# Worker Training in Dynamic Virtual Cellular Manufacturing System with Production Planning 

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#### Abstract

This paper develops a mathematical model in dynamic virtual cellular manufacturing systems with the multiperiod cell formation problem, production planning, dynamic virtual system reconfiguration and training workers. Since workers have important role in doing jobs on machines, assignment of workers to cells becomes a crucial factor in cellular manufacturing system. Also we have shown the role of training in increasing workers' flexibility and efficiency of resources is leading to more production, decrees total costs, in all over planning. The advantages of the proposed model are consideration of multi-period planning horizons with demand and part mix variation, machine capacity, and available time of worker and worker assignment. The aim of the proposed model is to minimize the holding and backorder costs, and training costs of worker. Finally, to validate and verify the proposed model, computational results are presented by solving a number of numerical examples, with the linearized formulation.


Keywords: Dynamic Virtual Cellular Manufacturing System (DVCMS), Worker Assignment, Training, Mathematical Programming.

## 1. INTRODUCTION

Group technology (GT) has emerged as a manufacturing strategy for controlling batch production. It identifies similarities among product designs and manufacturing processes throughout the manufacturing cycle. An application of GT known as cellular manufacturing (CM) is a production system in which similar parts are classified into part families and different machines are assigned into machine cells in order to utilize the costeffectiveness of mass production and flexibility of job shop manufacturing simultaneously. With increased global competition and shorter product life cycles, there has been a modification to demands for mid-volume and mid-variety product mixes. Job shops copes well with high product variety but does not provide adequate throughput with high product volumes. On the other hand, the flow lines enables fast product throughput when production volume is high but does not cope well with product variety because of the need for frequent set ups. CM have emerged to cope with such production necessities and have been implemented with approving results that it can merge the flexibility and variety, which are further important for any manufacturing industry.

The benefits of CM identified by Wemmerlov and Hyer [25], Heragu [10], Selim et al. [21] and Mansouri et al. [14] include: decline in setup time, throughput time, diminish in work-in-process inventories, reduce in material handling costs, simplified flow of parts and tools, centralization of responsibility, enhances product quality and production control, increment in flexibility, etc. In most research works, CFP has been considered under static conditions in which cells are formed for a single time period with known and constant product mix and demand. To overcome these disadvantages, the concept of dynamic cellular manufacturing system is introduced [19]. In dynamic environment a multi-period planning horizon is considered where every one of period has different product mix and demand necessities. Therefore, the formed cells in a period may not be optimal and well-organized for the next period.

To address this problem, several authors recently proposed models and solution procedures by considering dynamic cell reconfigurations over multiple time periods (e.g. [8]; [26]; [16]; [23, 24]; [3]; [9]; [11]; [20]). Most methods assumed that the production quantity is equal to demand in each planning period. In reality, however, production quantity may not equal the demand since it may be satisfied from inventory or by subcontracting. Production quantity should be determined based on production planning decisions in order to determine the number and type of machines to be installed in the system. By consideration of machine capacity, the production quantities in each planning period affect the number and type of machines to be installed in manufacturing cells. Balakrishnan and Cheng [3] presented a two-stage procedure based on the generalized machine assignment problem and dynamic programming for CFP under conditions of changing product demand. The aims were to minimize the material handling and machine relocation costs.

[^0]Defersha and Chen [9] designed a comprehensive mathematical programming model for CMS based on tooling requirements of the parts and tooling available on the machines, involves various aspects of manufacturing in addition to the CFP: dynamic cell configuration, alternative routings, lot splitting, sequence of operations, multiple units of identical machines, machine capacity, workload balancing among cells, operation cost, cost of subcontracting part processing, tool consumption cost, setup cost, cell size limits, and machine adjacency constraints. The non-linear mixed integer model is linearized by some linearization steps in order to obtain a mixed-integer linear problem and solve various scenarios. Also they developed heuristic methods to efficiently solve the proposed model for problems of larger sizes. Recently, Ahkioon et al. [1] developed a preliminary CM model that integrates several manufacturing attributes, considering multi-period planning, dynamic system reconfiguration, and production planning and alternate routings.

A relatively new alternative configuration of production facilities has been considered in recent years, namely virtual cellular manufacturing systems (VCMS). Retaining the functional layout, virtual manufacturing cells (VMC) have been defined as a provisionally grouping of machines and jobs to appreciate the profit normally related with CM. The logical grouping of jobs and machines is based on a predefined logic, and it is only resident in the production control system. In other words, machines are not physically relocated into cells in VCMS. VMC are created periodically, for example every week or every month, depending on changes in volumes and mix of demand as new jobs is accumulated during a planning period. VCMS combines the robustness and flexibility of process orientation with the advantages of product orientation, and this is expected to appreciate approving throughput time performance. In so doing, it provides opportunities to progress performance in situations where a cellular layout is technically infeasible. An example of VCMS is shown in Fig. 1. The first study addressing the concept of VCM is McLean et al. [15]. Baykasoglu [4] proposed a simulated annealing algorithm for developing a distributed layout for virtual manufacturing cell. Slomp et al. [22] presented the procedure is based on interactive goal programming methods for the design of VCMS considering labor assignment and part-machine grouping. The advantages of the proposed model are minimization of intercell movements of parts, provision of flexibility, capacity constraints, cell size restrictions, minimization of load imbalances, etc. The models in the two stages can be applied to maximize the setup savings, to minimize the number of intercell movements, and to keep the machine coverage and multifunctionality on a sufficient level.

Nomden et al. [17] reviewed the previous publications on the area of VCM. This results in a complete framework which identifies the fundamental principles of VMCs and classifies the diverse VMC concepts. They show that VCM can appreciably improve the performance of manufacturing systems. Also they suggested several definitions of VCM offered by various researchers and addressed the prospective issues for future researches.


Fig. 1. A virtual manufacturing system. Reprinted by permission. Copyright 2002 INFORMS. Benjaafar et al. [5].
One of the main points in CM is considering human issues since ignoring this factor can considerably reduce benefits of the utility of the cell manufacturing. But unfortunately, "while cellular manufacturing is a popular research area, there is a singular absence of articles that deal with the human element in cellular manufacturing. Human issues include: Worker assignment, Communication, Describing worker roles, Skill identification, Training, Reward/Compensation system, Teamwork and Conflict management. However, as the model complexity extend, it is often impossible to solve integer programming (IP) workforce planning models within a reasonable amount of time. Numerous researchers have developed heuristic algorithms for solving these problems. In some of the previous research papers this issue is discussed, and according to their assignment strategies they can be divided into two categories, Post-cell formation worker and Simultaneous formation of cells and worker assignment.

Norman et al. [18] developed a MIP model in manufacturing cells with worker assignment to maximize the profit. Bidanda et al. [6] studied an overview and evaluation of the diverse range of human issues concerned in CM based on an extensive literature review. Aryanezhad et al. [2] presented a new model to deal with dynamic
cell formation and worker assignment problem with considering part routing flexibility and machine flexibility and also promotion of workers from one skill level. Mahdavi et al. [13] presented a new mathematical model for CFP based on a three-dimensional machine-part-worker incidence matrix which demonstrates a cubic representation of assignment in cellular manufacturing system. Also, the new concept of exceptional elements (EEs) is discussed to show the interpretation of inter-cell movements of both workers and parts for processing on corresponding machines. The proposed method minimizes total number of EEs and voids in a cellular manufacturing system. Mahdavi et al. [12] presented a fuzzy goal programming-based approach for solving a multi-objective mathematical model of CFP and production planning in a dynamic VCMS. They considered the demand and part mix variation over a multi period planning horizon with worker flexibility.

In this paper, we proposed a mathematical model for production planning in dynamic virtual environment with an extensive coverage of important manufacturing features consideration of multi-period planning horizons with demand and part mix variation, machine capacity, and the main constraints are demand satisfaction in all over period, machine availability, machine time-capacity, available time of worker and training.
The remainder of the paper is organized as follows. In Section 2, a mathematical model integrating most of attributes of manufacturing for production planning is formulated. Also, linearization procedure is explained in this section. We present computational results in Section 3. Finally conclusions and further research is described in Section 4.

## 2. Problem formulation

In this section, a nonlinear programming mathematical model of CFP is presented based on dynamic VCMS with worker assignment. The objective is to minimize the sum of the penalty of deviation production volume from the desirable value of the part demand (holding and backorder costs) and training costs of workers. Main constraints are machine capacity, and available time of worker, production volume and training workers. Before presenting the model, it is necessary to state some assumptions which are as follows:

### 2.1. Assumptions

1. The processing time for all parts on each machine types with workers are known and deterministic. This time is independent of ability workers for processing on machines.
2. The demand for each part type in each period is known and deterministic.
3. The capacity and capability of each machine type is known and deterministic.
4. The available time of each worker is known.
5. There are several machines of each type with identical duplicates to satisfy capacity requirements.
6. Holding and backorder inventories are allowed among periods with known costs. Thus, the demand for a part in a given period can be fulfilled in the preceding or succeeding periods.
7. Only one worker is allotted for processing each part on each corresponding machine type.
8. Training for each worker in each period is only on one machine type.
9. Training for each worker on machine type is only one period.
10. Training, which is done to promote workers to increment in flexibility, is performed between periods and it takes zero time.
11. The productivity of experienced workers is assumed to be equal to $100 \%$.
12. The machines are accessible for using at the beginning of each period (time of erection is zero).

### 2.2. Notations

### 2.2.1. Subscripts

$P \quad$ Number of part types
W Number of worker types
$M \quad$ Number of machine types
$C \quad$ Number of cells
$H \quad$ Number of periods
$i \quad$ Index for part type $(i=1,2, \ldots P)$
$w \quad$ Index for worker $(w=1,2, \ldots W)$
$m \quad$ Index for machine type ( $m=1,2, \ldots M$ )
$k \quad$ Index for cell $(k=1,2, \ldots C)$
$h \quad$ Index for period $(h=1,2, \ldots H)$

### 2.2.2. Input parameters

$A B_{m w h} \quad 1$ if worker $w$ able to work on machine type $m$ in period $h ;=0$ otherwise
$a_{i m} \quad 1$ if part $i$ needs machine type $m ;=0$ otherwise
$L M_{k} \quad$ Minimum size of cell $k$ in terms of the number of machine types
$L P_{k} \quad$ Minimum size of cell $k$ in terms of the number of parts
$L W_{k} \quad$ Minimum size of cell $k$ in terms of the number of workers
$N_{m} \quad$ Number of machines of type $m$
$R W_{w h} \quad$ Available time for worker $w$ in period $h$
$R M_{m h} \quad$ Available time for machine $m$ in period $h$
$t_{i m w} \quad$ Processing time of part $i$ on machine type $m$ with worker $w$
$T^{\text {inter }} \quad$ The time of movement each worker between cells
$D_{i h} \quad$ Demand of part $i$ in period $h$
$\gamma_{i h} \quad$ Unit holding cost of part $i$ in period $h$
$\lambda_{i h} \quad$ Unit backorder cost of part $i$ in period $h$
$A \quad$ An arbitrary big positive number

### 2.2.3. Decision variables

$y_{i k h} \quad 1$ if part $i$ is assigned to cell $k$ in period $h ;=0$ otherwise
$z_{w k h} \quad 1$ if worker $w$ is assigned for cell $k$ in period $h ;=0$ otherwise
$x_{i m w k h} \quad 1$ if part $i$ is to be processed on machine type $m$ with worker $w$ in cell $k$ in period $h ;=0$ otherwise
$n_{m k h} \quad$ Number of machine type $m$ allotted to cell $k$ in period $h$
$T R_{m w h} \quad 1$ If worker $w$ to be trained on machine type $m$ in period $h ;=0$ otherwise
$P_{i h} \quad$ Number of part $i$ to be produced in period $h$
$I_{i h} \quad$ Inventory of part $i$ at the end of period $h ; I_{i 0}=0$
$B_{i h} \quad$ Backorder of part $i$ in period $h ; B_{i 0}=0$
$\beta_{m w h} \quad$ Training cost of worker $w$ on machine type $m$ in period $h$

### 2.3. Mathematical model

Min $=\sum_{h=1}^{H} \sum_{i=1}^{P} \gamma_{i h} I_{\text {ih }}$
$+\sum_{h=1}^{H} \sum_{i=1}^{P} \lambda_{i h} B_{i h}$
$+\sum_{h=1}^{H} \sum_{w=1}^{W} \sum_{m=1}^{M} \beta_{m w h} T R_{m w h}$

## Subject to

$\sum_{k=1}^{C} \sum_{m=1}^{M} \sum_{i=1}^{P} x_{i m w k h} P_{i h}\left\{t_{i m w}+2\left(1-z_{w k h}\right) T^{i n t e r}\right\} \leq R W_{w}$
$\forall w, h ;$
$\sum_{w=1}^{W} \sum_{i=1}^{P} x_{i m w k h} t_{i m w} P_{i h} \leq n_{m k h} R M_{m h}$
$\forall m, h, k ;$
$D_{i h}=P_{i h}+I_{i h-1}-B_{i h-1}-I_{i h}+B_{i h}$
$\forall i, h ;$
$\sum_{k=1}^{C} x_{i m w k h} \leq a_{i m} A B_{m w h}$
$\forall i, m, w, h ;$
$\sum_{k=1}^{C} \sum_{w=1}^{W} x_{i m w k h}=a_{i m}$
$\forall i, m, h ;$
$\sum_{k=1}^{C} \sum_{m=1}^{M} \sum_{w=1}^{W} x_{i m v k h} \leq A P_{i h}$
$\forall k, h ;$
$\sum_{h=1}^{H} T R_{m w h} \leq 1$
$\forall m, w$;
$\sum_{m=1}^{M} T R_{m w h} \leq 1$
$\forall w, h ;$
$A B_{m w h}=T R_{m w h}\left(1-A B_{m w h-1}\right)+\left(A B_{m w h-1}\right)$
$\forall m, w, h ;$
$\sum_{k=1}^{C} y_{i k h}=\min \left\{1, P_{i n}\right\}$
$\forall i, h ;$

$$
\begin{array}{ll}
\sum_{k=1}^{C} z_{w k h}=1 & \forall w, h ; \\
\sum_{k=1}^{C} n_{m k h} \leq N_{m} & \forall m, h ; \\
\sum_{m=1}^{M} n_{m k h} \geq L M_{k} & \forall k, h ; \\
\sum_{i=1}^{P} y_{i k h} \geq L P_{K} & \forall k, h ; \\
\sum_{w=1}^{W} z_{w k h} \geq L W_{K} & \forall k, h ; \\
y_{i k h}, z_{w k h}, T R_{m w h}, A B_{m w h}, x_{i m w k h} \in\{0,1\} & \forall i, m, w, k, h ; \\
P_{i h}, B_{i h}, I_{i h}, n_{m k h} \in \notin+ & \forall i, m, k, h ;
\end{array}
$$

The objective function given in Eq. (1, 2 and 3) is linear function. The objective function consists of several costs items as follows:
(1) Holding cost: The first term is the sum of the product of the holding for each part type at the end of the given period and associated cost.
(2) Backorder cost: The second term is the sum of the product of the backorder for each part type at the end of the given period and associated cost.
(3) Training cost: This cost is incurred when some workers have to be trained to improve their abilities to operate other machine. This cost is calculated based on the cost of training per each worker and the number of workers who are trained.
Constraints (4) and (5) ensure that the available time for workers and machines in each period are not exceeded, respectively, especially when the worker moves between cells. It should be noted that the available time for workers' movements includes two $T^{\text {inter }}$ (go and return time). Constraint (6) balances the amount of part $i$ between two consecutive periods. In other words, if $I_{i h} \geq 0$ then we have surplus inventory which results in holding cost, if $B_{i h} \geq 0$ it implies shortage inventory and lead to backorder cost. Constraint (7) implies that only one worker is allotted for processing each part on each machine type. This model is flexible to enable a worker to work on several machines. This means that, if one part is to be processed on a machine type, more than one worker would be able to service this machine type. Constraint (8) ensures that if $P_{i h}=0$ then no machine, worker and cell are considered for part $i$ in period $h$. Constraint (9) ensures that each part is either assigned to only one cell or is not assigned to any cell in period $h$. Constraints (10) and (11) guarantee that training for each worker in each period is only on one machine type and also training for each worker on machine type is only one period. Equation (12) guarantees that while worker type $w$ training on machine type $m$, hence it worker ability to process on this machine type. Equation (13) ensures that each part is assigned to only one cell when its production is planned for period $h$. Equation (14) guarantees that each worker will be assigned to only one cell. Constraint (15) guarantees that the total number of machines of each type assigned to different cells in each period will not exceed the total available number of machines of that type. Constraint (16) specifies the lower bound for the number of machines that can be allocated to each cell. Constraint (17) keeps the lower bound for the number of parts assignable to each cell. Constraint (18) ensures that at least $L W_{k}$ workers will be assigned to cell $k$. Constraints (19) and (20) specify that decision variables are binary or positive integer.

### 2.4. Linearization of the proposed model

Constraints (4), (5), (12) and (13) of the proposed model are non-linear. We need to introduce auxiliary variables to replace these nonlinear terms with additional constraints. The required new variables can be defined by the following equations.
$J_{i m w k h}=x_{i m w k h} P_{i h}$
$E_{i m w k h}=z_{w k h} J_{i m w k h}$
By considering these equations, following constraints should be added to the mathematical model:
$\begin{array}{ll}J_{i m w k h}+A\left(x_{i m w k h}-1\right) \leq P_{i h} & \forall i, m, w, k, h ; \\ J_{i m w k h}-A\left(x_{i m w k h}-1\right) \geq P_{i h} & \forall i, m, w, k, h ; \\ J_{i m w k h} \leq A\left(x_{i m w k h}\right) & \forall i, m, w, k, h ; \\ E_{i m w k h}+A\left(z_{w k h}-1\right) \leq J_{i m w k h} & \forall i, m, w, k, h ;\end{array}$

$$
\begin{array}{ll}
E_{i m w k h}-A\left(z_{w k h}-1\right) \geq J_{i m w k h} & \forall i, m, w, k, h ; \\
E_{i m w k h} \leq A\left(z_{w k h}\right) & \forall i, m, w, k, h ; \\
J_{i m w k h}, E_{i m w k h} \geq 0 & \forall i, m, w, k, h ; \tag{27}
\end{array}
$$

Therefore, the linear mathematical programming is as follows:
Min $=\sum_{n=1}^{3} E q .(n)$
Subject to:
Constraints (6) - (11) and (14) - (27) and new version of constraints (4), (5), (12) and (13):

$$
\begin{array}{ll}
\sum_{k=1}^{C} \sum_{m=1}^{M} \sum_{i=1}^{P} J_{i m w k h}\left(t_{i m w}+2 T^{\mathrm{inter}}\right)-E_{i m w k h} 2 T^{\mathrm{inter}} \leq R W_{w h} & \forall w, h ; \\
\sum_{w=1}^{W} \sum_{i=1}^{P} J_{i m w k h} t_{i m w} \leq n_{m k h} R M_{m h} & \forall m, k, h ; \\
\sum_{k=1}^{C} y_{i k h} \leq 1 & \forall i, h ; \\
P_{i h} \leq A \sum_{k=1}^{C} y_{i k h} & \forall i, h ; \\
P_{i h} \geq \sum_{k=1}^{C} y_{i k h} & \forall i, h ; \tag{32}
\end{array}
$$

The number of variables and constraints in the linearized model are presented in Table 1 and 2 respectively, based on the variable indices.

Table1. The number of variables in the linearized model

| Variable | Count | Variable | Count |
| :---: | :---: | :---: | :---: |
| $y_{i k h}$ | $P \times C \times H$ | $I_{\text {ih }}$ | $\boldsymbol{P} \times \boldsymbol{H}$ |
| $z_{w k h}$ | $W \times C \times H$ | $J_{\text {imukh }}$ | $\boldsymbol{P} \times \boldsymbol{M} \times \boldsymbol{W} \times \boldsymbol{C} \times \boldsymbol{H}$ |
| $\boldsymbol{x}_{\text {imwkh }}$ | $P \times M \times W \times C \times H$ | $E_{i m w k h}$ | $\boldsymbol{P} \times \boldsymbol{M} \times \boldsymbol{W} \times \boldsymbol{C} \times \boldsymbol{H}$ |
| $n_{m k h}$ | $M \times C \times H$ | $A B_{\text {mwh }}$ | $\boldsymbol{M} \times \boldsymbol{W} \times \boldsymbol{H}$ |
| $\boldsymbol{P}_{\text {ih }}$ | $P \times H$ | $T R_{m w h}$ | $\boldsymbol{M} \times \boldsymbol{W} \times \boldsymbol{H}$ |
| $B_{\text {in }}$ | $P \times H$ |  |  |
| Sum $=3(P \times M \times W \times C \times H)+(M \times C \times H)+(P \times C \times H)+(W \times C \times H)+\mathbf{2}(M \times W \times H)+\mathbf{3}(P \times H)$ |  |  |  |

Table2. The number of constraints in the linearized model

| Con. | Count | Con. | Count | Con. | Count |
| :---: | :---: | :---: | :---: | :---: | :---: |
| (6) | $P \times H$ | (16) | C× H | (25) | $\boldsymbol{P} \times \boldsymbol{M} \times \boldsymbol{W} \times \boldsymbol{C} \times \boldsymbol{H}$ |
| (7) | $P \times M \times W \times H$ | (17) | C×H | (26) | $\boldsymbol{P} \times \boldsymbol{M} \times \boldsymbol{W} \times \boldsymbol{C} \times \boldsymbol{H}$ |
| (8) | $P \times M \times H$ | (18) | $C \times H$ | (27) | $\boldsymbol{2} \times \boldsymbol{P} \times \boldsymbol{M} \times \boldsymbol{W} \times \boldsymbol{C} \times \boldsymbol{H}$ |
| (9) | $C \times H$ | (19) | $C \times H \times[P \times M \times W+P+W]+2(M \times W \times H)$ | (28) | $\boldsymbol{W} \times \boldsymbol{H}$ |
| (10) | $M \times W$ | (20) | $H[(M \times C)+(3 \times P)]$ | (29) | $\boldsymbol{M} \times \boldsymbol{C} \times \boldsymbol{H}$ |
| (11) | $W \times H$ | (21) | $P \times M \times W \times C \times H$ | (30) | $\boldsymbol{P} \times \boldsymbol{H}$ |
| (12) | $M \times W \times H$ | (22) | $P \times M \times W \times C \times H$ | (31) | $\boldsymbol{P} \times \boldsymbol{H}$ |
| (14) | $W \times H$ | (23) | $P \times M \times W \times C \times H$ | (32) | $\boldsymbol{P} \times \boldsymbol{H}$ |
| (15) | $M \times H$ | (24) | $P \times M \times W \times C \times H$ |  |  |

Sum $=9(P \times M \times W \times C \times H)+2(M \times C \times H)+1(P \times C \times H)+1(W \times C \times H)+7(P \times H)+3(M \times W \times H)+4(C \times H)+3(W \times H)+(P \times M \times W \times H)+($
$\boldsymbol{P} \times \boldsymbol{M} \times \boldsymbol{H})+(\boldsymbol{M} \times \boldsymbol{W})+(\boldsymbol{M} \times \boldsymbol{H})$

## 3. Computational results

To illustrate validity of the proposed model, one example has been solved by branch and bound (B\&B) method under CPLEX software package, which is executed on a Pentium 4, 5.2 GHz Windows XP using 3 GB of RAM.
Example. This example includes two cases, three cells, three machines types, six parts and four workers. The case 1 is with training workers and case 2 without training workers. The available time for both worker and machine in each period is 200 hours. The time of movement between cells for each worker is 0.1 hour. The processing time is presented in Table 3. Moreover, the number of available machine types 1,2 and 3 ; are 2 , 1 and 2 , respectively. The data set related to the machine-part and machine-worker incidence matrices are shown in Tables 4 and 5, respectively. For example, as seen in Table 4, machine types 2 and 3 are required for part type 3. Table 5 indicates capabilities of workers in working with different machines. For example, worker 1 is able to
work with machine types 1 and 3 . Thus, the term $\sum_{w} A B_{m w h}$ is equal to the number of alternative workers for processing part type $i$ on machine type $m$. Also, the quantity of demands, holding and backorder costs per part unit in each period are represented in Table 6. Moreover, the minimum size of each cell in terms of the number of machines, parts and workers are 1,2 and 1 , respectively. Tables 7 and 8 show the results of this example for two cases. Table 7 indicates the assignment of parts, workers with duplicate of machines in different cells and training worker 4,1 and 2 on machine 1,2 and 3 , respectively in period 2 . Moreover, it shows worker 2 is assigned in cell 1 , and worker 1 is assigned in cell 2 , and workers 3 , 4 are assigned in cell 3 in period 1 in case 1. Also machines type 1 and 3 are duplicated in cell 1 and 2 , cell 2 and 3, respectively. Table 8 presented the allotment of worker for each part, in cell for work on corresponding machine. For instance, part 3 shall process with machine 2 (see Table 4) and workers 3 and 4 capability of working to this machine (see Table 5) which this operation in period 1 in case 1 is executed by worker 3 in cell3 (see Table 8). The volume of products and objective function value including holding cost and backorder cost are indicated in Table 8. As can be seen, the demand for part 4 in period 1 in case 1 and 2 is 350 . But, 183 units of this part are produced in period 1 and 517 units are produced in period 2. It means that to satisfy the demand of 167 units of part 4 in period 2, the required units are produced in period 1 , which causes holding cost for part 3 . Also, it can be seen that backorder cost for case 1 is 41852 and holding cost is 500 , and the total cost is 43852 . But, backorder cost for case 2 is 184980 and holding cost is 1420 , and the total cost is 186400 . In fact, in this example shown the role of training in increasing workers' flexibility and efficiency of resources is leading to more production, decrees total costs, in all over planning. For more understanding, the reconfiguration of this example in case 1 is given in Figure 2. In this Figure, Structural changes in the virtual cell in a way that shows no physical changes resources (machines and workers), but only changes the cell boundaries as a virtual cell structure and the period has changed the case to demand changes in response to different periods does.

Table3. The processing time (hrs.)


Table 4. The input data of Machine -Part incidence matrix


Table 5. The input data of Machine -Worker incidence matrix in period 1

|  | Workers |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\mathbf{1}$ | $\mathbf{2}$ | $\mathbf{3}$ | $\mathbf{4}$ |
|  | $\mathbf{1}$ | 1 | 1 | 0 | 0 |
|  | $\mathbf{2}$ | 0 | 0 | 1 | 1 |
|  | $\mathbf{3}$ | 1 | 0 | 1 | 0 |

Table6. The quantity of demands, holding and backorder cost of each parts in periods

|  | Period 1 |  |  | Period 2 |  |  | Period 3 |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $D_{\text {ih }}$ | $\gamma_{i h}$ | $\lambda_{\text {ih }}$ | $D_{\text {ih }}$ | $\gamma_{\text {ih }}$ | $\lambda_{\text {ih }}$ | $D_{\text {ih }}$ | $\gamma_{i h}$ | $\lambda_{\text {ih }}$ |
| Part 1 | 200 | 10 | 60 | 950 | 10 | 60 | 400 | 10 | 60 |
| Part 2 | 250 | 20 | 50 | 500 | 20 | 50 | 500 | 20 | 50 |
| Part 3 | 250 | 30 | 50 | 250 | 30 | 50 | 300 | 30 | 50 |
| Part 4 | 350 | 40 | 40 | 350 | 40 | 40 | 200 | 40 | 40 |
| Part 5 | 350 | 50 | 40 | 200 | 50 | 40 | 200 | 50 | 40 |
| Part 6 | 400 | 60 | 40 | 200 | 60 | 40 | 400 | 60 | 40 |

## 4. Conclusions

In this paper, a new mathematical model is presented for cell formation problem which considering for production planning in a dynamic virtual cellular manufacturing system with worker flexibility. The proposed model minimizes holding, backorder costs and training costs of workers. Generally, training leads to acquiring
new skills and/or improvements in existing skills. These, in turn, lead to two different economic advantages: (1) improvements in personality choices and incomes, and (2) cost savings for the organization. Economic advantages of training for organizations contain important improvements in productivity (through improvements in quality, decrease in scrap and waste, reduction in throughput time, greater flexibility to respond to needs, etc.), and a competitive advantage of employers and the state as a whole [7].

Table7. The results of parts, machines and workers assignment to cells by the proposed model in two cases

|  |  | Parts assigned to |  |  | Machines in |  |  | Workers assigned to |  |  | $T R_{m w h}=1$ | $\beta_{m w h}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Cell 1 | Cell 2 | Cell 3 | Cell 1 | Cell 2 | Cell 3 | Cell 1 | Cell 2 | Cell 3 |  |  |
| $\begin{aligned} & \grave{0} \\ & \stackrel{y}{0} \end{aligned}$ | Period 1 | 3,4 | 1,2 | 5,6 | 1 | 1,3 | 2,3 | 2 | 1 | 3,4 |  |  |
|  |  |  |  |  |  |  |  |  |  |  | $(1,4,2)$ | 500 |
|  | Period 2 | 3,4 | 1,2 | 5,6 | 1,1,3 | 3 | 2 | 2,4 | 3 | 1 | $(2,1,2)$ | 500 |
|  |  |  |  |  |  |  |  |  |  |  | $(3,2,2)$ | 500 |
|  | Period 3 | 3,4 | 1,2 | 5,6 | 2 | 1 | 1,3,3 | 1,3 | 4 | 2 | Total cost | 1500 |
| $\begin{aligned} & \text { y } \\ & \vdots \\ & \vdots \\ & \hline \end{aligned}$ | Period 1 | 1,3 | 2,6 | 4,5 | 2,3 | 1 | 1,3 | 3,4 | 2 | 1 |  |  |
|  | Period 2 | 1,3 | 2,6 | 4,5 | 1,3 | 1,2 | 3 | 1 | 2,4 | 3 |  |  |
|  | Period 3 | 1,2 | 3,4 | 5,6 | 1,3,3 | 2 | 1 | 1,3 | 4 | 2 |  |  |

Table8. The solution obtained by the proposed model in two cases


[^1]

Fig. 2. Cell reconfiguration schema in each period for this example in case 1
We have shown the role of training in increasing workers flexibility and efficiency of resources is leading to more production, decrees total costs, in all over planning. Also in this article, the role and function of dynamic virtual cellular manufacturing systems addresses so that no physical changes in the system resources available only with the virtual cell boundaries change to meet the demand values in different periods can be. Numerical examples included in the paper show validity of the proposed model.

An attractive future research trend is to investigate work on other heuristic solution methods or other stochastic algorithms and meta-heuristic algorithms for solving the real size of industrial instances. Furthermore it would be appropriate to consider the problem studied here with the addition of some other assumptions like ability of workers for work as a team and the role of manpower in producing more quality of products.

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[^1]:    ${ }^{\text {a }}$ The worker movement between cells

