

# Design of Cellular Manufacturing using Mathematical Programming: A Comparative Study with Simulation Modelling

**H. Farsijani**

Industrial Management Department  
Faculty of management and Accounting, Shahid Beheshti University,  
Tehran, Iran  
E-mail: h-farsi@sbu.ac.ir

**M. Shafiei Nikabadi\***

Industrial Management Department  
Faculty of Economics and Management, Semnan University, Iran  
E-mail: mohsenshnaj@yahoo.com  
\*Corresponding Author

**S. Foroutan**

Industrial Management Department  
Faculty of management and Accounting, Shahid Beheshti University,  
Tehran, Iran

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**Abstract:** The problem of cell design is a very complex task with wide ranging implications for any organization. Cell design is generally understood as the problem of identifying a set of part types that are suitable for manufacturing on a group of machines. Among the many methods utilized in cell design, the distance or dissimilarity between two entries is fairly less used. The main goal of this paper is to combine different techniques such as the design and evaluation of a cellular manufacturing system. In this study, a mathematical programming model based on the Minkowski distance measure to minimize the total distance between entries is introduced. Furthermore, a hypothetical manufacturing facility with 10 machines and 15 parts is used as a case. Finally, simulation models are developed for two manufacturing systems, a new cellular manufacturing and a conventional job shop manufacturing system.

**Keywords:** Cellular Manufacturing System, Group Technology, Mathematical Programming, Simulation Modelling

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**Biographical notes:** **M. H. Farsijani** is Associate Professor of Shahid Beheshti University. He received his PhD in Industrial Management (Production Management for WCM) from Bradford University, UK, in 1997. He received Post Doctorate in Industrial Management (World-Class Manufacturing and Technology) from Bradford University, UK, in 1998. **M. Shafiei Nikabadi** is Assistant Professor of Industrial Management of Semnan University. He received his BSc, MSc, and PhD in Production and Operations Management from Allameh Tabatabaee University. **S. Foroutan** received his BSc and MSc in Industrial Management from Shahid Beheshti University.

## 1 INTRODUCTION

In the last decades, many challenging implications pertain to designing, programming, developing and control of manufacturing systems have been addressed and many others still remain as the scope of exhaustive research. These difficulties are continuously emerging as new manufacturing technologies evolve. In other words, manufacturing systems have gone through major changes due to the growth in manufacturing technologies and strategies. The present Manufacturing systems are principally based on computer control systems of automated and flexible manufacturing cells. Therefore, Group Technology (GT) and its application, Cellular Manufacturing System (CMS) may play an effective role in these systems.

GT has been recognized as the key to improve the productivity of manufacturing systems. The cell formation problem in GT begins with two fundamental tasks namely, machine cell formation and part family formation. The machine cell formation problem is a very complex task with wide ranging implications for any organization. Part families are identified such that they are fully processed within a machine cell. Numerous approaches have been developed in the scope of cell formation such as classification and coding systems, similarity coefficient based on clustering methods, graph-theoretic methods, machine-component group analysis, knowledge-based and pattern recognition methods, mathematical programming and heuristic approaches, fuzzy clustering methods, and neural network approaches.

Among the many methods utilized in cell formation, the mathematical programming model is most widely used. This paper presents an effective mathematical programming model based on the distance (dissimilarity) between two entries to identify part families and machine cells. Finally, a hypothetical manufacturing system with 10 machines and 15 parts is used as a case. Simulation modelling is developed for comparing the performance of two manufacturing systems, once, previous of implementing GT based on the mentioned model and other one, after that.

### 1.1. Group Technology

Group technology (GT) has been recognized as an effective scientific philosophy in increasing the productivity of manufacturing systems. This philosophy offers a systematic approach to the reorganization of job shop and flow shop manufacturing systems into cellular manufacturing systems. In other words, GT is a connection between design and manufacturing which results in manufacturing efficiencies. GT can be defined as a disciplined way to identifies and exploits the sameness among the attributes of a set of parts, processes, and

machines. A collection of parts that share some common features is part family and machines which dissimilar in function are grouped into a machine cell. The main objective of implementing GT is to capture benefits for manufacturing systems. These benefits include:

- Reduction in setup times
- Reduction in work in process
- Reduction in tool requirements
- Improving in product quality
- Reduction in lead times
- Reduction in throughput time
- Improving in overall control of operations

Full benefits from such systems can be obtained only when their design and implementation are carefully planned.

### 1.2. Cellular Manufacturing

Cellular manufacturing system (CMS) is one of the primary applications of group technology principles to manufacturing systems. CMS is defined as a manufacturing procedure which produces part families within a single line or cell of machines serviced by operators and/or robots that function only with the line or cell. The main objective of designing manufacturing cells is to develop a production environment of machining centers, either as a line or in cells, operated manually or automatically for the production of part families that are grouped according to a number of similarities in their design and manufacturing features. In CMS, a machine cell should basically be responsible for the complete processing of a group of parts called the part family. In fact, an important issue in CMS is the identification of part families and machine cells. This issue is defined as the cell formation problem. The cell formation problem can be divided into three categories, according to the formation logic used:

- Grouping part families or machine cells only
- Forming part families and then machine cells
- Forming part families and machine cells simultaneously

Part family grouping procedures are used for identifying groups of parts that are similar to one another. Some approaches focus attention on grouping machine cells only, but these procedures often assume that part families already have been formed. Part families grouping procedures are for identifying part families and machine groups sequentially and simultaneously [11].

The main objective in the design of a CMS is to create machine cells, identify part families, and allocate part families to machine cells. Therefore the intercellular movement of parts is decreased. While doing so, a number of constraints need to be considered. Safety and technology requirements pertaining to the location

of equipment and process must be met as well as the size of cell and number of cells [9].

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## 2 LITERATURE REVIEW

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Many researchers have developed techniques for solving the GT and CMS problems. Burbidge et al. [5] classified the techniques in the following three ways:

- Rule of thumb techniques: these techniques use some rules of thumb to identify the part families and machines cells. Clearly such techniques are not useful in solving large scale problems, but are relatively easy to use.
- Classification and coding techniques: this group technique parts are based solely on their processing characteristics. Grouping the parts is based on a number of attributes. This technique is sub classified as hierarchical codes, non-hierarchical codes, and hybrid codes.
- Production flow analysis (PFA) techniques: PFA techniques involve the systematic listing of information contained in route cards and identification of part families and machine cells by careful inspection. Some of the later forms of PFA techniques which use a part machine process indicator matrix specify the machining requirements on parts, and then attempt to manipulate the rows and columns of this matrix to identify clusters. Research simulation studies which use the functional system may be preferable to CMSs.

King and Nakornchai [13] used the following three categories:

- Similarity coefficient algorithms: these algorithms are devised from numerical taxonomy and attempt to measure the similarity coefficient between each pair of machines or parts.
- Set-theoretic algorithms: these techniques build super-sets of machines and parts that can be represented as a path along the edges of lattice diagrams using the union operation. Hence such techniques will not be number of parts and machines are typically large.
- Evaluation algorithms: these techniques are basically the same as PFA techniques.

Han and Ham [8] classified the GT algorithms in the following ways:

- Peripatetic and ocular technique: these techniques have knowledge concerning the parts and manufacturing systems which are used to determine machine cells and part

families. These methods are also not much use in practice.

- PFA technique: (similar as mentioned previously).
- Classification and coding technique: (similar as mentioned previously).
- Mathematical programming technique: These techniques use “fuzzy” mathematics, pattern recognition, cluster analysis, etc. to identify part family and machine cell combinations.

Vakharia[24] used the following classification:

- Descriptive technique: descriptive technique includes the PFA techniques and other component flow analysis (CFA) techniques.
- Block diagonal technique: this technique is similar to the clustering technique.
- Similarity coefficient technique: (similar as mentioned previously).

Luong[17] has developed new algorithms for grouping the machines, known as "machine chain similarity". These algorithms developed with the production volume and process sequences have brought the new concept of similarity between pairs of machines or between pairs of parts. An extensive analysis of some of the above classification and also various techniques, allows us to classify the GT techniques as follows:

- Techniques that identify part families without the help of machine routing
- Techniques that identify part families using routing
- Techniques that identify machine groups only
- Techniques that identify part families and machine groups simultaneously.

Various approaches to cell formation may fall under one of the six major general classifications: array-based clustering, similarity coefficient, mathematical programming, graph and network, heuristic and combinatorial optimization. There are two type of array-based clustering techniques; rank order clustering (ROC) and bond energy analysis (BEA). In ROC, a positional based value is assigned to each “1” in the machine-part incidence matrix and the values of all the “1”s in each row and each column are summed, the rows and columns being rearranged in decreasing order based on the values from top to bottom and from left to right respectively [12].

The bond energy which is defined as the product of the values of the adjoining row and column elements in the machine-part incidence matrix to determine the degree of clustering has been successfully implemented, with an optimal solution being one which maximizes the bond energy [20]. The first work to use similarity, measures to group machines and parts into cells utilizes a similarity matrix which contains all pair wise similarity coefficient between each machine. In fact,

McAuley calculated the Jacard similarity coefficient for each machine type pair [19]. The similarity matrix obtained is then used by the single linkage clustering algorithm (SLCA) to form the machine groups. The clustering algorithm based on the similarity coefficient fall into two classifications: hierarchical and non-hierarchical, both the single linkage clustering algorithm and the average clustering algorithm are hierarchical clustering algorithms. They only known non-hierarchical clustering reported so far include MacQueen's k-means method which requires the number of clusters to be specified in advance [18]. A number of mathematical approaches have been reported for the cell formation problem.

Choobineh proposed a two stage procedure for the design of a cellular manufacturing system [7]. In the first stage part families were formed by using the manufacturing operations and operational sequences. The machine cells were formed in the second stage by using an integer programming model. Integer programming model is a more rigorous and comprehensive approach for implementing GT because other information such as the cost of machines, part demand, and the cost of intercellular moves can be easily incorporated.

Atmani et al. [2] introduced an 1-0 integer programming model for the simultaneous solution of the cell formation and operation problem in cellular manufacturing. The objective of their model was too simultaneously for machine groups and allocates operations of the part types to the regrouped machines in such a way as to minimize the total sum of operators, re-fixturing and transportation costs.

Rajamani et al. [21] developed a mathematical model which aided in deciding the optimal variety of parts, portion of demand to be produced in cells, machines to select and plans to produce the parts. They also provided effective column generation schemes for the linear and relaxed mixed-integer programs. Rajamani et al. [22] also presented plans on resource utilization when the part families and machine groups are formed simultaneously.

They developed three integer programming models to successively study the effects of alternative process plans and simultaneous formulation of part families. Kumar et al. [14, 15] formulated the GT grouping problem as an optimal K-decomposition problem in graph theoretic terms in which decomposition of networks are considered rather than block diagonalisation of matrices. Several heuristics which give polynomial bounds on the required computation time, but do not guarantee the optimal solution include Ballakur and Steudel [3] and Kumar et al. [15]. Other approaches have been suggested by researchers include the use of neural networks [23] and simulated annealing [10].

Ang developed an algorithm for eliminating bottleneck parts in a cellular manufacturing setting [26]. Bottlenecks are eliminated by determining the machine duplication pattern that minimizes total duplication costs. A unique feature of the algorithm is that it recognizes that under some conditions machine duplication costs can be minimized by increasing the number of machine cells.

Huq et al. [29] presented a simulation analysis of factors influencing the flow time and through-put performance of functional and cellular layouts. Al-Ahmari introduced a fuzzy clustering approach for part-machine grouping in cellular manufacturing system [25]. This fuzzy approach offers a special advantages over existing clustering approaches as it presents the degree of membership of the machine or part associated with each machine cell or part family allowing users flexibility in formulating machine cells and part families. Das et al. [28] developed an effective cellular manufacturing system (CMS) design methodology by simultaneously considering system costs and individual machine reliabilities; and proposed a combinatorial search-based solution procedure to solve large-sized problems.

The algorithm in the paper solved the multi-objective CMS design model and generated near optimal solutions for medium to large-sized problems within reasonable limits of CPU time. Bashir and Karaa described a simple quantitative approach to testing whether an underlying pattern of relationships exists between machines of a given system, such that the machines may be rearranged into manufacturing cells [27]. They also were to support the approach by an index for measuring the clustering tendency. Ranjbar-Bourani et al. [30] present a multi objective (3 conflicting objectives) cell formation problem considering alternative process routes and machine utilization. This problem was NP-hardness, a multi objective scatter search (MOSS) method based on TOPSIS was designed in order to find locally Pareto Optimal frontier.

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### 3 MATHEMATICAL PROGRAMING MODEL

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The basic grouping of machines and parts is based on a binary machine-part incidence matrix that shows the occurrence of visits of parts to machine. The binary grouping is most appropriate at the early stage of design when more meaningful manufacturing parameters such as lot size and processing time are not accessible. In this paper a hypothetical manufacturing facility with 10 machines and 15 parts is used as a case. To illustrate the schematic view of machines and parts in this case, consider the following machine-part incidence matrix (Table 1).

Table 1 Machine-part incidence matrix

		Parts															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Machines	1	0	1	0	0	0	0	0	0	0	1	1	1	0	0	0	
	2	0	0	1	0	1	0	0	1	0	0	0	0	0	1	0	1
	3	1	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0
	4	1	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0
	5	0	0	1	0	1	0	0	1	0	0	0	0	0	1	0	1
	6	1	0	0	1	0	1	0	0	1	0	0	0	0	0	1	0
	7	0	1	0	0	0	0	1	0	0	1	1	1	1	0	0	0
	8	0	0	1	0	1	0	0	1	0	0	0	0	0	1	0	1
	9	1	0	0	1	0	1	0	0	1	0	0	0	0	0	1	0
	10	0	1	0	0	0	0	1	0	0	1	1	1	1	0	0	0

Rows and columns indicate machines and parts, respectively. Suppose  $M = (M_1, M_2, \dots, M_i, \dots, M_m)$  is a set of machines and  $P = (P_1, P_2, \dots, P_i, \dots, P_m)$  is a set of parts. A machine-part incidence matrix  $[a_{ij}]$  consists of "0", "1" entries, where an entry "1" ("0") indicates that machine  $i$  is used (not used) to process part  $j$ . To decompose matrix in figure, an integer programming model must be formulated. Integer programming models are classified into three types: part family In this article, a 0 – 1 quadratic programming model to group  $n$  parts into  $p$  families based on distance (dissimilarity) between entries is formulated, once part families are grouped, corresponding cells can easily be formed. A measure of proximity must be defined for every pair wise composition of the entries to be grouped. Usually, the measures of proximity quantify the similarity or distance (dissimilarity) between two entries. Proximity between a pair of objects depends on the attributes. It can be defined, mathematically, as a function of the attributes, which may be binary, discrete or continuous variables, depending on the nature of the variables describing the attributes [1]. In this study to ascertain the distance or dissimilarity between a pair of parts, a distance function which namely the Minkowski distance measure is used. The objective function is to minimize the total distance between entries.

3.1. Nomenclature

- Assumptions:

The model's assumptions are as follows

1. Parts are moved in batches between cells.
2. The maximum number of part family is predetermined and remain constant over the time.

models, machine allocation models, and cell formation models. A part family model attempts to group  $n$  parts into  $p$  families based on similarity or dissimilarity of part design and/or manufacture [16]. A machine allocation model allocates machines of different types to machine cells to process part families efficiently [6]. A cell formation model determines the grouping of parts and clustering of machines simultaneously [4].

3. The machine location cost for each machine type is independent of the cell to which the machine is assigned.

- Indices:

$i$  Part ( $i = 1, \dots, N$ )  
 $mm$  Machine type ( $m = 1, \dots, M$ )  
 $c$  Cell ( $c = 1, \dots, C$ )  
 $p$  Part family ( $p = 1, \dots, P$ )

- Parameters:

$max_p$  Maximum allowable number of parts in each part family  
 $d_{ij}$  Distance between part  $i$  and  $j$   
 $(d_{ij} = d_{ji})$   
 $r$  a positive and integer number  
 $(r = 1)$

$$d_{ij} = \left[ \sum_{m=1}^M |a_{im} - a_{jm}|^r \right]^{\frac{1}{r}}$$

Where

$$a_{im} = \begin{cases} 1, & \text{if part } i \text{ uses machine } m \\ 0, & \text{otherwise} \end{cases}$$

$$|a_{im} - a_{jm}| = \begin{cases} 1, & \text{if } a_{im} \neq a_{jm} \\ 0, & \text{otherwise} \end{cases}$$

$d_{ij}$  is minkowski distance function which measure the similarity of parts  $i$  and  $j$  in terms of their machine routing.

- Decision variables:

$$x_{ip} = \begin{cases} 1, & \text{if part } i \text{ is assigned to part family } p \\ 0, & \text{otherwise} \end{cases}$$

**3.2. Mathematical formulation**

Following the problem notation and description, the integer quadratic part family formation model comprising the Minkowski distance measure presented as follows:

$$\text{min} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \sum_{p=1}^P d_{ij} x_{ip} x_{jp}$$

Subject to:

$$\sum_{p=1}^P x_{ip} = 1 \quad \text{for all part } i$$

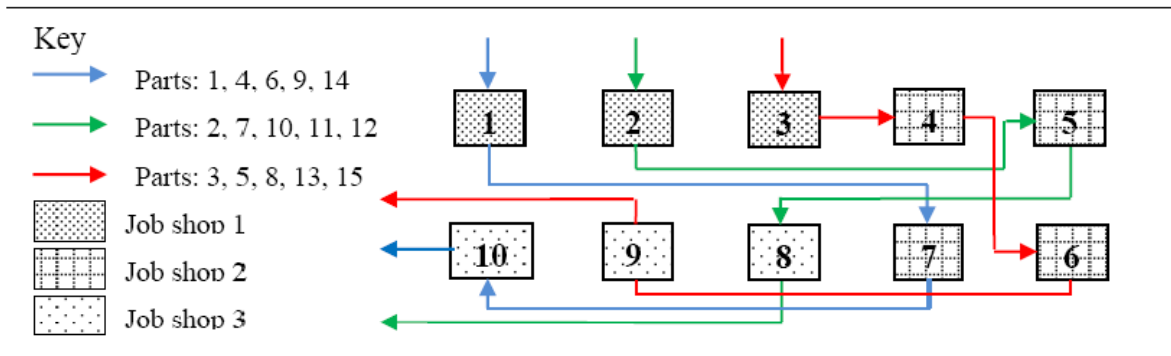
$$\sum_{i=1}^N x_{ip} \leq \max_p \quad \text{for all part family } p$$

$$x_{ip} = 0,1 \quad \text{for all } i, p$$

Once the part families are formed at the desired constraints of the part family size and number of part families, the machine cell identification begins. In this model, the objective function of the problem seeks to minimize the total distance between entries or parts in all cells.

First constraint refers to assignment constraint that means each part must assigned into only one part family, and the second constraint restricts the size of a part family. To illustrate the developed model in this paper for machine cells and part families' formation, a hypothetical manufacturing facility is used as a case.

This hypothetical plant consists of 10 machines which are located based on job shop manufacturing. Suppose that temporary buffer storage facilities and manual material handling systems are available for the existing plant. The job shop layout configuration of the hypothetical case is schematically illustrated in Figure 1. Each job shops A, B, and C performs a special type of operation, and each part travels in a special route.



**Fig. 1** The hypothetical facility layout

The Minkowski distance measure for each two entries is computed and the distance matrix is given in Table 2. It is useful to represent the Minkowski distance matrix as a half-Triangle, having values contained in the upper part of the diagonal and the lower part of the diagonal being zero.

Based on existence number of parts and machines in these hypothetical manufacturing facility, maximum allowable number of parts in each part family is estimated 5 parts.

Thus, the required number of part family will be at least 3 families. Finally, after the model is built, a linear programming package, Lingo (Ver. 8.0) is used to solve these quadratic integer programming models developed to group machines into part families.

The modifying machine-part incidence matrix which alludes to classifying 15 parts into 3 part families and forming 3 machines cells is solved as follows (Table 3):

**Table 2** Part-part incidence matrix

Parts	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	6	6	2	6	2	5	6	1	6	6	6	6	1	6
2	6	0	6	6	6	6	1	6	7	0	0	0	6	7	6
3	6	6	0	6	0	6	5	0	7	6	6	6	0	7	0
4	2	6	6	0	6	2	5	6	1	6	6	6	6	1	6
5	6	6	0	6	0	6	5	0	7	6	6	6	0	7	0
6	2	6	6	2	6	0	5	6	1	6	6	6	6	1	6
7	5	1	5	5	5	5	0	5	6	1	1	1	5	6	5
8	6	6	0	6	0	6	5	0	7	6	6	6	0	7	0
9	1	7	7	1	7	1	6	7	0	7	7	7	7	0	7
10	6	0	6	6	6	6	1	6	7	0	0	0	6	0	6
11	6	0	6	6	6	6	1	6	7	0	0	0	6	7	6
12	6	0	6	6	6	6	1	6	7	0	0	0	6	7	6
13	6	6	0	6	0	6	5	0	7	6	6	6	0	7	0
14	1	7	7	1	7	1	6	7	0	0	7	7	7	0	7
15	6	6	0	6	0	6	5	0	7	6	6	6	0	7	0

**Table 3** The modifying machine-part incidence matrix

		Parts															
		1	4	6	9	14	2	7	10	11	12	3	5	8	13	15	
Machines	3	1	0	1	1	1											
	4	1	1	0	1	1											
	6	1	1	1	1	1											
	9	0	1	1	1	1											
	1						1	0	1	1	1						
	7						1	1	1	1	1						
	10						1	1	1	1	1						
	2												1	1	1	1	1
	5												1	1	1	1	1
	8												1	1	1	1	1

This result in the final machine-part incidence matrix shows machines {3, 4, 6 and 9} from the first cell, machines {1, 7 and 10} from the second cell and machines {2, 5 and 8} from the third cell. The corresponding parts from the three part families are {1,

4, 6, 9, and 14}, {2, 7, 10, 11, and 12} and {3, 5, 8, 13, and 15} respectively. Figure 2 shows a possible configuration of this problem that consists of three cells and three part families.

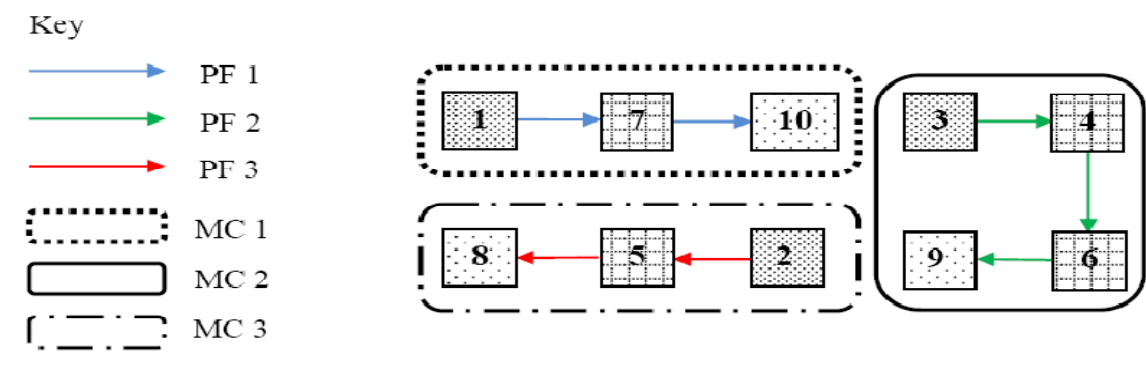


Fig. 2 The modification facility layout

The proposed modifications aim to improve the performance of the plant. With these changes it is assumed that time and cost are decreased and worker productivity improved. This means that workers can produce more parts at the same period and aims to achieve better space utilization. Furthermore, it is assumed that intercellular and additional movement decreased. So, in the next section, the simulation modelling is developed to the new model after implementing CMS compared with the previous existing model.

#### 4 SIMULATION MODELING

Simulation is defined as the imitation of the operation of a system or real-world process over time, and in many cases, manufacturing provides one of the most important applications of simulation. Simulation has been the dominant modelling tool of FMS, which has been used effectively in design, implementation and operation of manufacturing systems. In this study, the simulation model was developed in Arena version 10.0 with visual SIMAN.

Arena software is designed for analyzing the impact of changes involving significant and complex redesigns associated with supply chain, manufacturing, processes, logistics, distribution and warehousing, and service systems. It provides the maximum flexibility and breadth of application coverage to model any desired level of detail and complexity. Arena is a general-purpose simulation system that includes the visual SIMAN simulation language to build discrete event and continuous models. The discrete events simulation model of this study provides the framework for modelling the flow of parts through the cells.

This framework consisted of a set of control statement, a main network and same sub networks formed by specialized nodes and branches used to model

machines, queues for machines, activities, and part (entity) scheduling decisions. The sub-network models in this study were built in order to avoid respective modelling of the processing of parts within both states the previous and the next. The characteristic of the simulation package employed in this paper, Arena with visual SIMAN, are also introduced. There are some brief steps to be followed:

1. Creating necessary modules such as create, process and dispose.
2. Defining the parts types or entities.
3. Defining arrival patterns of parts into the system.
4. Defining operation for each work station and processing time.
5. Defining workflow which follows the sequence of the parts flow path.
6. Defining workers and assigning workers to a particular process.
7. Setting up the model specification, i.e. replication number, replication time and report required.

Finally, after the simulation model is built, a pilot simulation run will be executed. If any errors or warning are received, they will be corrected and the model will be re-simulated. At the end of each simulation, statistical reports are available. These reports summarize how the model performed and produce information such as machine and worker utilization, throughput, cost analysis and product lead time.

There has been a remarkable increase in the use of simulation by the manufacturing sector in many organizations. It is already playing an important role in solving real life manufacturing problems. However considerable difficulties are often encountered in applying simulation methodology.



This paper demonstrated how the simulation model can be used and experimented in order to compare alternative configurations and test various assumptions about group technology or cellular manufacturing system. In developing the simulation model, the following assumptions were made:

- Each machine can perform at most one operation at a time.
- Each paper may visit each machine only once.
- Pre-emption is not allowed.
- Setup times are not sequence-dependent.

The required production data for simulation modelling study are shown in Table 4. As are shown, only worker are required in each machine and production time in each machine is followed by uniform distribution with defined minimum and maximum values. The production sequence, travel distance in each state and first creation for each part or entity are shown in Table 5. It is assumed that time between arrivals is constant distribution with 2 minutes value. These two states are two alternatives which have been modelled to achieve a high level of productivity of the plant:

1. Previous state: existing plant model, previous of implementing the proposed method.
2. New state: cellular manufacturing model, after implementing the proposed mathematical programming technique.

After the model is simulated and run, statistical reports are available.

**Table 4** Production data for Simulation Modelling

Machine	No. of workers	Production time Uniform distribution	
		Minimum (minutes)	Maximum (minutes)
M1	1	0.10	0.15
M2	1	0.12	0.17
M3	1	0.09	0.14
M4	1	0.04	0.06
M5	1	0.04	0.05
M6	1	0.04	0.06
M7	1	0.05	0.06
M8	1	0.05	1.00
M9	1	0.05	1.00
M10	1	0.05	0.85

**Table 5** The operation requirements

Parts	Order of operation	Travel distance		First creation
		Previous	New	
P1	M3-M4-M6	7	5	0.02
P2	M1-M7-M10	18	4	0.03
P3	M2-M5-M8	13	4	0.035
P4	M4-M6-M9	11	5	0.13
P5	M2-M5-M8	13	4	0.135
P6	M3-M6-M9	16	7	0.14
P7	M7-M10	9	2	0.15
P8	M2-M5-M8	13	4	0.16
P9	M3-M4-M6-M9	16	7	0.17
P10	M1-M7-M10	18	14	0.17
P11	M1-M7-M10	18	4	0.175
P12	M1-M7-M10	18	4	0.18
P13	M2-M5-M8	13	4	0.185
P14	M3-M4-M6-M9	16	7	0.19
P15	M2-M5-M8	13	4	0.2

Table 6 shows a typical processing station report by the Arena package. It is assumed that this model is implemented for 4 hours (240 minutes). Information

about percentage of idleness and busyness for each machine and worker is presented in table 6.

**Table 6** Arena model reports

Replication processing station report 09.10.2009 10.30 (From 0. Minute to 240.0 minutes) Status (%)				
Machine	State	Work	Idle	Wait
M1	previous	35.3	65.2	0.0
	new	64.2	34.3	0.0
M2	previous	31.5	70.3	0.1
	new	66.7	30.0	0.0
M3	previous	30.1	66.3	0.0
	new	66.4	31.2	0.0
M4	previous	17.4	82.2	4.7
	New	55.3	25.0	1.0
M5	previous	20.3	75.9	2.0
	New	65.9	22.3	0.0
M6	previous	20.0	73.5	3.3
	New	66.0	20.1	0.3
M7	previous	15.7	77.8	0.0
	New	57.9	15.0	0.0
M8	previous	24.3	68.9	1.2
	New	76.5	14.7	0.5
M9	previous	27.1	76.6	2.4
	New	75.5	17.5	0.0
M10	previous	24.8	73.0	3.7
	New	66.8	21.0	0.9

## 5 RESULTS AND DISCUSSION

Referring to the summarized results of the simulation models in Table 6, for the previous state job shop system, the average utilization of workers and machines are 32% and 25% respectively. The average lead time and wait time is quite high. The average wait time is 220, which shows that performance for the existing system is inefficient and indicates that certain areas need modifications in order to achieve better system performance.

Relocation of the cells in parallel positions and dividing the plant into 3 cells and 3 families are considered in the new state, cellular layout based on the proposed method. It is observed that the travelling time of parts decreased, because the total length of the conveyor is decreased. These achieve better results, and balance worker and process utilization. Furthermore, the space availability for further expansion of the plant is increased to approximately 25%. By observing the simulation, summarizing results of two manufacturing

models and considering all factors, new state proposed cellular system has significantly better results as compared to previous state conventional job shop system. The graphical presentation of the results is shown in Figure 3.

**Table 7** Simulation modal summarizing results

	Previous state	New state
Average machine utilization (%)	25	70
Average worker utilization (%)	32	77
Average wait time	220	57
Average lead time	470	225

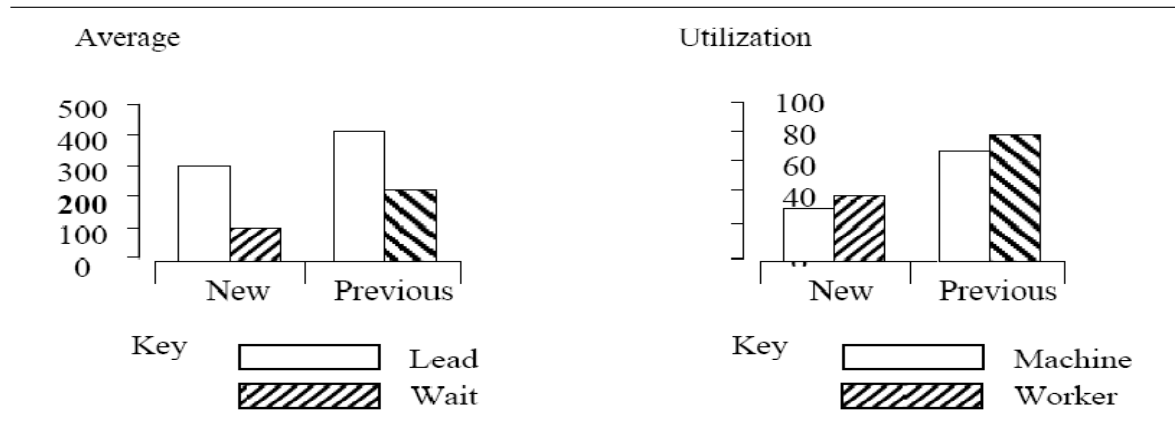


Fig. 3 Graphical presentation of the results

## 6 CONCLUSION

Cellular manufacturing system (CMS) is a production technique that leads to increasing productivity and efficiency in the production floor. The design of CMS consists of machine-part family formation problem. Continually, researchers attempt to find a better solution for solving it. In this paper, a 0-1 quadratic programming model based on the Minkowski distance measure for solving the machine-part family formation problem is applied. The proposed method is implemented in a hypothetical manufacturing facility in terms of conventional job shop layout with 10 machines and 15 parts.

According to the obtained results that are illustrated in section 4, it is shown that the proposed method offers a new cellular manufacturing layout with 3 machine cells and 3 part families in the same manufacturing layout environment. Simulation modelling is used to compare and evaluate the goodness of two manufacturing systems: the conventional job shop system and the innovative cellular system. The main distinction between job shop and cellular system is given by the type of parts they can produce and cell layout. The cellular system allows the process of independent family parts in defined cells while the job shop system manufactures parts in specialized workshops.

Several observations were made from the results of this study. The manufacturing system design factors have a significant impact on the performance of the system. The results that are shown in section 5, indicates that the cellular layout based on the proposed method is more efficient than the previous state, job shop layout. The conclusion cannot be generalized, as the result is dependent upon data and size of the problem. An extension of this study would be to include other optimization models for solving the machine-part family formation problem. The proposed quadratic

programming model was solved by using a linear programming package, LINGO (Ver. 8.0) and also, a simulation package; ARENA (Ver. 10.0) with Visual SIMAN was applied to simulate manufacturing systems.

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