired and newly trained workers can improve their productivity by repeating their tasks. According to the reduction of learning curve time of performing a task, the time of action after some iteration is equal to ki^b where k is initial time of job activity, i is number of iteration and b is a negative coefficient (for illustrative explanation, readers are referred to Figure 1) [9, 18]. Each worker has at least one skill which exactly belongs to only one skill level and can be assigned to certain machine levels depending on their skill levels. In each period, workers can be trained to improve their working abilities to operate other machine levels. Being aware of demand estimates for a number of future periods and an initial number of machines from each type located in each cell as well as initial number of workers of each skill level who are assigned to their related machine levels, we would like to determine the optimal strategy (minimum cost) to plan this cell manufacturing in the planning horizon. Particularly, in order to satisfy the total demand of each period, we are interested in determining:

- How many machines and of which types to purchase, relocate, install or remove in each cell and in each period;
- How many workers, with which skill levels to hire or fire in each period;
- How many workers to train, promoting from which skill levels to which higher ones, in each period.
- How many workers with which skill levels to assign to each machine level in each period.

The machine related part of proposed model is derived from previous DCF models in the literature, some improvement and changes applied to the part and human-related issues such as notice learning curve, motivation effect, reward cost, over time cost.

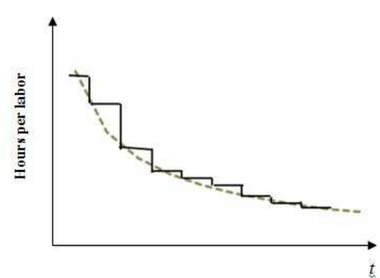

Figure1- Schematic of a learning curve

Assumptions

1. The demand for each part in each period is known.
2. Parts are moved between cells in batches. The cost of inter-cell material handling per batch between cells is known and depends on the distance between cells.
3. The machine purchasing cost is known and removal cost for newly purchased machines are not incurred by the location where machines are actually being relocated. It is performed between periods and requires zero time.
4. The maximum number of cells should be specified and it remains constant over time.
5. Bounds and quantity of machines in each cell must be specified and remain constant over time.
6. The machine relocation cost of each machine type is known and it is independent of where the machine is relocated.
7. Each machine type can perform one or more operations (machine flexibility). Each operation can be done on one or more machine type with different times (routing flexibility). Workers can only be assigned to machine levels which they are able to work.
8. Salary is merely dependent on worker's skill level and not depending on machine levels.
9. All of the machine types which need the same skill levels assumed to be similar in worker assignment.
10. Cost of hiring and firing are known and they merely depend on skill levels.
11. Each machine needs just one worker. To process a specific operation, the related machine and worker must be available at the same time.
12. Training, which is done to promote workers to upper levels, is performed in particular periods and worker can work in an upper level after training is finished. While the worker is getting trained, he/she must work in last level.
13. The productivity of experienced workers is assumed to be equal to 100% in the first period and by considering motivation the productivity decreases by spending time. Figure 2 shows the relation between time and productivity by considering motivation. From time t_0 to t_f the productivity decreases and after t_f its rate is fixed.
14. The productivity of newly trained workers and newly hired is assumed to be fewer than that of experienced ones, and it depends on the skill level to which they are trained and it increases by considering learning effect. Learning curve is indicated in Figure 2.
15. Training cost from one skill level to another is known and different. It depends on both skill levels.
16. Learning curve is considered in the model formulation.
17. In order to increase benefit and productivity of organization effective reward systems.

In previous models assume that cost of part handling is constant but in real is not true so here we assume that handling cost is depend on distance. Deljoo et al.'s model [6] does not notice learning curve and assumes that the productivity of expert workers is constant and 100% although by adding motivation effect their productivity changes during time.

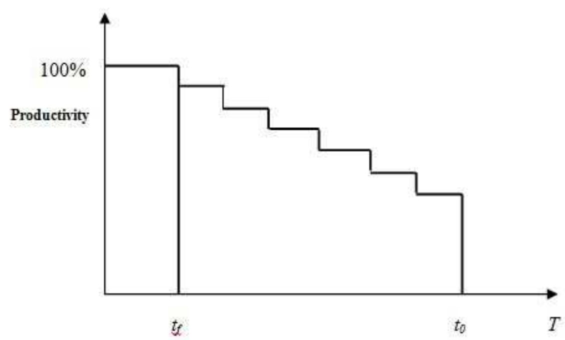

Figure2- Relationship between motivation and productivity

Proposed Model

Indices

C	Number of cells
M	Number of machine types
T	Number of time periods
OP	Number of operations required to produce part *p*
Ψ	Number of skill levels
MS	Number of machines levels
C	Index for manufacturing cells (*1*,…,*C*)
M	Index for machine types (*1*,…,*M*)
P	Index for part types (*1*,…,*P*)
T	Index for time periods (*1*,…,*T*)
j	Index for operations required for part *p* ($1,\ldots,O_p$)
k, k'	Index for machine levels (*1*,…,*MS*)
t_0	Index for time period α-level workers hired (*1*,…,*T*)

Input Parameters

C_m	Upper bound of cell size
RC_m	Lower bound of cell size
IN_m	Time required to perform operation j of part type *p* on machine type *m*
O_m	Inter-cell material handling cost per batch
MT_m	Big number
$h_{\alpha,t}$	Batch size of inter-cell material handling
$f_{\alpha,t}$	Available working time per worker in hours per time period
$TR_{\alpha,\beta,t}$	Demand for part type *p* in period *t*
$S_{\alpha,t}$	Time period require to train from 2 different levels
$p_{\alpha,t}$	Cost of over working
$T_{\alpha,t,k}$	Time of over work for *α*-level worker in period *t*
δ_α	Cost of reward for *α*-level worker in period *t*
t_p	Salary of *α*-level worker in period *t*
$D_{p,t}$	Training cost of *α*-level worker to level *ß* in period *t*
A	Firing cost of *α*-level worker in period *t*
B	Hiring cost of *α*-level worker in period *t*
R	Capacity of machine type *m*
γ	Operation cost per hour for machine type *m*
$T_{j,p,m}$	Installing cost of machine type *m*
LB	Removal cost of machine type *m*
UB	Purchasing cost of machine type *m*

$$\alpha_{j,p,m} = \begin{cases} 1 & \text{if operation } j \text{ of part } p \text{ is done on machine type } m \\ 0 & \text{otherwise} \end{cases}$$

$$MBT_{m,k} = \begin{cases} 1 & \text{if machine of type } m \text{ belongs to machine level } k \\ 0 & \text{otherwise} \end{cases}$$

$$WP_{\alpha,k} = \begin{cases} 1 & \text{if working on machine level } k \text{ with the skill level is possible} \\ 0 & \text{otherwise} \end{cases}$$

Decision Variables

$N_{m,c,t}$	Number of machine type *m* used in cell *c* during period *t*
$N^+_{m,c,t}$	Number of machine type *m* added in cell *c* during period *t*
$N^-_{m,c,t}$	Number of machine type *m* removed from cell *c* during period *t*
$W_{\alpha,k,t}$	Number of machine type *m* removed from cell *c* during period *t*
$W^+_{\alpha,k,t}$	Number of *α*-level workers assigned machine level *k* during period *t*

$W^{-}_{\alpha,k,t}$ Number of α-level workers hired and assigned machine level k during period t

$W_{\alpha,\beta,t,k,k'}$ Number of α–level workers assigned to machine level k in period t-1 and they are

$Z_{j,p,c,t}$ $\begin{cases} 1 & \text{If operation } j \text{ of part type } p \text{ is done in cell } c \text{ in period } h \\ 0 & \text{otherwise} \end{cases}$

$X_{j,p,m,c,t}$ $\begin{cases} 1 & \text{If operation } j \text{ of type } p \text{ is done in machine type } m \text{ in cell } c \text{ during period } t \\ 0 & \text{otherwise} \end{cases}$

$X'_{\alpha,v,k,k'}$ $\begin{cases} 1 & \text{if training of } \alpha\text{-level workers, assigned to machine level } k\text{, to level } v \\ 0 & \text{otherwise} \end{cases}$

$Y_{\alpha,t,k}$ $\begin{cases} 1 & \text{If } \alpha\text{-level workers assigned to machine level } k \text{ are training during period } t \\ 0 & \text{otherwise} \end{cases}$

Objective function

$$
\begin{aligned}
\text{Min} \quad & \overbrace{\sum_{m=1}^{M}\sum_{c=1}^{C}\sum_{t=1}^{T} C_m N_{m,c,t}}^{(1)} + \overbrace{\sum_{m=1}^{M}\sum_{c=1}^{C}\sum_{t=1}^{T} IN_m N^{+}_{m,c,t}}^{(2)} + \\
& \overbrace{\sum_{m=1}^{M}\sum_{c=1}^{C}\sum_{t=1}^{T} RC_m N^{-}_{m,c,t}}^{(3)} + \overbrace{\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{t=1}^{T}\sum_{c=1}^{C} X_{j,p,m,c,t} T_{j,p,m,t} O_m}^{(4)} + \\
& \overbrace{1/2 \sum_{t=1}^{T} \gamma \left[\frac{D_{p,t}}{B}\right] \sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{c=1}^{C} \left| Z_{j+1,p,c,t} - Z_{j,p,c,t} \right| d_{c,c'}}^{(5)} \\
& + \overbrace{\sum_{\alpha=1}^{\Psi}\sum_{t=1}^{T}\sum_{k=1}^{M_s} h_{\alpha,t} W^{+}_{\alpha,t,k}}^{(6)} + \overbrace{\sum_{\alpha=1}^{\Psi}\sum_{t=1}^{T}\sum_{k=1}^{M_s} f_{\alpha,t} W^{-}_{\alpha,t,k}}^{(7)} + \\
& \overbrace{\sum_{\alpha=1}^{\Psi}\sum_{t=1}^{T}\sum_{k=1}^{M_s} S_{\alpha,t} W_{\alpha,t,k}}^{(8)} + \overbrace{\sum_{\alpha=1}^{\Psi}\sum_{t=1}^{T}\sum_{k=1}^{M_s} p_{\alpha,t} W_{\alpha,t,k}}^{(9)} + \\
& \overbrace{\sum_{\alpha=1}^{\Psi}\sum_{t=1}^{T}\sum_{k=1}^{M_s} \delta_\alpha W_{\alpha,t,k} T_{\alpha,t,k}}^{(10)} + \overbrace{\sum_{\alpha=1}^{\Psi}\sum_{t=1}^{T}\sum_{k=1}^{M_s}\sum_{t=1}^{T}\sum_{\beta} W_{\alpha,\beta,t,k,k'} TR_{\alpha,\beta,t}}^{(11)}
\end{aligned}
$$

Subject to:

$$\sum_{p=1}^{P}\sum_{j=1}^{J} D_{p,t} X_{j,p,m,c,t} T_{j,p,t} \leq MT_m N_{m,c,t} \qquad \forall m,c,t \qquad (1)$$

$$N_{m,c,t} + N^{+}_{m,c,t+1} - N^{-}_{m,c,t} = N_{m,c,t+1} \qquad \forall m,c,t \qquad (2)$$

$$W_{\alpha,t,k} + W^{+}_{\alpha,t+1,k} - W^{-}_{\alpha,t+1,k} + W_{v,\alpha,t,k',k} = W_{m,t+1,k} \qquad \forall \alpha,t,k \qquad (3)$$

$$A\varepsilon_{\alpha,t}\sum_{\alpha=1}^{\Psi}\left(\left[t-t_0\right]^b W_{\alpha,t_0,t,k} + W^{+}_{\alpha,t,k}\right) - W^{-}_{\alpha,t,k} + \sum_{\alpha=1}^{\Psi}\sum_{\substack{k=1\\k\neq k'}}^{K} X_{v,\alpha,k',k} W_{v,\alpha,k',k} + \left(1-X'\right) W_{v,\alpha,k',k} \geq \qquad \forall t,k\ ,t_0 \geq t \qquad (4)$$

$$\sum_{c=1}^{C}\sum_{m=1}^{M} MT_m N_{m,c,t} MBT_{m,k}$$

$$\sum_{m=1}^{M} N_{m,c,t} \geq LB \qquad \forall c,t \qquad (5)$$

$$\sum_{m=1}^{M} N_{m,c,t} \leq UB \qquad \forall c,t \qquad (6)$$

$$\sum_{m=1}^{M} X_{j,p,m,c,t} = Z_{j,p,c,t} \qquad \forall j,p,c,t \qquad (7)$$

$$\sum_{v=1}^{\Psi}\sum_{k'=1}^{K} W_{v,\alpha,t,k,k'} + W^{-}_{\alpha,t,k} \leq W_{\alpha,t-1,k} \qquad \forall \alpha,t,k \qquad (8)$$

$$\sum_{v=1}^{\Psi}\sum_{k'=1}^{K} W_{v,\alpha,t,k,k'} \leq R\left(X'_{v,\alpha,t,k,k'} + Y_{\alpha,t,k'}\right) \qquad \forall \alpha,t,k' \qquad (9)$$

$$W^{-}_{\alpha,t,k'} \leq R\left[1-\left(X'_{v,\alpha,t,k,k'} + Y_{\alpha,t,k'}\right)\right] \qquad \forall \alpha,t,k' \qquad (10)$$

$$\sum_{k=1}^{K}\sum_{k'=1}^{K} W_{\alpha,\alpha+1,t,k,k'} = \sum_{k=1}^{K}\sum_{k'=1}^{K} W_{\alpha-1,\alpha,t-t_p,k,k'} + W^{+}_{\alpha,t-t_p,k} \qquad (11)$$

$$W^{+}_{\alpha,t,k} \leq RWP_{\alpha,k} \qquad \forall \alpha,t,k \qquad (12)$$

$$W^{-}_{\alpha,t,k} \leq RWP_{\alpha,k} \qquad \forall \alpha,t,k \qquad (13)$$

$$W^{+}_{v,\alpha,t,k,k'} \leq MWP_{v,k'} \qquad \forall v,\alpha,t,k,k' \qquad (14)$$

$$W^{+}_{v,\alpha,t,k',k} \leq MWP_{v,k} \qquad \forall v,\alpha,t,k,k' \qquad (15)$$

The objective function consists of different cost items as followings; Term (1) ensures machine purchasing cost and it depends on the number of machines. Term (2) declares installing cost after removing them to another cell. Term (3) shows removal cost. Term (4) is about machines operation cost for manufacturing parts. Term (5) ensures cost of transferring parts between cells that depends on the distance between cells and the number of batches. Term (6) shows hiring cost that is incurred when workers have to be hired to assign to specific machine level because of the lack of available workers. It depends on number of workers and the cost of per each worker. Term (7) ensures firing cost that is incurred when workers have to fire because they aren't requiring right now and training of them is not useful. Term (8) ensures salary that depends on worker level and the number of worker. Term (9) declares reward cost paid to workers in order to encourage them. It is different for each work and depends on the number of workers. Term (10) shows overtime cost that calculates the cost of over time works and it depends on the time of work and the number of workers. Term (11) ensures training cost and it depends on the training per each worker and the number of workers. In addition to the proposed objective function, Constraints 1 ensure that machine capacities are constant and do not exceed and satisfy demands. Constraints 2 ensure that the number of machines in current period is equal to the number of machines in previous period plus machines moved in minus machines moved out. Constraints 3 represent the workers balancing equation. Constraints 4 ensures that in order to satisfy the demand the available worker hours in the period can be obtained from hired, trained and fired workers assigned to available machine hours and also considering motivation effect and learning curve. Constraints 5 and 6 ensure lower and upper bound of machine number in cells. Constraints 7 ensure that if at least one of the operations of part p is processed in cell c in period h, then the value of $Z_{j,p,c,t}$ will be equal to one; otherwise it is equal to zero. Constraints 8 ensures that in specific period workers who are fired or trained to upper levels must be lower than workers in previous period. Constraints 9 and 10 show that workers who are trained or are getting trained can't be fired in the same period. Constraints 11 ensure that the workers must be trained in a specific period. Constraints 13 and 14 ensure that an α-level worker can be fired or hired, if and only if this assignment is possible. Constraints 15 and 16 ensure that, training for skill level ν, is possible, only if the former assignment and the latter are being possible and also training from initial skill level to skill level ν is possible too.

Solution Methodology

SA algorithm

Simulated Annealing (SA) is a general random search to obtain some global near-optimal solutions for NP-hard problems. This technique is a reassertion of the gradual cooling process of a physical system to reach to a state of a minimum potential energy. It is an improving mechanism which starts with a primary solution (S_0). The controlling parameter of temperature (T) takes an initial value of T_0. Then from the solution space, other solutions are searched by the following manner. The primary temperature systematically decreases and according to temperature reduction function and in each stage of temperatures reduction, the process stops in order to reach a thermal equilibrium the value of which is determined as the length of the Markov chain, also called Epoch length. During this time, another solution (S_n) is created in the neighborhood of the previous solution (S). If the value of the objective function ($f(S_n)$) in minimization problems is less than the previous value ($f(S)$), the new solution is accepted. Otherwise to escape from the local optimal solution, the new solution will be accepted with a probability $P = e^{-\Delta/T}$, $\Delta = 1 - \frac{f(S)}{f(S_n)} \times 100$. This process is repeated until the desired state of the algorithm is reached [25].

Simulated annealing steps:

1- Get an initial solution (S)
2- Get an initial temperature (T) and a reduction factor (τ) (0<τ<1)
3- While not yet frozen, do:
   3.1 Perform the following loop *L* time
      3.1.1) Pick a random neighbor S' of S
      3.1.2) let $\Delta = f(S') - f(S)$
      3.1.3) If $\Delta \le 0$ set $S = S'$
      3.1.4) If $\Delta > 0$ set $S = S'$ with probability $e^{-\Delta/T}$
   3.2 Set $T \leftarrow r \times T$ (reduce temperature)
4- Return the best solution found.

As reported in [24] on solving dynamic cell formation by meta heuristic SA algorithm found better near-optimal solution in shorter average computational time than Genetic Algorithms (GA) and Tabu Search (TS) in most problems. In general, the probability of achieving optimal solutions is increased by improving and developing GA operations, because those operations can be used in generating neighboring solutions in SA [24].

Experimental results

In order to compare the Meta heuristic results with exact approach, 3 problems are solved with different sizes; small, medium and big size problems. Tables 2 and 3 show the parameters of these problems. The Meta heuristic approach used here is a hybrid approach of simulated annealing (SA) and genetic algorithms (GA). Exact approach is obtained by solving the model in GAMS software. GAMS couldn't solve the large size problem therefore SA was used to solve it and check the answers. The results are shown in Table 4.

Table 2- CF and Hybrid SA inputs

CF input parameters	Batch size (*B*)=20	Cost of inter-cell movement (O_m)=15	Min capacity of cell (*LB*)=4	Max capacity of cell (*UB*)=12
Hybrid SA parameters	Rate of cooling=cost	Rate of freezing=rate or cooling*le-4	Stopping criterion= 1000	Number of solution accepted in each temperature=2

Problem size / **Problem parameters**	**Small problem**	**Average problem**	**Big problem**
Number of machines(*M*)	4	6	8
Number of cells(*C*)	4	6	8
Number of time period(*T*)	3	5	7
Number of part type(*P*)	4	5	7
Number of operations of part type(*J*)	3	4	5
Number of skill levels(Ψ)	5	7	9
Number of machine level(*MS*)	2	3	4

Table3- Problem parameters in different sizes

Example 1-(*Small size problem):* Tables 3-8 show the information of the first problem and Table 9 presents the solution results. This problem has feasible solutions but there is an unsuitable gap between the solutions of SA and GAMS solution. Figure 3 shows the diagram of this problem.

Table 4- Information of workers

worker level	**salary**			**hiring**			**firing**		
	period 1	**period 2**	**period 3**	**period 1**	**period 2**	**period 3**	**period 1**	**period 2**	**period 3**
1	1500	1600	1700	1500	1600	1700	15	16	17
2	1600	1700	1800	1600	1700	1800	16	17	18
3	1600	1700	1800	1600	1700	1800	16	17	18
4	1700	1800	1900	1700	1800	1900	17	18	19
5	1900	2000	2100	1900	2000	2100	19	20	21

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Table 5- Workers information

worker level	**reward**			**productivity**			**time of over working**		
	period 1	**period 2**	**period 3**	**period 1**	**period 2**	**period 3**	**period 1**	**period 2**	**period 3**
1	125	133	142	0.9	0.8	0.75	1	2	0
2	133	142	150	0.9	0.8	0.75	2	0	1
3	133	142	150	0.95	0.85	0.8	3	1	2
4	142	150	158	0.95	0.85	0.8	3	2	3

5	158	166	175	1	0.9	0.85	2	1	2

Table 6- Machines information

machine level	purchasing cost	operation cost	removing cost	installing cost	capacity
1	1500	40	40	40	50
2	1200	25	25	25	60
3	1000	30	30	30	50
4	1500	20	20	20	70

Table 7- Demands per part

part type	period 1	period 2	period 3
1	200	50	100
2	50	50	200
3	100	10	100
4	50	120	100

Table 8- Training cost for α-level worker in period t

worker level	level 1			level 2			level 3			level 4			level 5		
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	45	50	55	0	0	0	0	0	0	0	0	0	0	0	0
3	0	55	60	50	55	60	0	0	0	0	0	0	0	0	0
4	0	0	65	0	60	65	60	65	70	0	0	0	0	0	0
5	0	0	0	0	0	70	0	70	75	80	85	90	0	0	0

Table 9- Result of solving the first problem

Problem size	GAMS		SA	
	Objective	Average Time	Objective	Average Time
Small size	999.674	0.015 SECONDS	18049319	2.713491 seconds

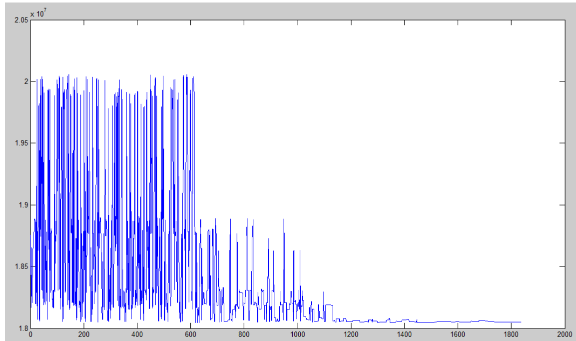

Figure 3- Cost figure for small size problem in SA solution

Example 2*-medium size:* Tables 10-18 show the information of second problem and Table 18 presents the solution results. This problem couldn't also be solved by GAMS because of its size. Figure 4 shows the diagram.

Table 10- Machines information

machine level	purchasing cost	operation cost	removing cost	installing cost	capacity
1	1500	40	40	40	50
2	1200	25	25	25	60
3	1000	30	30	30	50
4	1500	20	20	20	70
5	1600	30	40	20	80
6	1500	25	20	25	70

Table 11- Time of over working of α-level worker in period *t*

worker level	time of over working				
	period 1	period 2	period 3	period 4	period 5
1	1	2	0	2	3
2	2	0	1	0	1
3	3	1	2	1	2
4	3	2	3	1	1
5	2	1	3	0	1
6	1	2	1	0	1
7	1	3	0	1	0

.

Table 12- Productivity of α-level worker in period *t*

worker level	productivity				
	period 1	period 2	period 3	period 4	period 5
1	0.7	0.75	0.7	0.65	0.65
2	0.9	0.8	0.75	0.7	0.7

3	0.9	0.8	0.75	0.7	0.7
4	0.95	0.85	0.8	0.75	0.75
5	0.95	0.85	0.8	0.75	0.75
6	0.95	0.85	0.8	0.75	0.75
7	1	0.9	0.85	0.8	0.8

Table 13- Rewards of α-level worker in period t

worker level	reward				
	period 1	period 2	period 3	period 4	period 5
1	125	133	142	150	158
2	133	142	150	158	166
3	133	142	150	158	166
4	142	150	158	166	175
5	158	166	175	180	185
6	166	175	180	185	192
7	166	175	180	154	192

Table 14- Salary of α-level worker in period t

worker level	salary				
	period 1	period 2	period 3	period 3	Period3
1	1500	1600	1700	1800	1900
2	1600	1700	1800	1900	1950
3	1600	1700	1800	1900	1950
4	1700	1800	1900	1950	2000
5	1800	1900	1950	2000	2050
6	1900	1950	2000	2050	2100
7	1900	1950	2000	2050	2100

Table 15- Rewards of α-level worker in period t

worker level	hiring				
	period 1	period 2	period 3	period 4	period 5
1	1500	1600	1700	1800	1900
2	1600	1700	1800	1900	1950
3	1600	1700	1800	1900	1950
4	1700	1800	1900	1950	2000
5	1800	1900	1950	2000	2050
6	1900	1950	2000	2050	2100
7	1900	1950	2000	2050	2100

Table 16- Demand per part in period *t*

part type	period 1	period 2	period 3	period 4	period 5
1	200	50	100	50	100
2	50	50	200	20	100
3	100	10	100	50	70
4	50	120	100	30	40
5	30	100	120	30	50
6	100	40	20	40	100

Table 17- Firing cost of α-level worker in period *t*

worker level	firing				
	period 1	period 2	period 3	period 4	period 5
1	15	16	17	18	19
2	16	17	18	19	20
3	16	17	18	19	20
4	17	18	19	20	21
5	18	19	20	21	22
6	18	19	20	21	22
7	19	20	21	22	23

Table 18- Result of the second problem

Problem size	GAMS		SA	
	Objective	Average Time	Objective	Average Time
Medium size	infeasible	----------	3.87E+09	8.856480 seconds

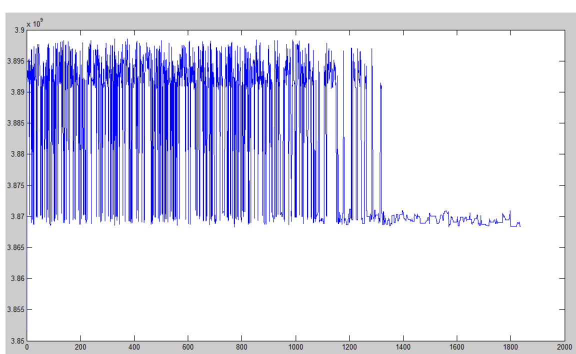

Figure 4- Cost figure for medium size problem in SA solution

***Example 3**-large size problem:* Tables 19-21 show the information of second problem and Table 22 presents the solution results. This problem couldn't also be solved by GAMS because of its size. Figure 5 shows the diagram.

Table 19- Salary and hiring cost of α-level worker in period t

worker level	salary					
	period 1	**period 2**	**period 3**	**period 4**	**period 5**	**period6**
1	1500	1600	1700	1800	1900	1900
2	1600	1700	1800	1900	1950	1950
3	1600	1700	1800	1900	1950	2000
4	1700	1800	1900	1950	2000	2050
5	1800	1900	1950	2000	2050	2100
6	1900	1950	2000	2050	2100	2150
7	1900	1950	2000	2050	2100	2150
8	2000	2050	2100	2150	2200	220
worker level	**hiring**					
	period 1	**period 2**	**period 3**	**period 4**	**period 5**	**period6**
1	1500	1600	1700	1800	1900	1900
2	1600	1700	1800	1900	1950	1950
3	1600	1700	1800	1900	1950	2000
4	1700	1800	1900	1950	2000	2050
5	1800	1900	1950	2000	2050	2100
6	1900	1950	2000	2050	2100	2150
7	1900	1950	2000	2050	2100	2150
8	2000	2050	2100	2150	2200	220

Table 20- Firing cost of α-level worker in period t

worker level	firing					
	period 1	**period 2**	**period 3**	**period 4**	**period 5**	**period 6**
1	15	16	17	18	19	20
2	16	17	18	19	20	21
3	16	17	18	19	20	22
4	17	18	19	20	21	23
5	18	19	20	21	22	23
6	19	20	21	22	23	24
7	20	21	23	24	25	25
8	21	22	23	23	24	25

Table 21- Reward cost of α-level worker in period *t*

worker level	reward					
	period 1	period 2	period 3	period 4	period 5	period 6
1	125	133	142	150	158	166
2	133	142	150	158	166	175
3	133	142	150	158	166	175
4	142	150	158	166	175	180
5	158	166	175	180	185	185
6	166	175	180	185	192	200
7	166	175	180	154	192	210
8	175	180	185	192	210	220

Table 22- Result of the third problem

Problem size	GAMS		Hyprid SA	
	Objective	Average Time	Objective	Average Time
Big size	infeasible	------------	8.5E+09	11.782694 seconds.

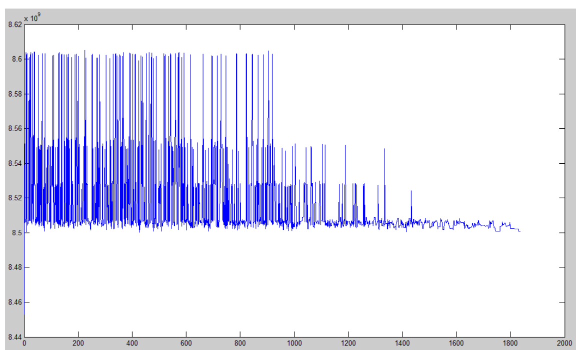

Figure 5- Cost figure for big size problem in SA solution

Conclusion &Future Research Directions

In this paper we presented a mathematical model which considers dynamic cell formation and worker assignment problem simultaneously by also taking into account motivation and learning effect and also rewards in human issues. In real world problems available time of workers is not constant but variable in different days therefore learning curve and motivation effects have been noticed in order to indicate the real available workers time. It is the first time that motivation and learning effect and rewards is considered in human issues in cell formation. The mathematical problem was solved by GAMS software which utilizes exact approaches and hybrid Meta heuristic solution approach based on simulated annealing (SA) and genetic algorithms (GA).

Experimentally, if the number of machines parts ordinate greater than 6 and 5 and the number of cells is greater than 4 and the number of periods is greater than 3, exact approaches cannot find a suitable solution for the presented model in a meaningful time. It is suggested to consider aspects of motivation in order to develop and improve presented mathematical models in literature. Also using other meta-heuristic approaches may lead to better solutions.

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