EXPERT SYSTEM FOR GROUP TECHNOLOGY

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ABSTRACT

Modern manufacturing enterprises are increasingly faced with fierce international competition and fluctuating market conditions. To gain flexibility from a functional manufacturing system and efficiency from mass production, group technology has emerged as an effective compromise between the two. Identification and grouping of parts, that share similar processes into cells, is the basic problem in the design of cellular manufacturing systems.

The design of cellular manufacturing systems is a complex, multi – criteria and multi – step process which can have significant implication for the entire organization. The formation of machine cell and part families have a number of constraints such as number of cells, cell size, technological requirements, and any other constraints like cost and time.

This research proposes an expert system called CAEGT, which controls a number of constraints during the formation of machine cells and part families by using three methods. The system was tested in a manufacturing company and it gives an efficient results.

الخلاصــة

تواجه الشركات والمؤسسات الصناعية الحديثة المنافسة الصناعية والتجارية العالمية ومتطلبات السوق المتغيرة. فالصناعات اليوم تواجه مشكلة تقليل كلف الانتاج والتصنيع وتأدية طلبات المستهلك في تجديد المنتجات، تقليل الكلف، وتحسين النوعية. ومن اجل الحصول على المرونة الأنتاجية المرتبطة عادة بأنظمة التصنيع الوظيفي بالأضافة الى رفع الكفاءة الأنتاجية المرتبطة عادة بأنظمة الانتاج الكمي، فقد توجه النظر الى استخدام تقنية المجاميع التكنولوجية كوسيلة فعالة بين الاثنين. وتعتبر عملية تكوين عوائل الأجزاء، التي تكون متشابهة في الخواص أو العمليات، وخلايا المكائن الخاصة بهذه العوائل هي المشكلة الأساسية في تصميم أنظمة التصنيع الخلوي.

عملية تصميم انظمة التصنيع الخلوي هي عملية معقدة، ذات معايير ومراحل متعددة والتي لها تأثير هام على المؤسسة الصناعية. أن مرحلة تكوين خلايا المكائن وعوائل الأجزاء ذات محددات كثيرة مثل عدد الخلايا، حجم الخلية، المتطلبات التكنولوجية وغيرها من المحددات مثل الكلفة والوقت.

البحث الحالي يقدم نظام خبير سمي (CAEGT)، والذي بواسطته يمكن السيطرة على عدد من المحددات الداخلة في عملية تكوين خلايا المكائن وعوائل الأجزاء بأستخدام ثلاثة طرق مختلفة. النظام المقترح أختبر في شركة انتاجية وكانت النتائج المستحصلة ذات كفاءة جيدة.

KEY WORDS

Group Technology, Cellular Manufacturing, Cell Formation, Expert System.

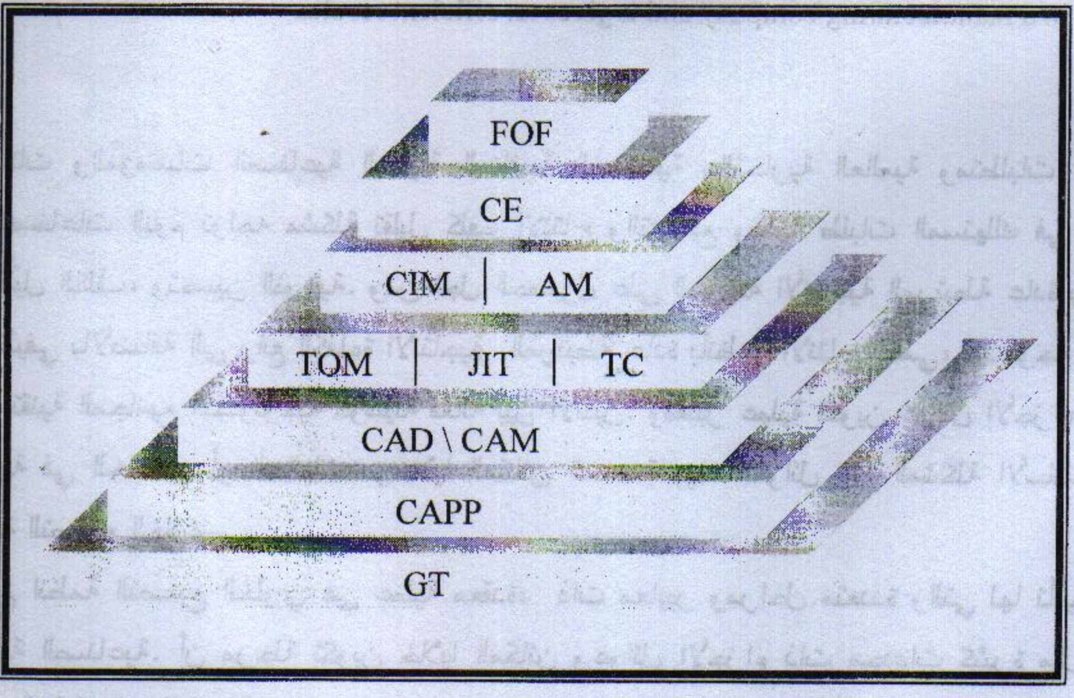
INTRODUCTION:

Group Technology (GT) has been extensively employed as an efficient approach to meet diversified production requirements which are results of the market's demand for production differentiation and the trend towards shorter product life cycle [Chan, and others, 1998].

GT is a theory of management based on the principle that similar things should be done similarly [Arzi, and others, 2001]. One aspect of GT in manufacturing is Cellular Manufacturing (CM). This term relates to the organization of the manufacturing facility on the basis of dedicated cells of dissimilar machines, which process sets of similar parts, called part families (PF). Each cell is designed as a modified flow – shop and most machines in a cell can perform multiple operations.

New technologies such as the application of robotics and other forms of mechanized /automated material handling systems along with the desire to build closely – coupled manufacturing systems with low throughput times, reduced complexity in material flow patterns, low cost of work – in – process inventory, low equipment cost, low direct/indirect labor cost and improvement in quality, machine utilization, space utilization and employee moral often support and mandate a cellular manufacturing approach before embarking upon implementation of such manufacturing concepts like Just – In – Time (JIT), Quick Response Manufacturing (QRM) or Agile Manufacturing (AM) [Ramabhatta and others, 1998].

It may be conclude that group technology (cellular manufacturing) represents the basis on which many technologies depend on, and considered as the first step to reach the summit of the pyramid of technologies **Fig. (1).**



GT = Group Technology; CAPP = Computer Aided Process Planning; CAD = Computer Aided Design; CAM = Computer Aided Manufacturing; TQM = Total Quality Management; JIT = Just In Time; TC = Tolerance Chart; CIM = Computer Integrated Manufacturing; AM = Agile Manufacturing; CE = Concurrent Engineering; FOF = Factory Of Future.

Fig. (1) : The Pyramid of Technologies (Researcher).

Cellular Manufacturing (CM) can allow the small batch – type production to gain an economic advantage similar to that of mass production, and can also provide the flexibility in association with job – shop production. As a result, (CM) has received considerable interest from both practitioners and academics.

However, the design of a (CM) system is a challenging task because it involves many strategic issues, such as [Chan and others, 1998; and Kusiak, 1988]:-

- Cell Independence where maximum independence, given imposed constraints, is aimed for if complete independence is not achieved.
- Cell Flexibility where processing of parts on alternative machines inside a cell and the ability to release parts to alternative cells as also the ability of the cells to accommodate new parts are aimed at.
- Cell system layout which aims at an optimal arrangement of cells with minimized move distances and material flow patterns.
- Cell size and utilization levels which bring in workload constraints during cell formation.

An important issue in (CM) system design is the 'cell formation' process – grouping parts families into cells. Cell formation techniques identify part families and machine cells according to information on available machines and processing requirements of the parts.

This problem is nonpolynomial – complete (NP), hence, most of the proposed algorithms are heuristic [Arzi, 2001].

A few number of researchers present the use of expert system or knowledge – based system in the design of cellular manufacturing system. From those researchers, [Kusiak,1988] presents a knowledge – based system (EXGT-S) for solving the generalized group technology problem. The formation of machine cells was based on the matrix of processing times. It involves four constraints which consider availability of processing time at each machine, reqiurement for material handling carriers and machines for each cell and technological constraints. The knowledege – based system involves a heurisitic alogrithm (cluster identification algorithm) and an expert system. According to him the approach allows one to take advantage of the user's production expertise. [Heragu, 1989] attempts to integrate the machine grouping and layout problems using knowledge – based system. The methodology involves three stages. In the first stage, an algorithm for solving the machine grouping problem is utilized. In the second and third stages, mathematical programming models of the machine cell and machine layout problems are formulated and solved using suitable algorithms. An expert system will be a useful tool for a manufacturing system which plans to implement the group technology concept. [Basu et al.,1995] proposes an expert system approach to cell system design. The starting point for the expert system is the initial solution generated by traditional mathematical techniques (ranked order clustering). Based on a flexible set of user – driven quantitative and qualitative factors, the expert system evaluates these preliminary solutions for feasibility and quality. The proposed system is currently under development. [Govindarajan,1995] develops a methodology for the design of cellular manufacturing system utilizing the group technology output. The design process is built into an expert system. A new algorithm for forming a groupable matrix using alternate process plans is also developed. The algorithm gives alternatives at various stages which can be evaluated and a solution can be selected by the user. A new method for the joint selection of layout and material handling systems is also proposed.

From the above researches, it is clear that non of them studied the using of expert system or knowledge – based system in solving the cell formation problem by different methods, and this is the aim of this research.

GROUP TECHNOLOGY FORMATION METHODS:

The first step in implementing GT in manufacturing is to find a methodology to decompose the manufacturing system into independent cells consisting of various machines and part families assigned to it.

Families formation and machines grouping are the most important steps and the key elements of GT. This is considered as the crucial and the most difficult step in planning the introduction of GT. The difficulty inherent in this technique, arises from the problem of identification of similar parts. There is usually a problem of defining how parts are similar to each other. Similarity may be in shape, processing method or function [Ajang, 1997].

Different approaches are currently being used in planning GT. A number of researchers have offered classifications for cell formation techniques [Kamal and Burke, 1996, Suresh and Kay,1998, and Arzi, 2001].

Most of the approaches and techniques are based on machine – part incidence matrix to represent the cell formation problem. Such matrix is transformed into block diagonal form to generate part families and machine cells. The machine – part incidence matrix is a zero – one matrix (A) of size n × m, where (n) is the number of machines and (m) is the number of parts; an element $a_{ij}=1$ indicates that part (j) is processed on machine (i), and $a_{ij}=0$ otherwise. So, the complete matrix is a random array of 0's and 1's.

In order to achieve the advantages of GT, the manufacturing cells (represented by the diagonal block in a part – machine incidence matrix) must be formed in such a way that there are less voids (zeros) inside the diagonal blocks and less exceptional elements (ones) outside the diagonal blocks. The lessening of voids reduces the part movements across the different machines within a manufacturing cell, thus improving the utilization of the machines. The efficiency of each manufacturing cell can thus be improved. By reducing the exceptional elements outside the diagonal blockes, the part movements across the different manufacturing cells can be minimized, and thus the productivity can be enhanced. In addition the handling cost associated with part movements can also be reduced [Chan, 1998].

This research will focus and deal with the problem of cell formation based on similarity coefficient techniques and heuristic methods that depend on machine – part incident matrix.

EXPERT SYSTEMS

When an organization has a complex decision to make or a problem to solve, it often turns to experts for advice. These experts have specific knowledge and experience in the problem area. They are aware of alternative solutions, chances of success, costs that the organization may incur if the problem is not solved. The more unstructured the situation, the more specialized and expensive is the advice [Turban and others, 1998].

Expert systems (ESs) are an attempt to mimic human logic and solve problems much as a human expert would [Lugar and others, 1998].

Typically, an ES is a decision – making software that can reach a level of performance comparable to (or even exceeding) that of a human expert in some specialized and usually narrow problem areas. The basic idea behind an ES is simple. Expertise is transferred from an expert (or other sources of expertise) to the computer. This knowledge is then stored in the computer. Users can call on the computer for specific advice as needed. The computer can make inferences and arrive at a conclusion. Then, like human expert, it advises the nonexperts and explains, if necessary, the logic behind the advice [Turban and others, 1998; and Karwatzki, 1987].

ESs is the subfield of artificial intelligence (AI) that has evoked the most interest in business and industry and has resulted in the greatest number of practical applications[Prerau, 1990].

Components of an Expert System

The architecture of a typical ES includes the following, [Turban, 1998; Luger, 1998; and Forsyth, 1989]:

knowledge base, inference engine, explanation subsystem (justifier), and user interface.

Their relationships are shown in **Fig. (2).**

METHODOLOGY

This section discusses methods used in (CAEGT) system to form machine cell and part families. They have been selected from literature after comprehensive study of the existing methods. They are; Heuristic Similarity Coefficient method (HSC), Occupancy Value method (OV), and Liner Cell Clustering method (LCC).

These methods have the following properties :

1- They are insensitive to the direction of coding, meaning that interchanging rows and columns in an incident matrix has no effect on the solution.

2- The main objective for them is to minimize the interactions between cells (inter – cell moves). Other methods depend on minimizing the number of duplicated machines needed to obtain mutually exclusive cells, which is not preferable.

3- The range for the similarity coefficient methods is ($0 \leq S_{ij} \leq 1$). It would enable the analyst to recognize the relative strength of a relationship measured by S_{ij}. This range may be ($-1 \leq S_{ij} \leq 1$) for others that does not give a realistic value.

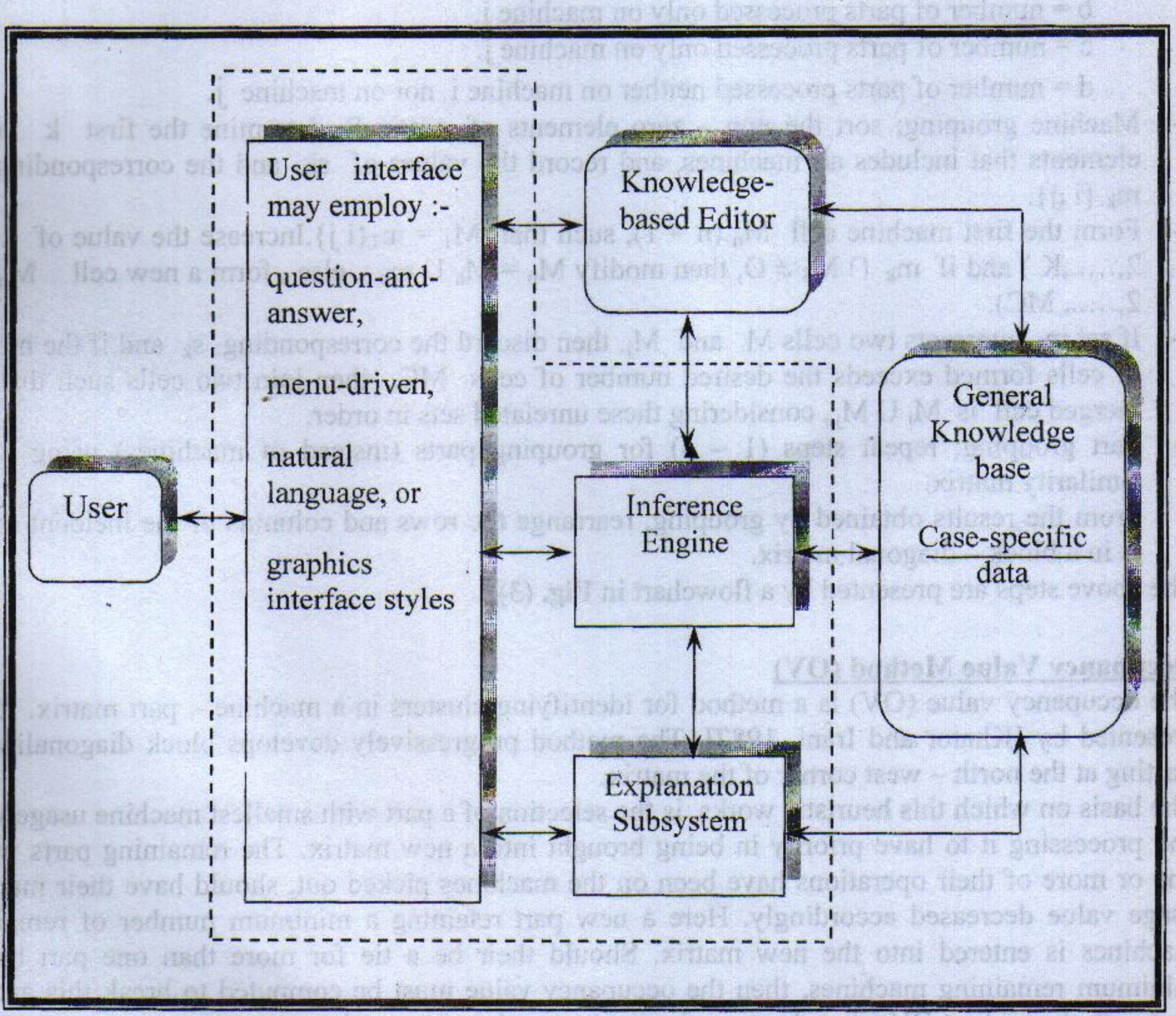


Fig. (2): Structure of an Expert System (Ref. 12).

Heuristic Similarity Coefficient Method (HSC)

Islam and Sarker, 2000; introduced heuristic similarity coefficient method (HSC). They developed a new similarity coefficient and heuristic procedures to form machine cells and part families by rearrange the rows and columns of the machine – part incident matrix into a block – diagonal matrix.

Steps of HSC

a- Given an incident matrix $A = [a_{ij}]$. Calculate the lower triangular relative machine matching similarity matrix, $S = [s_{ij}, i \geq j ; i, j = 1, \ldots, M]$, where :

$$s_{ij} = \frac{a + \sqrt{ad}}{a + b + c + d + \sqrt{ad}}$$

Where

a = number of parts processed on both machines i and j.
b = number of parts processed only on machine i.
c = number of parts processed only on machine j.
d = number of parts processed neither on machine i nor on machine j.

b- Machine grouping; sort the non – zero elements of matrix S, determine the first k largest elements that includes all machines, and record the values of sk and the corresponding sets $m_k \{i, j\}$.

c- Form the first machine cell M_n (n = 1), such that $M_1 = m_1\{i\ j\}$.Increase the value of k (k = 2,…..,K) and if $m_k \cap M_1 \neq \emptyset$, then modify $M_n = M_n \cup m_k$, else , form a new cell M_n (n = 2,….., MC).

d- If set m_k intersects two cells M_i and M_j, then discard the corresponding s_k and if the number of cells formed exceeds the desired number of cells MC, then join two cells such that the merged cell is $M_i \cup M_j^*$, considering these unrelated sets in order.

e- Part grouping; repeat steps (1 – 4) for grouping parts (instead of machines) using a part similarity matrix.

f- From the results obtained by grouping, rearrange the rows and columns of the incident matrix A in a block – diagonal matrix.

The above steps are presented by a flowchart in **Fig. (3).**

Occupancy Value Method (OV)

The occupancy value (OV) is a method for identifying clusters in a machine – part matrix. It was presented by [Khator and Irani, 1987]. The method progressively develops block diagonalization starting at the north – west corner of the matrix.

The basis on which this heuristic works, is the selection of a part with smallest machine usage value and processing it to have priority in being brought into a new matrix. The remaining parts whose one or more of their operations have been on the machines picked out, should have their machine usage value decreased accordingly. Here a new part retaining a minimum number of remaining machines is entered into the new matrix. Should their be a tie for more than one part having minimum remaining machines, then the occupancy value must be computed to break this and the part with the highest OV takes the precedence to enter the new matrix.

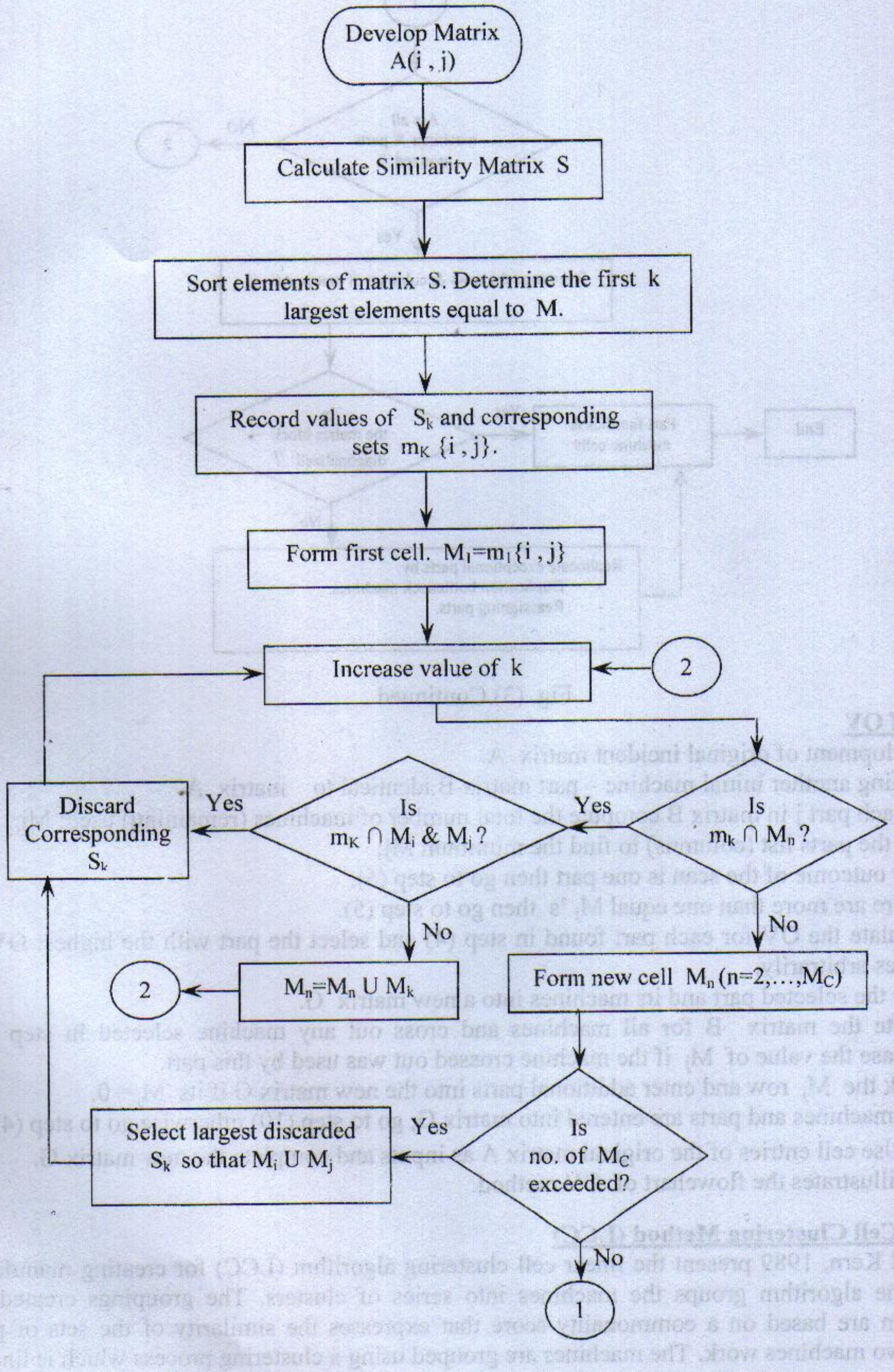


Fig. (3) The Flowchart of HSC Method (Researcher).

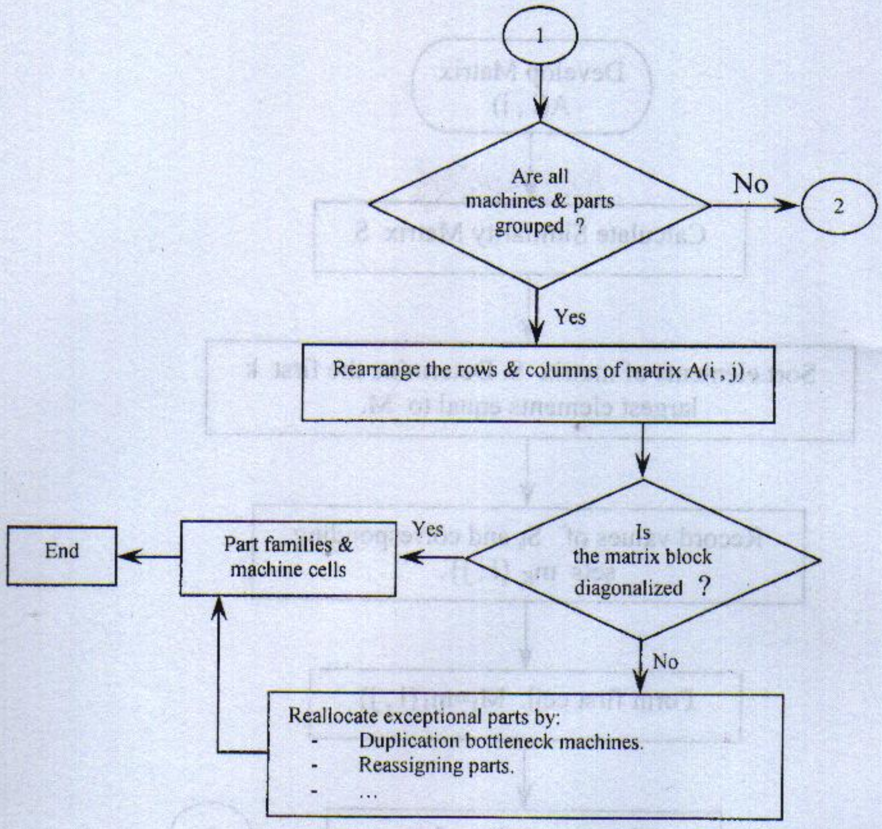


Fig. (3) Continued

Steps of OV

1- Development of original incident matrix A.
2- Forming another initial machine – part matrix B identical to matrix A.
3- For each part j in matrix B compute the total number of machines (remaining) used; Mj.
4- Scan the parts list (columns) to find the minimum Mj;
a. If the outcome of the scan is one part then go to step (6).
b. If there are more than one equal M_j 's then go to step (5).
5- Calculate the OV for each part found in step (4) and select the part with the highest OV, break the ties arbitrarily.
6- Enter the selected part and its machines into a new matrix G.
7- Update the matrix B for all machines and cross out any machine selected in step (6) and decrease the value of M_j if the machine crossed out was used by this part.
8- Check the M_j row and enter additional parts into the new matrix G if its $M_j = 0$.
9- If all machines and parts are entered into matrix G, go to step (10) otherwise go to step (4).
10- Use cell entries of the original matrix A as inputs and complete the new matrix G.

Fig. (4) illustrates the flowchart of OV method.

Linear Cell Clustering Method (LCC)

Wei and Kern, 1989 present the linear cell clustering algorithm (LCC) for creating manufacturing cells. The algorithm groups the machines into series of clusters. The groupings created by the algorithm are based on a commonality score that expresses the similarity of the sets of parts on which two machines work. The machines are grouped using a clustering process which is linear.

Commonality Scores

The definition of a similarity score for part pair i and j as

$$c_{ij} = \sum_{k=1,p} \delta\left(a_{ik}, a_{jk}\right)$$

$$\delta(a_{ik}, a_{jk}) = \begin{cases} (p-1), & \text{if } a_{ik} = a_{jk} = 1 \\ 1, & \text{if } a_{ik} = a_{jk} = 0 \\ 0, & \text{if } a_{ik} \neq a_{jk}. \end{cases}$$

In most clustering problems, there are more parts (p) than there are machines (m) involved. Therefore, a similarity score that produces an (M×M) matrix should therefore require (in most cases) less processing time to cluster. The above commonality score produces such a (M×M) matrix.

The commonality score includes two conditions for adjusting similarity score:

1- if $a_{ik} = a_{jk} = 1$, then add $p - 1$ points to the commonality score c_{ij}.

2- if $a_{ik} = a_{jk} = 0$, then add 1 point to the commonality score c_{ij}.

In this way, only one case adds zero points to a commonality score: if $a_{ik} \neq a_{jk}$, which implies that one of the machines is used in producing part k , and the other is not.

Note that such a commonality formulation will not be affected by the initial positioning of data within the incidence matrix. If two columns in the incident matrix are exchanged, it will only affect the relative position of the specific c_{ij} within the commonality matrix. The score itself remains consistent.

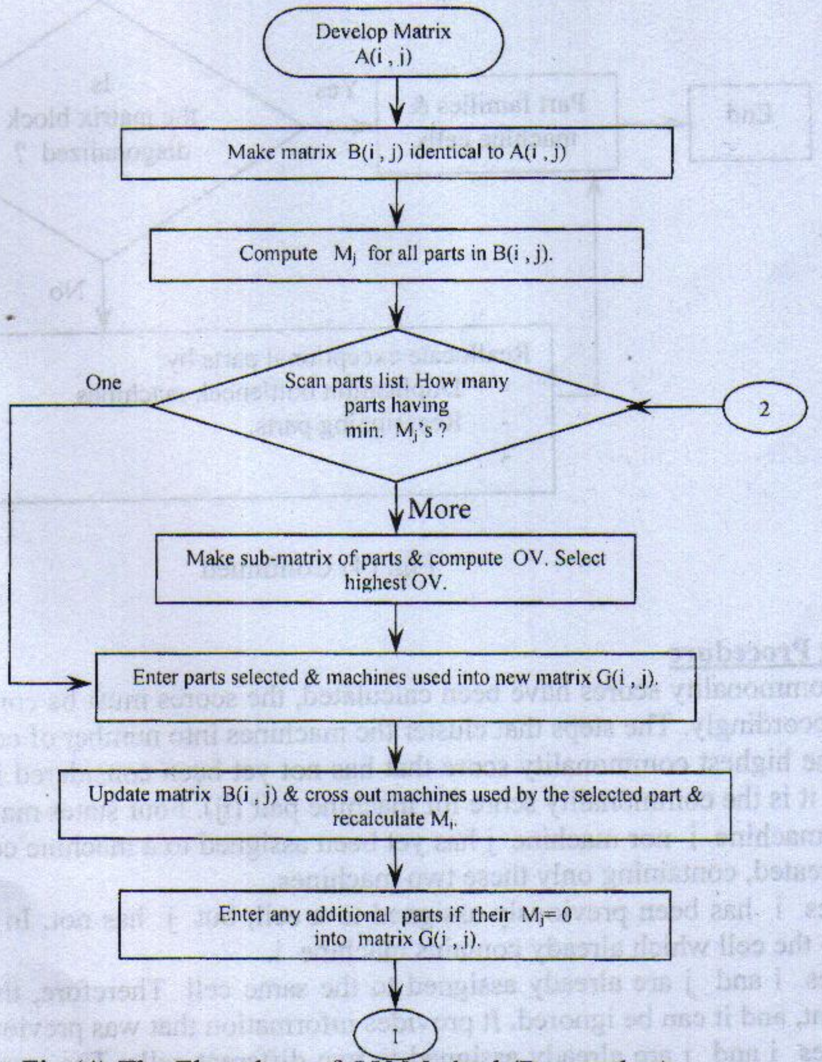


Fig (4) The Flowchart of OV Method (Researcher).

Fig (4) The Flowchart of OV Method (Researcher).

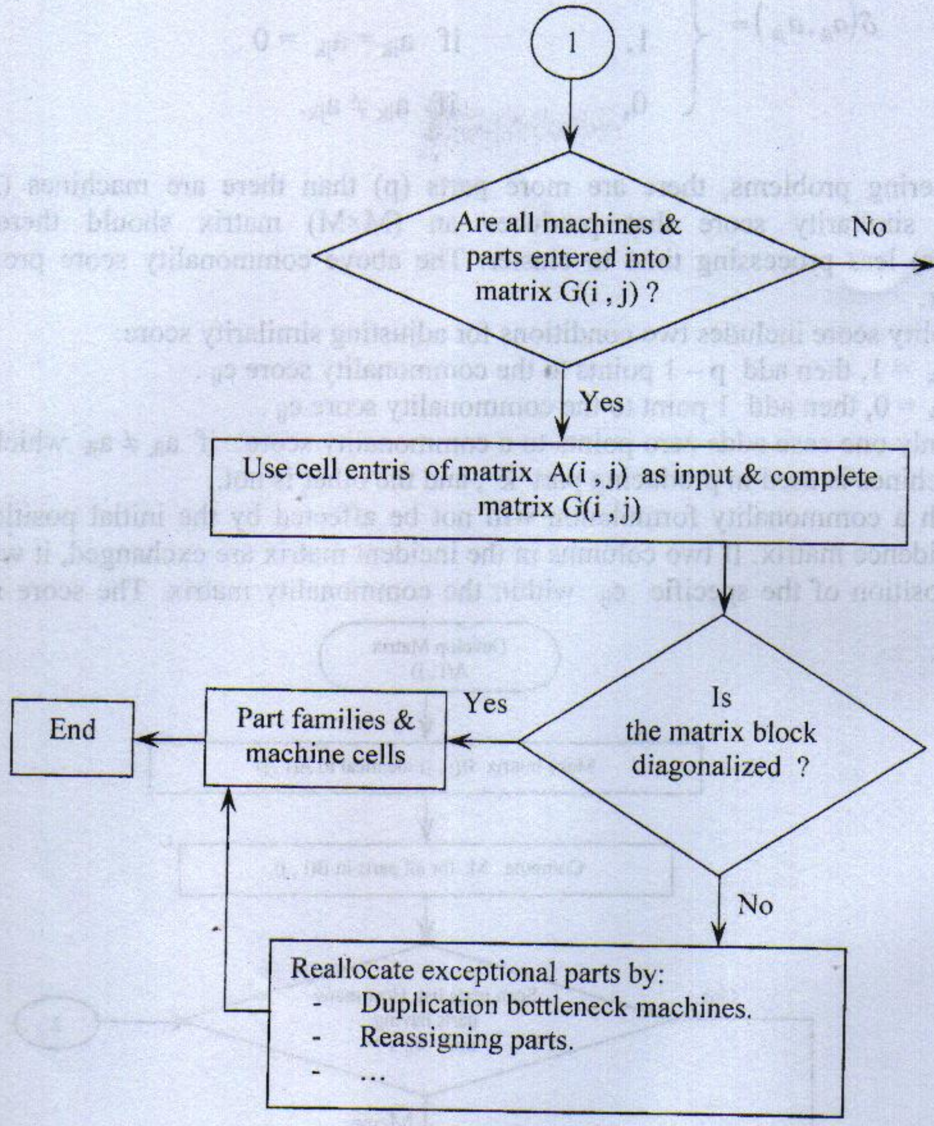


Fig. (4) Continued

Clustering Procedure

Once the commonality scores have been calculated, the scores must be compared and the machines clustered accordingly. The steps that cluster the machines into number of cells are:

1- Select the highest commonality score that has not yet been considered in the clustering process. Assume it is the commonality score for machine pair (ij). Four states may exist as given below.

a- Neither machine i nor machine j has yet been assigned to a machine cell. In such a case, a new cell is created, containing only these two machines.

b- Machines i has been previously assigned to a cell, but j has not. In this case, machine j is added to the cell which already contains machine i.

c- Machines i and j are already assigned to the same cell. Therefore, this commonality score is redundant, and it can be ignored. It provides information that was previously concluded.

d- Machines i and j are already assigned to two different cells. The commonality score signifies that the two cells may be joined in later processing. Reserve this score for possible use in future processing.

2- Repeat step (1). Go to step (3) when all m machines have been assigned to a cell.
3- Step (1) and (2) create the maximum number of clusters that would fit the situation defined by the original incident matrix. If there are no bottleneck parts created by this clustering, the solution is optimal. However, this solution may not contain the desired number of cells. If fewer cells are desired, refer back to the scores identified in step (1 – d).
4- Starting with the largest commonality score that qualifies for condition (1 – d), begin to join cells. Again, if the commonality score refers to the machine pair (ij), combine the two cells that present cell which contains machines i and j. If the resultant cell is too large, or does not qualify due to other established constraints, do not perform the join operation. Instead, consider the next – largest commonality score identified in step (1 – d).
5- Repeat step (4) until all pre – defined constraints on number of cells, cell size, or cost, have been met.

The flowchart for the method is shown in **Fig. (5).**

THE PROPOSED SYSTEM

The programming language used to build CAEGT system is Visual BASIC (VB), version 6.0, which is a suitable environment to design applications and user interfaces for this research.

CAEGT system is supported by an expert system. An ES offers advanced problem – solving capabilities by prompting the user to answer several questions, explaining the reasons for the questions, and offering conclusions, advice and solutions. CAEGT system asks a number of questions to be answered by the user (facility designer, or plant manager) to specify the number of cells, cell size, and any other constraint.

The architecture of CAEGT system consists of the following modules and stages, as shown in **Fig. (6):**

- Incident Matrix Module (IMM). This module is for entering data in the form of zero – one matrix , either from data base or a new matrix is created.
- Solution Method Module (SMM). This module includes the methods used in the system that is discussed in sections (5.1, 5.2, and 5.3).
- Machine cells and Part families Formation Module (MPFM). This is an expert system which uses SMM module to form machine cells and part families according to specific constraints.
- Data Base (DB). This is a data base which contains information on parts and machines. It consists of iccident matrix data base (IMDB) and method evaluation data base (MEDB).
- User Interface (UI). This is an interactive interface between the user such as a production engineer or plant manager and the system to have the best utilization of the sytem.

The knowledge is represented as rules, that are called rule – based system, which consists of rules in the form of condition – action pairs.

The rule – based system consists of three parts :

1- A rule base composed of a set of rules.
2- A special, buffer – links working memory, which is sometimes referred to as context.
3- An interpreter check to see if the conditions specified in the "IF" part of a rule match similar pattern in the knowledge data base .

The condition of the part of a rule is checked every time a rule is selected for firing. CAEGT system modules use different inference strategies, forward chaining and backward chaining depending on a known data or goal.

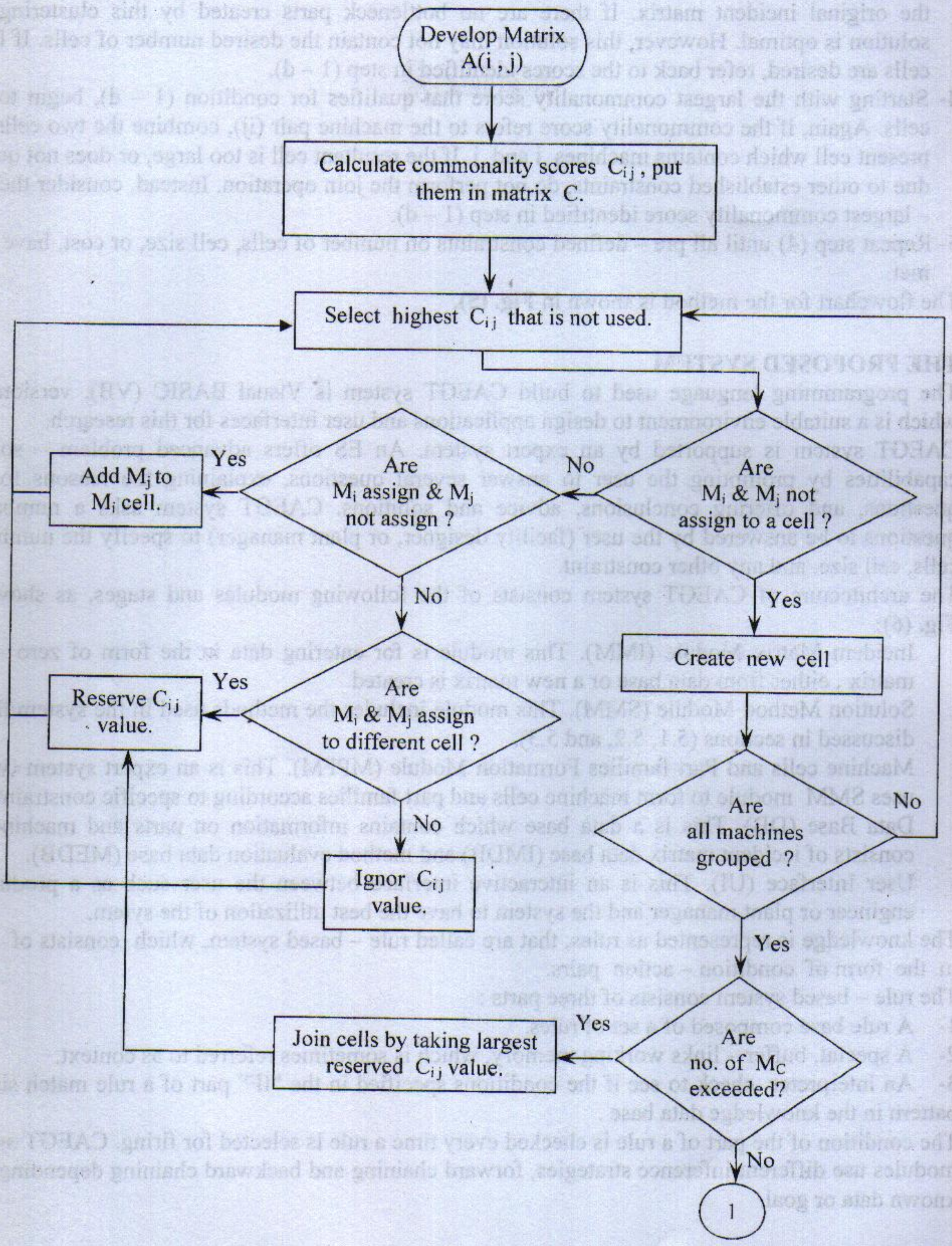


Fig. (5) The Flowchart of LCC Method (Researcher).

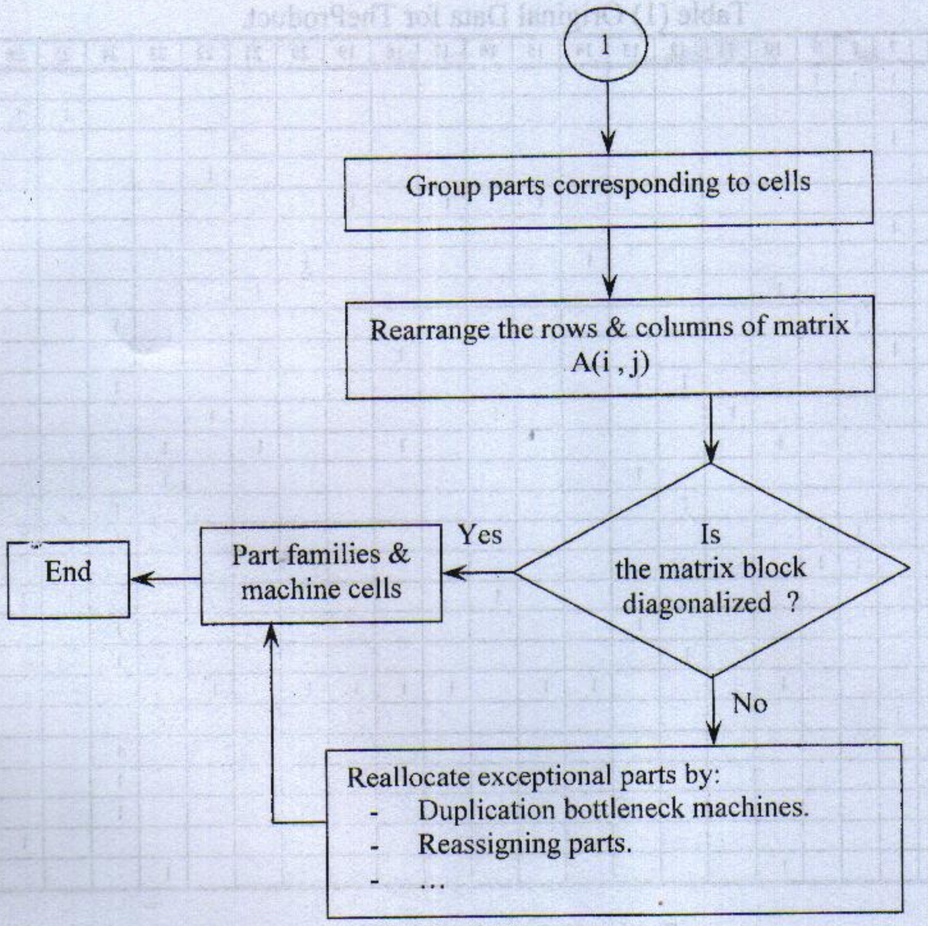


Fig. (5) Continued

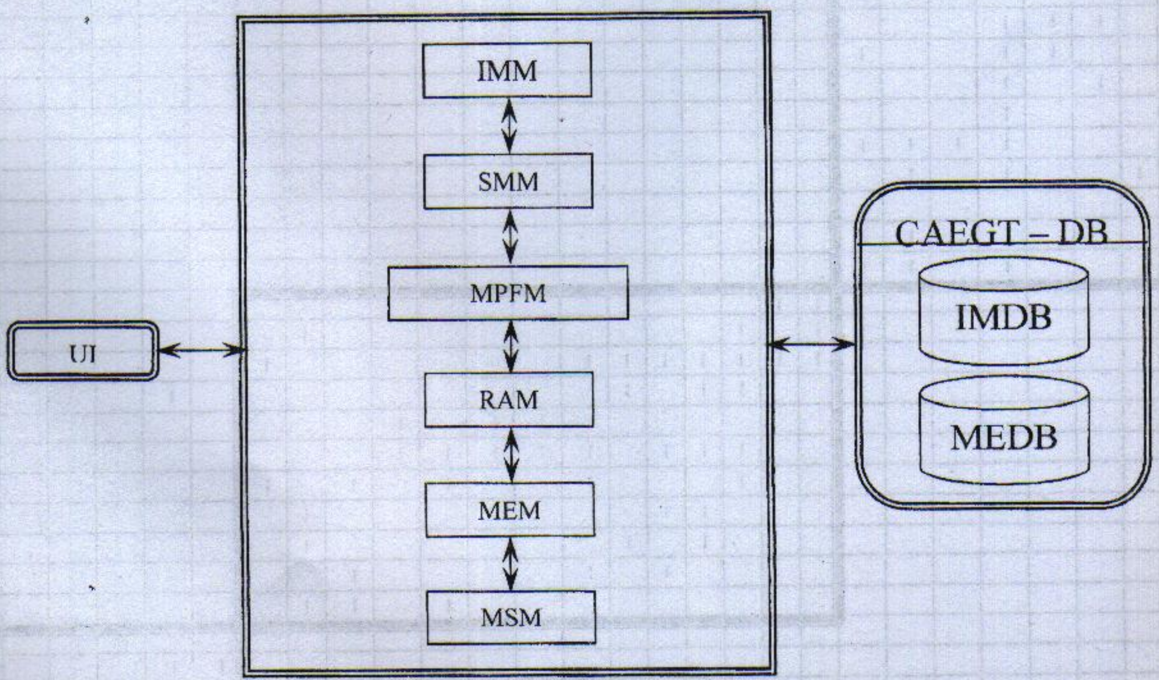


Fig. (6) CAEGT System Architecture (Researcher).

Table (1) Original Data for TheProduct.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	1	1					1	1	1																					
2	1	1				1																			1	1			1	
3	1		1				1																							
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25																								1						
26			1	1		1																				1				
27	1	1	1	1	1	1				1													1							

Table (2) Solution by HSC.

	8	9	12	13	24	27	28	30	1	2	3	4	5	6	10	15	17	18	19	21	7	23	25	26	14	20	11	16	22	29
1	1	1							1	1											1									
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18																							1	1				1		
12																											1	1	1	
4																													1	1

Table (3) Solution by OV

	1	2	2	1	1	2	1	1	1	2	2	6	4	5	2	1	3	1	7	1	2	2	1	1	2	3	2	8	9	2
1	1	1	1																											
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1																							1	1						1
1																							1			1				1
1																								1	1					1
2																								1						1
9																									1	1	1	1		1
2																										1	1			1
2																										1	1			1
1																											1	1	1	1
1																												1	1	
2																														1

Table (4) Solution by LCC

	1	2	7	3	4	5	6	10	15	17	19	22	23	25	26	29	11	14	16	18	20	21	24	27	28	8	9	30	12	13
2	1	1					1																							
27	1	1		1	1	1	1	1					1																	
1	1	1	1																							1	1			
3	1		1	1																										
6			1		1		1																							
22			1		1	1																								
26				1	1		1								1															
8						1		1														1								
5									1	1	1																			
21				1	1	1		1	1	1	1																			
7																		1			1									
4												1				1														
10			1																	1		1								
18														1	1				1											
13				1				1					1							1		1								
12												1					1		1											
9																							1	1	1	1				1
16																							1		1	1	1			
17																										1	1			
23																							1		1			1		
24																							1		1			1		
15																							1	1					1	
14													1											1						1
11																							1						1	1
19																							1					1		1
20																							1						1	
25																							1							

DISCUSSION

In this paper, an expert system based approach to the formation of machine cells and part families in group technology has been discussed. The proposed system, which called CAEGT system, controls the formation process which consists of a number of constraints such as number of machine cells and cell size (maximum number of machines in the cell) which is cosidered an important constraints in the design of cellular manufacturing systems. The system was tested in a manufacturing company and the results obtained from it are very promising in providing better solutions to the machine – part grouping problem. The study shows that the proposed approach possesses the following advantages:

1- Using of expert system to support the solution of cell formation problem in group technology has proved a powerful and very useful tool.
2- The proposed system has proved to be flexible and easy to use, so that it can be used for any product with unlimited data size.
3- Reassigning the solution obtained by any method is usually needed if the data contains botteleneck machines and high exceptional elements.
4- The three methods have been successful in identifying machine cells and part families whenever the data is of the type perfectly groupable.
5- Using several methods results in different solutions that give facility designer more flexibility to choose between alternative solutions.
6- The facility designer has the flexibility to specify the required number of cells and to control the cell size by using HSC or LCC method.

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