Flexible Labor Assignment in Cellular Manufacturing System (A Simulation and DEA Approach)

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Abstract

A model considering labor flexibility is proposed to assign workforce to a cell in CMS environment. There are three input parameters and four output variables which are determined via simulation of a cell. Utilizing DEA methodology, the most efficient assignment strategies are found. Then, efficient strategies are ranked using modified MAJ model and the best assignment strategy is determined in such a way that besides determination of an appropriate transfer batch size, best values for output variables are also obtained. With an illustrative example some points which are applicable in various manufacturing cells are discovered.

Keywords
Cellular Manufacturing System, lobar assignment, lobar flexibility, Data Envelopment Analysis, ranking efficient

1. Introduction
Depending on the presence of humans, manufacturing cells are divided into manned and unmanned cells. In manned cells, human operators are doing all the activities including loading, unloading, handling of parts and tools, setup of machines , and inspection of parts for holding the desired dimension and quality control. The number of mentioned tasks assigning to each operator depends on automation level. In unmanned cells these tasks are on robots and computer numerically controlled (CNC). Most of the time changing manned cell to unmanned cells results in quality, reliability, and scheduling improvement. But achieving these, installing unmanned cells begs huge investment. Consequently, manned cells are still more common than unmanned cells which paying attention to human aspect in this kind of cells are still attracts many researchers as an interesting subject [1].

Manned cells depending on automation level and the amount of human's works can be categorized to labor intensive and machine intensive cells. In labor intensive cells, most of works are done with simple tools and manual control machines so it needs permanent presence of operators [2]. On the other hand, in machine intensive cells main tasks is done by automatically machine and only loading, unloading, and setup are done by labor. In between, among machining, operator can complete other work on the other machines. So an operator can manage simultaneously more than one machine [3]. Because an operator can work on more than one machine, finding an assignment strategy to maximize the performance of the cell in order to have maximum human recourses efficiency is an important problem. So assignment of operators to cells is an attractive problem to researchers [3].

Bidanda et al (2005) with a comparative evaluation among published papers with focus on human themes in have shown that there are eight human aspects involved in cellular manufacturing system (CMS). These issues are assignment strategies, finding skills, education, relationships, job independence, intensive plans, team works, and conflict management. Which among them labor assignment of strategies are the most addressed subject [4]. Labor assignment strategies are those methods that allows engineers and supervisors to assign persons to cell's tasks in order to achieve the most cell and labor efficiencies. These assignment strategies based on man-machine assignments can be grouped to four distinct categories [5]:

1- Dedicated: each worker is responsible of one or more machines.
2- Shared: when more than one person work on one or a group of machines.
3- Combined: in this case operator has both dedicated and shared assignment.

4- Completely shared: when all workers are responsible of all machines in the cell

It is obvious to having such strategies, flexible or multi skills operators with different skills are necessary. Bobrowski and Park [6] have defined flexibility of workforce as capability to go from one working station to another working station. In CMS, flexibility of workforce depends on the route they can travel in. Based on this, two kind of flexibility of workforce are considered, intra-cell flexibility which focuses on traveling of workers from one cell to another cell and inter-cell flexibility which addresses traveling of labor from one machine to other machine in a cell [7]. Because workforce's flexibility has many strategic benefits it is a useful tool for improving performance of cells. Utilizing multi skills workforces allow the company to response quickly to unbalanced and unpredicted fluctuation in demand. Also exploiting multi skills workforces reduces production times and decreases work in process (WIP) and if it combines with efficient utilizing of machines and workforces, it can improve customers' satisfaction [8]. Steudel and Cesani' [7] had a study on a manufacturing cell with two and three workers. In their study, all four strategies, dedicated, shared, combined, completely shared were examined. They considered three parameters, degree of shared job, measure of balance, and cell productivity and found out that with increase of shared job between workers, system productivity considerably amplified. But if degree of shared job and cross training goes beyond limitation, improving system productivity eventually would decrease.

Because of significant inter connection of human and technological skills in a CMS, many of researches paid attention to available skills of workforce in labor-task problem. Warner et al [9] introduced a procedure to assign workers according to human and technological skills. Technological skills are defined as capability of calculation and measuring and also mechanical skills and human skills are those which are related to relationship, leadership, team working capability, and decision making. Fitzpatrick and Askin [10] considered grouping workforce with respect to their technological skills. Bhaskar and Srinivasan [11] introduced a mathematical model for assigning labor in two dynamic and static cases. The goal was balancing workload and minimizing makespan. In static assignment, workers are assigned in a way that workload balance is reached for all products in every cell. But in dynamic assignment, when different products enter the cells, workers are free to move between cells.

Rassell et al [12] examined workforce assignments strategies in a tacit group technology workshop which built of three cells. Having only one kind of workforce is the result of their study. In other words, each worker must have gained complete cross training and must have had capability that he/she can be assigned to every machine in every cell. Murali, et al [13] derived a worker assignment model that determines the fitness attributes of each worker for each cell in terms of machine coverage ratio, multi-functionality and the total processing time, considering the cell formation solutions available in the literature. They used a new approach based on artificial neural networks (ANNs) which proposed to assign workers into virtual cells. Eratay and Ruan [3] tried to find number of workers and proper assignment strategy in cellular manufacturing environment by means of simulation and Data Envelopment Analysis (DEA). They evaluated only some special assignment strategies. They did not consider balancing the workload. Actually they presumed that ability of workforces to travel between workstations can resolve the workload balancing.

One of the important factors which affect labor assigning is cell loading. Assigning parts to cells with defining their production sequencing in each cell is cell loading. Dagli and Suer [2] considered a labor intensive cell and introduced a Fuzzy solution to minimize movement of workers between workstations. In this research we have focused on assignment of labor to the tasks within each cells, which we called it labor assignment strategies. This kind of assignment is an important subject in CMS. And performance of cells mostly depends on choosing proper strategies to maximize utilizing of human working capacity. Up to now there have been a few researches on this subject. Most of these researches only consider labor assignment on special cases. In this research we have tried to approach the labor assignment problem with a global view and introduce an algorithm to find an efficient strategy. Also concept of workload balancing is considered in this study.

This paper is comprises of 5 sections. Section 2 is devoted to introduce the methodology to help to define and to determine assignment strategies. It is including some essential definition of related concepts, introducing DEA method and its related topics like output-oriented BCC to find efficient strategies, and at last adjusted MAJ (Merababian, Alirezaee, Jahanshahloo) method [16] to rank efficient assignment strategies. In section 3 a procedure is proposed for labor assignment. Implementation of the proposed procedure is discussed in section 4. And paper is ended with some conclusions and also some hints for further research.

2. Methodology

2.1 Measures

There is a cell with *k* workstations which are controlled with *N* operators. This cell is a machine incentive cell which is including *M* machines. The number of machines can be higher, lesser, or equal to the number of workstations. As it mentioned earlier in this kind of machine intensive cells, some of work is done automatically by machine and the rest of it is accomplished manually by operator (s). Operators are responsible of loading, unloading, machine setup in each station, and perform material movement within cell from one station to another one. These manual operations which perform by operator are called manual work volume in the cell and operators must have enough training and skills to do them.

Manual operation time in each workstation is $t_j\ , j = 1,2, \ldots , k$. Machining time is $t_m\ , m = 1,2, \ldots , M$. Workstation's set up time for each part is $ts_j\ , j = 1,2, \ldots , k$. During automatic machining time, t_m , operator is free to move from one station to another station to perform other manual operation. The goal is finding a strategy for labor assignment in order that with the least number of flexible operators, high cell performance achieves.

To find a proper assignment strategy, at first *D* feasible assignment strategies according to four assignment categories; dedicated, shared, combined, and completely shared are defined. In each assignment strategy, two factors; closeness of assigned machines and required skills to perform the task, must be considered. For evaluation of different strategies, a set of parameters have been used. Here in this research the number of operators, workload sharing, and transfer batch size are considered as input parameters and production volume, average operator utilization, workload balancing, and work in process are used as output parameters. In strategy *d*, $\mathrm{N_d}$ is the number of operators, n_d is the number of responsible operators in station *j* in strategy *d*, and production volume, P_d is calculated via simulation of the cell during a period of time.

- **Work load sharing:**

Workload here is manual task related to each machine which has been assigned to operators. Workload sharing is a proportion of manual tasks which has been shared by more than of one operator. Amplifying the workload sharing will improve; workload balancing, efficiency of workforce, number of operators (reduced), and the overall performance of the cell. On the other hand, increasing workload sharing will result rising in training expenses which is a burden to company and growing traveling time between stations which results more tiredness of operators. Therefore we are penetrating a proper level of workload sharing which with least training expense and the smallest amount of operators' movement, achieve a desired outcome.

Workload sharing in each cell for strategy *d* is S_{Td} which is defined as follows:

(1)

In above equation, *S* is the total number of stations which its manual operations are done by sharing. *T* is the total manual operations time within cell. s_jd is the proportion of shared workload in station *i* and is defined as follows:

(2)

In equation (2) it is assumed that whether the operation time of a station is higher, it has more influence on increasing workload balance and also on cell performance. In this case operators need more training. All operators who are responsible for that station should be trained for all manual tasks carry in that station. Therefore, workload sharing in each station has a direct relationship with manual operation times and number of responsible operators in that station.

- **Transfer batch size :**

Transfer batch size is the number of parts which has been transferring by operator from station *j* to station *j*+1. Actually the processed parts will have retained after completion on every station and when the total number of them reaches to transfer batch size they relocate by a pallet or a rack to the next station for further required processes. After the feasible batch sizes with regard to technical factors like size, weight, parts' material, and pallet size is determined, then with solving the model the proper batch size will be selected. Transfer batch size in strategy *d* is shown by BS_d.

- **Average operator utilization:**

Average operator utilization is the average proportion of time which operators are busy in a cell. $\overline{OPU}_d$ is the average operator utilization in assignment strategy *d*. OPU_{id} , the percent of utilization of operator *i* in strategy *d* is found via simulation of the cell.

(3)

- **Workload balancing:**

Workload balancing shows the balance of workload of operators in the cell.

(4)

In equation (4) MB_d, is the measure of balance in percent for strategy *d* which in that the higher level of *MB* means more balance on assigned workload to the operators.

- **Work in process:**

Number of work in process explains the number of uncompleted parts in cell during a presumed period. If this number will be high enough, there will be less free space in cell and also total holding cost gets higher. Number of work in process depends on transfer batch size, line balancing, and the kind of work assignment to the operators. WIP_d is the number of work in process in strategy *d*.

2.2 Determining efficient assignment strategies with DEA

In general efficiency can be divided into two kind; absolute efficiency and relative efficiency. Absolute efficiency can be checked with comparing a unit with some standards and relative efficiency will be found when the unit is compared with other similar units. Data envelopment Analysis is a mathematical programming technique which is utilized for evaluation of relative efficiency of similar units in an organization. DEA uses a number of inputs and outputs. In DEA, each under study unit in organization is called a decision making unit (DMU). Generally, DMU is an entity which conveys a number of inputs to a few numbers of outputs and the performance evaluation of that entity is sought. Let's assume that there are *n* decision making units. For comparison of DMUs, *m* inputs and *s* outputs are selected such that for unit *j*, inputs are $(x_{1j}, x_{2j}, \dots, x_{mj})$ and outputs are $(y_{1j}, y_{2j}, \dots, y_{sj})$. The goal of this model is to find minimum inputs to have minimum expected outputs. This model is called output-oriented or CCR [13]. In this technique *n* optimization problems must be solved and each time there is a new objective function. Every time one DMU makes the new objective function then its efficiency with compare to other DMUs' efficiency is calculated. The objective function has been defined in order to maximize the efficiency of DMU. This model is called CCR and introduced initially by Charnes, Cooper, and Roods in 1978 [15]. Another model which is output-oriented will be explained shortly. In comparison with CCR, it tries to maximize outputs in a way that all inputs hold on their maximum previous level.

The labor assignment strategies all have similar inputs and outputs. So, one can consider them as DMUs and DEA methodology can be utilized to find efficient assignment strategies. For each assignment strategies, two inputs, number of operators and workload sharing and four outputs, production volume, average operator's utilization, workload balancing, and number of work in process are considered. Transfer batch size is an input which affects on outputs but neither a big size of it nor a small size is advantage. With regard of technical factors, feasible sizes of transfer batch are found and each strategy simulate with its feasible transfer batch size. Since in DEA structure, having least inputs and most outputs are a merit, transfer batch size is not consider as an input, but after determining the best assignment strategy, the transfer batch size corresponding to the best strategy which results the best outputs is selected as appropriate batch size. Also for matching to DEA structure and furthermore because assignment strategies with less WIP are sought, work in process for strategy d, WIP'_d , as an output variable should be rescaled. Therefore the following equation is used for rescaling:

(5)

In presented model it is assumed that having more outputs like production volume and average operator utilization are much more essential than reducing input variables like number of operators and shared workload. Also, because of enclosing more output variables, emphasizing on them can separate assignments strategies much better. So it is better to use output oriented DEA. Since in CCR model there is a constant return to scale, relationship between inputs and outputs, if input gets *t* times bigger than output must adjust the same. If not so, then corresponding unit has not considered as an efficient unit. But in workforce issue such an idea is not rational since having twice number of workforce does not mean reaching double production volume or with double workload sharing there will be twice as workload balancing. To correct this assumption, BCC model is proposed which utilized variable return to scale and is more suitable to compare workforce assignment strategies [15]. Therefore BCC model with output-oriented nature is used to find efficient assignment strategies. The formulation of this model is as follows:

(6)

In equation (6) x_{io} and y_{ro} are respectively ith and rth output strategies of unit under the evaluation (DMU_o). Also x_{id} and y_{rd} are ith input and rth output of strategy d. v_i is weight of ith input and u_r is the weight of rth output which will be found after the model is solved and it is possible to be different from one strategy to another strategy.

Definition 1: if (φ^*, v^*, u^*) is the optimum solution of input-oriented BCC model then efficiency defines as:

1. DMU_0 is efficient if $\vartheta^*=1$ and there must be at least an optimum solution which $u^*>0, v^*>0$.
2. Otherwise DMU_0 is inefficient [16].

2.3The most efficient assignment strategy with adjusted MAJ

The result achieved via DEA is divided to efficient and non efficient strategies which most of the strategies are assessed as efficient assignment and 1 are assigned to them as their efficiency number. Consequently a further step to distinct efficient units from each other is necessary. So a complete rating is required. In DEA concept this is called ranking. There are many methods to rank efficient DMUs. Each method uses a special character or a quality as a measure of ranking. Jahanshahloo et al (1999) utilized adjusted MAJ to rank efficient units [16]. In this model, the objective DMU is eliminated from list of DMUs. In this case variable scale to return is used. Modified MAJ model is as follows:

(7)

In the above equation definition of the variables are as before. Also,δ_o , which is a free variable forces the adjusted MAJ model to work as variable scale of return. In adjusted MAJ model all strategies' inputs and outputs must be normalized. Equation (8) and (9) are used for this purpose.

(8)

(9)

3. A Procedure for Labor Assignment

In this part a framework for labor assignment strategies in a cellular manufacturing environment is proposed. This framework facilitates the comparisons of labor assignment strategies in a measurable manner and helps to select the best strategy. There are eight steps in this framework:

1- Collect necessary data for simulation of the cell which is including of total setup times, loading & unloading time for each part, machining time of each part, transfer time between workstations, and feasible transfer batch sizes.
2- Define number of operators per shift for those cells which work more than a shift per day.
3- Describe a feasible assignment strategies' set for every presumed number of operators.
4- Define operator's responsibilities (loading, unloading, and transferring time) for each strategy and then calculate total workload sharing.
5- Simulate (with aim of simulation software) each labor assignment strategy for different transfer batch sizes and calculate or collect the output variables for each strategy with results from simulation run.
6- Utilize DEA and output-oriented BCC model; find the efficient labor assignment strategies. Each strategy comprises from two inputs; number of operators and total workload sharing, and four outputs; production volume, average labor utilization, workload balancing, and number of WIP.
7- Rank all efficient strategies with variable scale to return adjusted MAJ. The input and output variables are the same as BCC.
8- Select the most efficient strategy as the best labor assignment strategy. Highlight the corresponding number of required operators, operators' responsibilities in cell, workload sharing, and transfer batch size.

4. Implementing the Procedure

The examined cell is a U-shaped cell with linear layout and 8 stations. Figure 1 shows this cell [3]. There is one machine in each station and manual tasks related to each machine can be done by one operator. This cell is a machine oriented manned cell so each operator has enough time to complete manual tasks in other station. There is only one part to be manufactured in this cell and as a result of common route they pass through, all setups are done once. Hence setup times have not been considered in this study.

Loading time, unloading time and machining time in practice are not constant and usually depend on operator's skill, necessary machine gagging, environmental factors, and so on. Therefore these times are randomly distributed which assumed follow a normal distribution in a way that standard deviation of loading and unloading times which is done by operators is 30% of its average and because of less machining time fluctuation, standard deviation of machining is 15% of its average. Distance between machines is equal and time to carry transfer batches which is done by operators is constant and equal $t'_j = 5, j = 1,2,\ldots,7$ minutes.

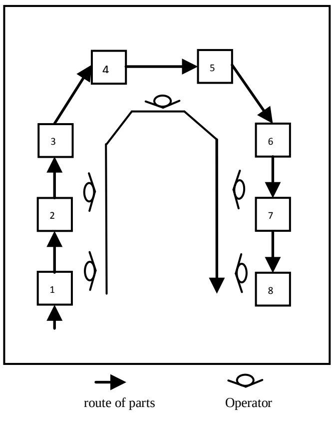

Figure 1: Example of manned cell used in this study

To determine appropriate labor assignment strategies, feasible assignment strategies according to four categories of assignment; dedicated, shared, combined, and completely shared must be defined in advance. Closeness of machines and they accessibility by operators are presumed. Since cross movement between machines are possible, no walking times are considered. Also operators have adequate skills to carry out all kind of assigned works. Because cell comprises of eight machines, eight operators at most are necessary. Therefore assignment strategies consistent with eight or less operators must be defined. Reduction the number of operators will not go beyond that which in accordance with simulation results; average operators' utilization goes up to 95%. Thus, along with simulation results, assignment strategies for 4, 5, 6, 7, and, 8 operators have been defined. Table 1 introduces a total of 100 employed strategies.

Table 1: Employed strategies

Number of operator	Strategy	Total number of strategies
8	One dedicated, eight shared & combined, one completely shared	10
7	Five dedicated, nine shared & combined, one completely shared	15
6	Ten dedicated, fourteen shared & combined, one completely shared	25
5	Ten dedicated, fourteen shared & combined, one completely shared	25
4	Ten dedicated, fourteen shared & combined, one completely shared	25

Workload sharing for all strategies is calculated based on equation (1) and (2). For dedicated strategies, workload sharing is zero or $S_T = 0$ and for completely shared strategies $S_T = 1$. Three different transfer batch sizes; 1, 25, and 50, have been selected by try and error. Thus 100 assignment strategies each under three transfer batch sizes have been simulated. Subsequently after 300 runs the simulation results are collected.

In this study, performance of the cell is evaluated by utilizing Arena software 11 to build the simulation model. To find output parameters, performance of the cell has been watched for 120000 minutes or 250 working days (8 hours per day). This duration is large enough to allow the system reaches to a stable status. All assumptions and applied restrictions are listed in table 2. To be along with reality and spending least travel distance, after unloading a part from a machine, loading must be done by operator. Thus, total time of these two jobs is used in this study.

At the end of simulation run and collecting output variables, all the input variables and output variables are ready to use to find efficient assignment strategies by BCC model equation (6). There are two input variables; number of operators and workload sharing, and four output variables; production volume, average operator's utilization, workload balancing, and number of WIP. In this study, DEAP 2.1 is utilized to determine efficient strategies. Among 100 assignment strategies with three transfer batch sizes or from a total of 300 strategies, 68 strategies consistent with definition (1) are efficient. In next step, efficient assignment strategies utilizing adjusted MAJ with variable scaled to return model or equation (7) are ranked. WinQSB software is used to find rating score of the efficient assignment strategies by adjusted MAJ. Ranked efficient assignment strategies with adjusted MAJ and some useful information are presented in Table 3. The higher the rating score is corresponding to the better strategy. As it can be seen from the table 3, strategy with 5 operators is the best strategy. In this strategy one operator is responsible of machines (1, 3) and all other stations are controlled jointly by four remaining operators.

Table 2. Assumptions and restrictions of simulation model

1. All operators work with 100% efficiency
2. All movements are inter cell
3. Transferring parts is a manned job
4. Unlimited material supplies
5. No machine breakdowns and defective products
6. Rule First-in-First-out is applied
7. Jobs randomly assign to free operators
8. Unlimited warehouse capacity

Table 3. Ranked efficient assignment strategies with adjusted MAJ

Ranking	Assignment		WIP	MB		P	BS		N
1	One operator machines (1, 3), the rest of machines shared by 4 operators	1.0192	166	92.3	82.9	32750	25	61.0	5
2	One operator machines (1, 4), One operator machines (6,2), the rest of machines each to one operator	1.0179	233	82.3	71.2	32625	25	0	6
3	One operator machines (1, 4), the rest of machines shared by 4 operators	1.0152	31	94.6	86.1	31696	1	62.1	5
4	One operator machines (1,8), one operator machines (7,2), two operators machines(3,4,5,6)	1.0142	113	97.4	97.1	28540	1	25.6	4
5	One operator for each pair of machines (1,8),(5,2),$,3),(7,6)	1.0123	425	98.1	96.2	29275	25	0	4
6	One operator machines (1,6), and the rest of machines for six operators	1.012	17	86.1	64.0	32989	1	67.03	7
7	One operator machines (1,4) one operator machine (6,2), each remaining operator one machine	1.0112	46	81.9	71.7	31701	1	0	6
8	One operator machines (1,6), each remaining operator one machine	1.0102	114	85.1	63.6	32515	1	0	7
9	One operator machines (1,3), one operator machines (2,6), each remaining operator one machine	1.0097	9	80.6	69.3	30659	1	0	6
10	One operator machines (1,8), one operator machines (5,2), two operators machines(3,4,6,7)	1.0081	269	99.4	97.7	28105	1	25	4

5. Conclusion

In this study, a comprehensive procedure for labor assignment in cellular manufacturing is proposed. In this method human issues especially labor flexibility, workload sharing, and workload balancing has been considered. At last a practical example is introduced which helps to evaluate the ability of the method. Some good tips are identified from the results which confirm its capability of cell's labor assignment:

1- Increase of workload sharing in a cell does not amplify the production volume continually. It enhances only if WIP does not rise. Therefore, complete workload sharing is not always capable of adding of production volume.

2- It is better that stations with less manual and machining operations are controlled dedicatedly and bottleneck stations with long operations controlled jointly by operators. Because under this condition, WIP is reduced and production volume amplifies.

3- Large transfer batch size brings in idle time for low stream stations and small transfer batch size engages operator to transfer parts in cell. Therefore it is necessary to find the best transfer batch size among feasible batch sizes by utilizing this model.

To extend the research, authors recommend that other human issues and qualitative subjects like cross relationship, conflict management, and so on be considered in labor assignment problem. Also because the weights in DEA are explored from available data, assigning other weights to important parameters is not accessible, therefore using other methods instead of DEA may help to discover predetermined weights to compare assignment strategies.

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