A New Approach To Virtual Cell Formation

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In recent years there has been a tremendous growth in the number of cell formation methods. The surge of interest in the area has been fueled by the substantial industry interest in implementing cellular manufacturing (CM) system to reduce movement of jobs, set-up times and lead times. In this paper, a new approach for cell formation that integrates machine grouping and layout design, neglecting part-family formation has been presented. The procedure includes four phases. In Phase 1, primary cells are formed by dividing operations into three ranges (high, medium and low). The frequency of flow occurring between the operations has been taken as a measure for dividing flows into three ranges. Phase 2, involves redesigning of primary cells for minimization of the number of intercell travels and to address the machine duplication problem. Priority levels entered by the users solve the machine duplication problem. Phase 3, involves decomposition of individual primary cells into sub-cells. Sub-cells are formed by employing Phases 1 and 2 again on individual primary cells until further division into sub-cells becomes impossible. Phase 4, involves forced decomposition of sub-cells in order to obtain multiple cell designs. Multiple cell designs are based on criteria of maximum number of machines that can be accommodated in a cell. Multiple cell designs are formed by forcing excess operations to other cells based on the criteria of maximum number of operations that can be accommodated in a cell. The methodology is demonstrated using an illustrative example.

Keywords: *Group technology, cellular manufacturing, hybrid layout, virtual cell formation, intracell flows, intercell flows.*

1. Introduction

The manufacturing sector has become increasingly competitive as markets become more globalized. As a result producers of goods are under constant and intense pressure to quickly and continuously improve their operations by enhancing productivity, quality and responsiveness. Driven by the need to reduce manufacturing costs, and improve quality and flexibility, there has been a major shift in the design of manufacturing planning and control systems using innovative concepts such as just-in-time (JIT) production, flexible manufacturing systems (FMS), cellular manufacturing (CM), and group technology (GT). The adoption of CM, forms a central element of many of these efforts and has

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received considerable interest from both practitioners and academicians.

Organization, design, planning and control of production system are very significant areas for achieving improvements. The design of a CM system is quite challenging because so many strategic issues, e.g. the selection of parts suitable for manufacturing on a group of machines, the level of machine flexibility, the layout of cells, the types of material handling equipment, and the types and numbers of tools and fixtures, must be considered during design. Several techniques like hierarchical clustering (Gupta and Seifoddini, 1990), mathematical programming (Vishwanathan, 1995), the graph theorotic approach (Srinivasan, 1994), rank ordering clustering (King and Nakornchai, 1982), Cluster identification algorithm (Kusiak and Chow, 1987), non-hierarchical clustering (Srinivasan and Narendran, 1991), have been introduced to solve the cellular manufacturing problem. Most of these approaches and techniques fail to address the following issues properly:

Feasibility of non-independent cells having intercell flows and machine sharing among them (Wemmerlov and Hyer, 1989)

Concentration on machine grouping and part family and neglecting flow directions and flow volumes (Irani et al., 1993)

Impact of layout of cells and layout of machines within a cell (Logendran, 1991)

Effect of sequence of operations on material handling costs and times. (Harhalakis et al., 1990)

The issues mentioned above have received relatively little attention in the literature so far. In the past, these problems have been treated as individual design issues. Yet it is important to integrate these related problems. So there exists a need to develop a new methodology, which addresses the above mentioned issues. Most of the methods developed are yet to be solved satisfactorily for large industry-size data sets, in conjunction with many practical considerations in cell formation.

This paper presents a four-phase approach for virtual cell formation, which integrates machine grouping and layout design, neglecting part family formation. The main objective of this paper is to propose a systematic procedure for converting an existing manufacturing system with predefined facility structure to a virtual cellular manufacturing (VCM) system. A VCM system represents a novel fusion of both cellular and functional grouping of several shared machine types, with limited physical duplication of shared machines and intercell flows. The rest of the paper is organized as follows. In section 2, a brief review of literature that motivated us to formation of a new approach is presented. The need for creation of virtual cells is focused in section 3. Models employed in the methodology are presented in section 4 and section 5. The proposed methodology, consisting of a four-phase procedure is explained in section 6. An illustrative example is presented in section 7. This is followed by conclusions in the last section.

2. Literature Review

Because of the complexity of the design of cellular manufacturing systems, numerous algorithms, heuristics or non-heuristics have emerged. Existing approaches to cell formation force each part of a part family to belong to one machine cell (Offodile et. al, 1994). Machines of a particular manufacturing cell operate upon parts of only the corresponding class in order to attain mutual separability in machine part cluster. Thus creating independent cells, i.e. cells with no linkages to other cells in the factory, is a common goal for cell formation (Burbridge, 1975, Wemmerlov and Hyer, 1987). However, it is not always economical or practical to achieve cell independence

(Wemmerlov and Hyer, 1989). Forcing parts into families or duplicating machines without any economic considerations and neglecting layout and handling strategies, might result in more cost than intercellular material movement or subcontracting. This is counter-productive to the essence of GT. These approaches fail to merge part families with overlapping machine requirements. This paper presents a new approach for cell formation, which integrates machine grouping and layout design, neglecting part family formation.

Most of the methods developed so far have been demonstrated with a small number of parts and operations, which is an illusion in a typical manufacturing industry. Miltenburg and Montazemi (1993) have described the computational problems encountered with traditional algorithms in an industrial context involving a large number of parts. Most of the traditional algorithms have been beset with such computational problems. Many authors from time to time have been bringing out the computational difficulties associated with traditional algorithms (e.g. Harhalakis et al., 1990).

The traditional approaches to cell formation create independent cells by taking machine-part matrix as input. This approach discourages machine sharing and intercell flows. This method also fails to capture the information about the flow of material. However, with the advances in handling system capabilities machine duplication is being discouraged. Part families with overlapping machine requirements are assumed to be merged to eliminate the need to duplicate shared machines among competing cells (Irani et al., 1993). Logendran (1991) states that for an accurate analysis of a CM problem, one should consider operation sequence in the part-machine grouping. Several other authors have also stated about the importance of operation sequence in the part-machine grouping (e.g. Selvam and Balasubramaniam, 1985; Choobineh, 1988; Tam 1988; Harhalakis et al., 1990; Vakharia and Wemmerlöv, 1990; Kang and Wemmerlöv, 1993; Dahel, 1995; Nair and Narendran, 1998). The motivations for considering sequence of operations to solve the part-machine grouping problem is due to the following reasons:

Inclusion of operation sequence into part-machine grouping leads to formation of a flow line, which with their streamlined work flows, achieves a complete realization of benefits of cellular manufacturing, with less backtracking and material handling, improved control of cell activities, and easier use of conveyors within the cell. Also operation overlapping can be achieved, which leads to further reduction in lead-time and work-in-process inventory (Suresh et al., 1999).

Part-machine grouping does not consider two of the most fundamental elements in cellular manufacturing, the facility layout and the material handling strategies (Irani et al., 1993). Harhalakis et al. (1990) and Dahel (1995) showed that the goal of minimizing exceptional elements without considering operation sequences may not necessarily constitute to minimization of material handling.

Identifying part-families with similar operation sequences also facilitates the implementation of JIT production systems. Besides cell formation, this problem is of interest in the general context of streamlining material flows and re-engineering production and service systems (Suresh et al., 1999).

Some of the traditional approaches like part-machine incidence matrix require an upper bound on the number of machines within a cell and the number of cells as a pre-requisite. This contradicts the fundamental philosophy of part-machine grouping into cells (Burbridge, 1977; Chandrasekhran and Rajgopalan, 1986; Choobineh, 1988; Srinivasan and Narendran, 1991). At the stage of design, it is only logical that the number of groups should be an outcome of the solution procedure and not an input parameter (Srinivasan et al., 1990).

Part quantities are generally processed in unequal volumes. The '1' outside the diagonal block of a matrix can indicate more than one intercell move depending on the type of operation and the volume of particular part being processed. When intercell flow exists, it is more important to eliminate these flows by machine duplication since these will have even higher queuing delays. However, with the advances in handling system capabilities, the intracell machine duplication problem can be considered secondary to that of intercell flows (Irani et al., 1993). Material handling cost and time are dependent on the volume of intercell moves, so there is a need to minimize the volume of intercell moves leading to reduced material handling (Venugopal and Narendran, 1992). Moreover, intracell movement of material is generally faster than intercell movement (Harhalakis et al., 1990).

Irani *et al.* (1993) proposed a two stage flow based approach for the formation for virtual manufacturing cells which integrates machine grouping, shop layout design and intercell flow handling. In their work, machines shared by several cells were assumed to be retained in functional sections if these cells can be located adjacent to each other. Phase 1 is a linear programming model to generate a maximal spanning tree, which tries to minimize intracell travel distances. Phase 2 finds the optimal orientation of the tree by flipping paths at one or more branching nodes in order to minimize intercell flow distances.

Irani *et al.* (1993) generated a maximal spanning tree by heuristics, but do not give any methodology for generating the maximal spanning tree. The application of multi-criteria approach to solve the cell formation problem is one of the highlights of their study. Our work addresses the problem of formation of virtual cells based on operation sequence of the parts. The work tries to overcome the limitations of the earlier studies through the development of four-phase methodology. We treat the restriction of complete processing within a single cell as a desirable goal, but not a constraint.

3. Virtual Cells

The virtual manufacturing concept was first developed at National Bureau of Standards to address specific control problems encountered in the design phase of the automated manufacturing of small batches of machined parts (Simpson et al., 1982). A virtual cell was defined as a *logical grouping* of products and resources within a controller. It allows time sharing of workstations with other cells by virtue of overlapping resource requirements. This is referred to as VCM. The job shop based upon virtual manufacturing cells provides greater flexibility than GT shop configurations by time-sharing of machines. Machines are at all times under the control of either a particular virtual cell or a pool of idle machines. Basically, the shop control system schedules cell activation and allocate machine and other resources to these cells.

Virtual cells may also help to minimize load balancing problems, which are due to sharing of machines by various part families (Irani et al., 1993). Further, the authors argue that the machine groups can be ‘virtual’, i.e. parts of several families can be loaded on a particular machine shared by several cells. Several studies (Shambu and Suresh, 2000; Kannan and Ghosh, 1996;

Flynn and Jacobs, 1987; Ang and Willey, 1984; and Gupta and Tompkins, 1982) have investigated the utility of a hybrid layout for batch manufacturing by using simulation. Hybrid layouts relaxes the traditional view that a cell must be dedicated to a part family and represent a novel fusion of partial conversion to a cellular layout, functional grouping of several shared machine types, limited physical duplication of shared machines and intercell flows.

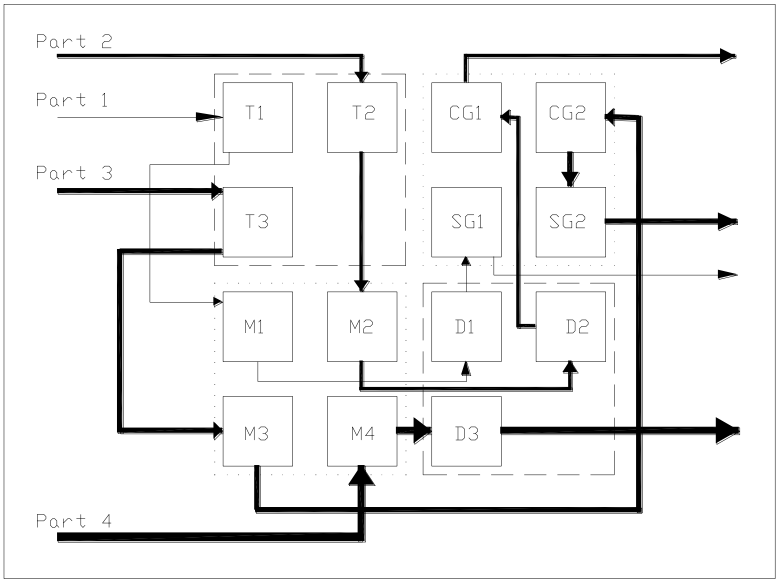


FIGURE 1(a): Functional layout (Source: Gallagher and Knight, 1973)

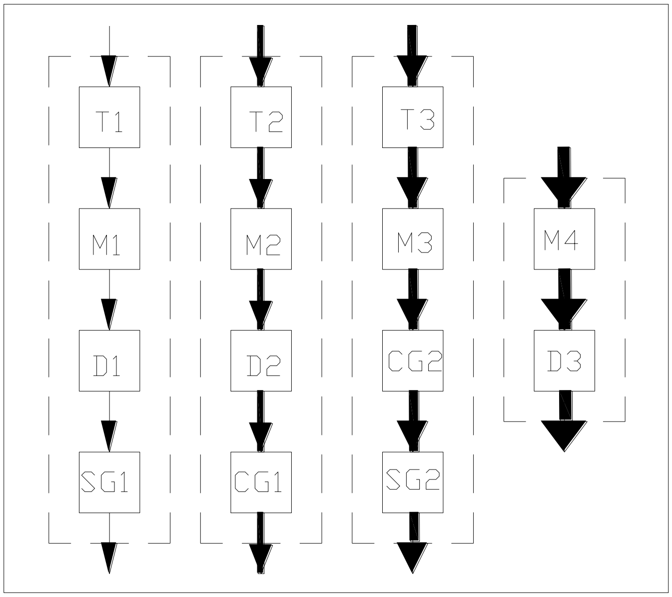


FIGURE 1(b): Cellular layout (Source: Gallagher and Knight, 1973)

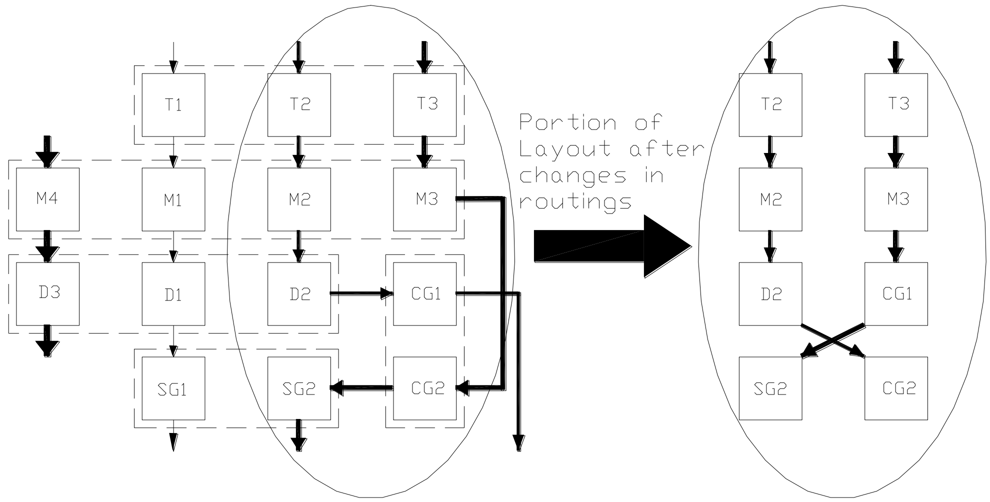


FIGURE 1(c): Hybrid layout (Source: Gallagher and Knight, 1973)

Figure 1(a) is a standard functional layout, which when reorganized on a part family basis into cells, appears as in Figure 1(b). Figure 1(c) demonstrates the concept of hybrid layout that combines the functional layout and the cellular layout. The flow lines in the Figure 1(b) have been permuted in order to bring the identical machines next to each other without destroying the allocations of the machines to particular part families. However, they are retained in functional layouts to allow flexibility in machine reassignments when machines breakdown or the part mix and/or demand volumes change. Virtual cells allow those flowlines that use the same sequence of machines to be merged. These cells also create functional sections for the shared machines. This will result in a hybrid layout of functional sections and machine groups only for those machines that are specific to a single part family. Hybrid layout are realized by modifying (a) the machine-part compositions of the cell or (b) the shapes of the cells or (c) the orientations of the cells or (d) the locations of the cells (Huang and Irani, 1999). Hence, to create virtual cells, an appropriate methodology is required, which allows company to not only limit machine duplication but also time and cost involved in physically reorganizing a layout.

4. Model Formulation

Based on the discussion in literature review section, two mathematical programming models are presented in this paper for the proposed cell formation method. Often cells formed are not well designed, as they do not minimize the intercell flow distances. Model I implicitly gives best design for the cells by minimizing forward, backward and cross flows. It tries to minimize the distances of flow based on flow volumes. Of all the flows, the in-sequence flows are maximum encouraged. Often there are scenarios in the manufacturing systems, where manufacturer's foremost performance measure is to minimize manufacturing cycle time or produce goods by employing minimum capital expenditure though there may be a little increase in product life cycle. So the manufacturer may or may not like to duplicate machines. For example, often in semiconductor industries foremost performance measures are the manufacturing facility's cycle time (Grewal et al., 1998). So for achieving this, the company might like to duplicate the machines. So there should be some sort of priority level system, which allows user to choose priority levels that suits the requirement. Model II evaluates the cell design based on the manufacturer's priorities. It measures efficiency in terms of time and cost, which can be set to optimum value, based on the type of industry. These efficiencies judge the operations contribution towards intracell flows. Often there are operations in the cells, which contribute more towards intercell flow rather than intracell flows. So these types of operations need to be identified and shifted to a cell in which they contribute maximum towards intracell flow, provided they do not increase the overall processing cost for the whole manufacturing system. Later on, justification of shifting can be checked on the basis of overall increase in processing cost by evaluating Model IIa once again or by using time criterion in Model IIb to judge whether shifting is justified or not.

5. Model inputs

The inputs to the model are:

(i) Routing for individual parts
(ii) Manufacturing priority levels
(iii) Material handling cost per unit distance
(iv) Time and cost factors as suitable for industry.

5.1 Model I

This model implicitly gives best design for the cells by minimizing forward, backward and cross flows only for a particular configuration of operations.

Minimize:

$$\sum_{i=1}^{n} f_i \sum_{j=1}^{m-1} l(\mu_{(j,j+1)}) X_{(j,j+1)}$$

subject to constraint depending on the type of flow between i and j

for all in-sequence, by-pass and back-track flows :

$$X_{(j,j+1)} = 1, \forall j \neq S$$

$$X_{(j,j+1)} = 0, \forall j = S$$

for all cross flows :

$$X_{(j,j+1)} = \sqrt{(a^2 + b^2)}, \forall j \neq S$$

$$X_{(j,j+1)} = 0, \forall j = S$$

where

n	=	Number of parts
m	=	Number of operations in the i^{th} part routing
R, S	=	Common root (or raw material store) and sink (or finished goods store) modes of the travel chart occurring in the operations sequences of all parts.
f_i	=	Batch quantity for i^{th} part
a	=	k if cross flow, i.e. node j+1 is reachable from node j vertically by a path μ_{ij} containing k arcs,
$l(\mu_{(j,j+1)})$	=	Vertical distance between levels of nodes j and j+1

= 1 if in-sequence flow,
= k if by-pass and back-track flow, i.e. node j+1 is reachable from node j vertically by a path μ_{ij} containing k arcs,
= b if cross flow, i.e. node j is reachable from node j+1 horizontally by a path μ_{ij} containing b arcs

5.2 Model II

This model duplicates, retain or move operations among cells based upon the cost and time factors as set by the designer of the cells.

5.2.1 Model IIa

Evaluate

$$c_f = c_{intra} / (c_{intra} + c_{inter})$$

subjected to

$$c_{intra} = \sum_{i=1}^{(f_{intra})_i} l(\mu_i) * C$$

$$c_{inter} = \sum_{i=1}^{(f_{inter})_i} l(\mu_i) * \mathrm{C}$$

$$(f_{intra})_i \leq (f_{intra})$$
$$(f_{iner})_i \leq (f_{inter})$$

where

c_f = cost factor for a particular operation
(f_{intra}) = total number of intracell flows caused by the operation
(f_{inter}) = total number of intercell flows caused by the operation
$(f_{intra})_i$ = total number of individual intracell flows [in $(f_{intra})_i$ duplicated flows of $(f_{intra})_i$ are eliminated] caused by the operation
$(f_{inter})_i$ = total number of individual intracell flows [in $(f_{inter})_i$ duplicated flows of $(f_{inter})_i$ are eliminated] caused by the operation
c_{intra} = total processing cost for intracell flows caused by the operation
c_{inter} = total processing cost for intercell flows caused by the operation
C = average material handling cost per unit distance
$l(\mu_i)$ = d if in-sequence flow,
= $k * d$, if by-pass and back-track flow,
= $\left(\sqrt{a^2 + b^2}\right) * d$, if cross flow

5.2.2 Model IIb

Evaluate

$$t_f = t_{intra} / (t_{intra} + t_{inter})$$

Subjected to

$$t_{intra} = \sum_{i=1}^{(f_{intra})_i} l(\mu_i) * T_{intra}$$

$$t_{inter} = \sum_{i=1}^{(f_{inter})_i} l(\mu_i) * T_{inter}$$

where,

t_f = time factor for a particular operation
t_{intra} = total time for all intracell flows caused by the operation
t_{inter} = total time for all intercell flows caused by the operation
T_{intra} = Average time for intracell flow per unit distance
T_{inter} = Average time for intercell flow per unit distance
$l(\mu_i)$ = 1 if in-sequence flow,

= k, if by-pass and back-track flow,

= $\sqrt{a^2+b^2}$, if cross flow

6. Methodology

Our methodology consists of four phases:

Phase 1: Formation of primary cells by dividing operations into three ranges (high, medium and low) based on GT philosophy by employing frequency of flow occurring between operations as a measure.

1a - Division of flows in to 3 equal ranges (high, medium and low) based on GT philosophy by employing frequency of flow occurring between individual operations in the part routings for various parts.

1b - Shift operations causing only intercell flows to its respective cells

1c - Evaluation of best intracell design based on Model I

Phase 2: Redesigning of primary cells for minimization of number of intercell travels and to address the problem of machine duplication problem

2a – Retain, shift or duplicate machines (by employing Model II) based on priority levels entered by user for –

1. Minimization of intercell flows and material handling costs
2. Minimization of duplicated machines
3. Maximization of intracell flows

2b - Evaluation of best intracell design based on Model I

Phase 3: Decomposition of individual primary cells into sub-cells by employing Phases 1 and 2 repeatedly till further division into sub-cells becomes impossible.

3a - Execute Phases 1 and 2 again for each individual primary cell

3b - Find maximum number of operations in a cell out of newly formed sub-cells.

Phase 4: Forced decomposition of sub-cells by shifting excess operations to other cells to obtain multiple cell design solutions based on criteria of maximum number of machines in a cell.

4a - Identify the excess operations in sub-cells formed

4b - Shift excess operations to other cells based on the criteria of having minimum number of intercell flows due to shifting

4c - Evaluation of best intracell design based on Model I

We treat the restriction of complete processing within a single cell as a desirable goal, but not a constraint. This relaxed definition of manufacturing cells result in the complete partition of machinery.

TABLE 1: Operation sequences for the selected list of Parts

Part Number	Part Routing
1	K,L,M,N,O
2	K,A,B,C,D
3	A,K,L,N,O
4	L,M,N,O
5	O,N,D,N,M
6	B,L,M,N
7	K,L,K,M,N,O
8	L,M,L,N,O
9	K,L,K,L,M
10	A,K,B,C,D
11	L,A,C
12	L,C,M,N,M
13	L,M,L,D
14	O,N,L,C
15	M,D,N,O
16	K,A,L,M,N,M
17	B,K,L,N,L
18	K,B,C,M,O
19	A,L,M,O
20	L,B,C,B,L
21	B,M,O,M
22	M,D,C
23	C,M,O,N,O
24	K,M,L,M,O
25	L,N,M,O
26	O,D,C,D,B,A
27	A,B,A,I,J,C
28	I,B,L,K,L,M,N,O

Part Number	Part Routing
29	I,B,L,K,L
30	J,B,K,L,K,L
31	J,C,M,N,O,N,M
32	J,D,N,O,N,M,L
33	A,B,A,H,I,J
34	I,J,H,A,B,C,B,C
35	C,D,C,B,A
36	D,A,B,D,C,B
37	P,Q,P
38	Q,R,S,R,P
39	R,S,Q,S,T
40	S,T,S,R
41	P,Q,R,G
42	Q,R,S
43	R,S,T,R,Q
44	P,Q,R,S
45	Q,R,T,R,Q,R
46	E,P,Q,P
47	R,Q,P,E
48	F,P,S,T,S,T
49	Q,P,F
50	S,R,P,F,P,R
51	T,S,R,Q,P,F
52	G,P,Q,S,T,S
53	G,Q,P,S,T
54	Q,G,R,S,R,Q
55	E,F
56	F,E
57	E,F,G
58	F,E,G
59	F,E,F,G

7. An Illustrative Example

The four-phase methodology developed for formation of virtual cells is explained through a sample data shown in Table 1. To make the example realistic, we have considered a large set of parts (59) with 20 operations. Also it is assumed that complete processing within a single cell as a desirable goal, but not a constraint. The example tries to maximize intracell flows and minimize intercell flows. In order to show the capability of the methodology in generating multiple cell designs priority levels are selected as: 1, 3, 2 (which represent minimization of intercell flows and material handling costs as first priority, minimization of duplicated machines as second priority, and maximization of intracell flows as third priority respectively). Also batch quantity for all the parts is assumed to be 1.

<u>Phase 1a</u> -Formation of primary cells by dividing flow into three ranges: This phase converts the frequency matrix into a lower triangular matrix. Table 2 presents the actual flow that is occurring between various operations in the manufacturing system prepared from the part routings given in Table 1. Table 3 presents the flows by summing of similar flows under one operation head.

TABLE 2: Operations frequency chart

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
A	-	5	1	-	-	-	1	1	-	2	2	-	-	-	-	-	-	-	-	-
B	4	-	6	1	-	-	-	-	-	2	4	1	-	-	-	-	-	-	-	-
C	-	4	-	4	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-
D	1	1	4	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-
E	-	-	-	-	-	3	1	-	-	-	-	-	-	-	1	-	-	-	-	-
F	-	-	-	-	3	-	2	-	-	-	-	-	-	-	2	-	-	-	-	-
G	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-
H	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
I	-	2	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
J	-	1	2	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
K	2	2	-	-	-	-	-	-	-	-	1	10	2	-	-	-	-	-	-	-
L	1	1	2	1	-	-	-	-	-	-	5	-	10	4	-	-	-	-	-	-
M	-	-	-	2	-	-	-	-	-	-	-	4	-	8	6	-	-	-	-	-
N	-	-	-	1	-	-	-	-	-	-	-	2	6	-	10	-	-	-	-	-
O	-	-	-	1	-	-	-	-	-	-	-	-	1	5	-	-	-	-	-	-
P	-	-	-	-	1	3	-	-	-	-	-	-	-	-	-	-	5	1	2	-
Q	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	6	-	6	2	-
R	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	2	5	-	6	1
S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	5	-	7
T	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	4	-

TABLE 3: Summation frequency chart for all operations

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C	1	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D	1	2	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
G	-	-	-	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
I	1	2	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
J	-	1	2	1	-	-	-	1	3	-	-	-	-	-	-	-	-	-	-	-
K	4	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L	3	5	2	1	-	-	-	-	-	-	15	-	-	-	-	-	-	-	-	-
M	-	1	4	2	-	-	-	-	-	-	2	14	-	-	-	-	-	-	-	-
N	-	-	-	4	-	-	-	-	-	-	-	6	14	-	-	-	-	-	-	-
O	-	-	-	1	-	-	-	-	-	-	-	-	7	15	-	-	-	-	-	-
P	-	-	-	-	2	5	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Q	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	11	-	-	-	-
R	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	3	11	-	-	-
S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	3	11	-	-
T	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	11	-

The maximum frequency as obtained from Table 2 is 15. Then divide the maximum frequency in three parts based on GT philosophy, the primary cell ranges and cells are obtained and shown in Tables 4 and 5.

TABLE 4: Primary cells obtained and range or operations in each cell

Cell type	Operation ranges
Low frequency cells	0-5
Medium frequency cells	6-10
High frequency cells	11-15

<u>Phase 1b</u>- Shift operations causing only intercell flows to its respective cells: Operation G in low frequency cell is only contributing to intercell flows with medium frequency cells. Hence it needs to be shifted to medium frequency cell. After shifting of operations the primary cell causing only intercell flows is shown in Table 6.

TABLE 5: Operations assignment to various primary cells

Cell type	Operations assigned to each cell
Low frequency cells	G, H, I, J
Medium frequency cells	A, B, C, D, E, F
High frequency cells	K, L, M, N, O, P, Q, R, S, T

TABLE 6: Primary cell types and operations assignment

Cell type	Operations assigned to each cell
Low frequency cells	H, I, J
Medium frequency cells	A, B, C, D, E, F, G
High frequency cells	K, L, M, N, O, P, Q, R, S, T

Phase 1c- Evaluation of best intracell design based on Model I: The evaluation results (refer Table 7) indicate that primary cells obtained are not properly designed, because the flow distances are not reduced. Hence the cells need to be redesigned to minimize the flow distances.

TABLE 7: Intracell designs for primary cells based on Model I

Cell type	Operations assigned to each cell
Low frequency cells	H, J, I
Medium frequency cells	D, C, B, A, F, G, E
High frequency cells	O, N, M, L, K, T, S, R, P, Q

Phase 2a - Retain, shift or duplicate operations based on priority levels: Model II was executed for the priority levels of 1, 3, and 2. It was assumed machine duplication is not allowed. The following inferences are drawn from the model results.

- Operations H, I, J, D, C, B, A, F, G, E, M and L have more intercell flows than intracell flows. But shifting caused an overall increase in the material handling cost of the system. Hence they were shifted back to their original positions.
- Operations T and S caused only intracell flows. Hence they were retained in the original cells.
- Operations O, N, R and Q caused more intracell flows than intercell flows. Hence they were retained in the respective cells.

Phase 2b - Evaluation of intracell designs: Here various cell designs are evaluated for intracell flows using Model I.

Phase 3a - Decomposition of individual primary cells into sub-cells: Here Phases 1 and 2 are executed again for each individual primary cell. The decomposition produces three sub-cells. Out of these three sub-cells, two are four-cell combination and one is a five-cell combination. For example, in sub-cell 1, high frequency cell was split into two cell combination as (O, N, M, L, K) and (T, S, R, Q, P). Three sub-cells obtained by executing Phases 1 and 2 again are given in Table 8. Figures 2(a), 2(b) and 2(c) show various layout representations of sub-cells.

TABLE 8: Details of sub-cells and operations assignment

Sub-cell	Cell no.	Operations assigned to each cell
1	1	H, J, I
	2	D, C, B, A, F, G, E
	3	O, N, M, L, K
	4	T, S, R, Q, P
2	1	H, J, I
	2	D, C, B, A
	3	O, N, M, L, K, T, S, R, P, Q
	4	E, F, G
3	1	H, J, I
	2	D, C, B, A
	3	O, N, M, L, K
	4	F, G, E
	5	T, S, R, Q, P

Phase 3b - In this phase the maximum number of operations in a cell out of newly formed sub-cells is computed. The maximum operations that are present in various sub-cells are shown in Table 9.

TABLE 9: Operations assignment to various sub-cells

Sub-cell	Number of cells	Maximum number of operations
1	4	7
2	4	10
3	5	5

Phase 4 - Forced decomposition of sub-cells by shifting excess operations: In this phase the criteria of maximum number of machines in a cell is used to obtain multiple cell designs. Multiple cells are generated through execution of Phases 4a, 4b and 4c. For example, in sub-cell 1 maximum number of operations that can be accommodated is 6 and 5. Hence for sub-cell 1, two cell combinations were generated. The multiple cells generated by forced decomposition are shown in Tables 10 to 12. Figures 3(a) to 3(c) show layout representations for various sub-cells.

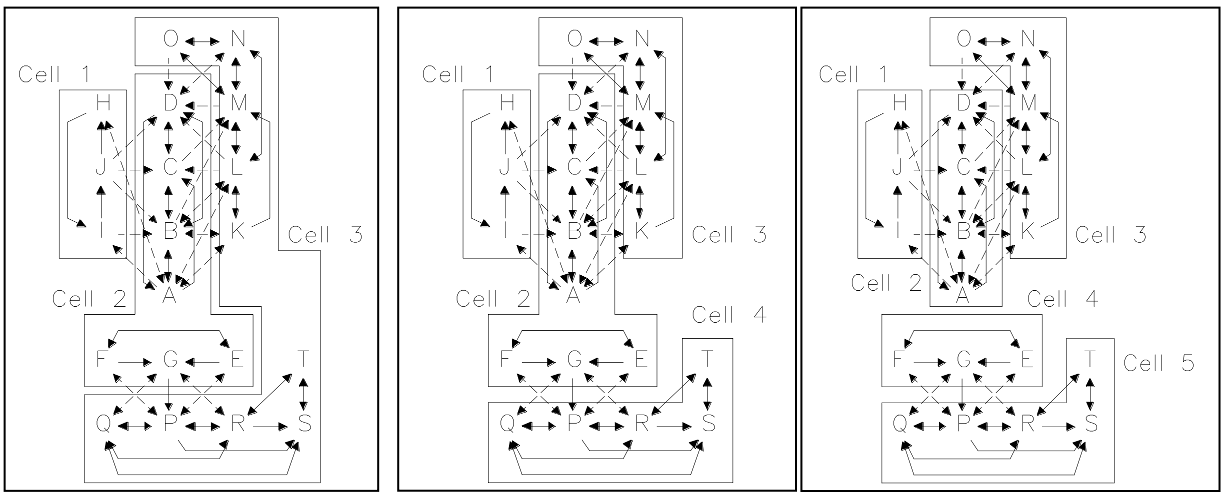


FIGURE 2: Network representation of facility layout for various sub-cells obtained during Phase 3a

TABLE 10: Multiple cell designs obtained for sub-cell 1

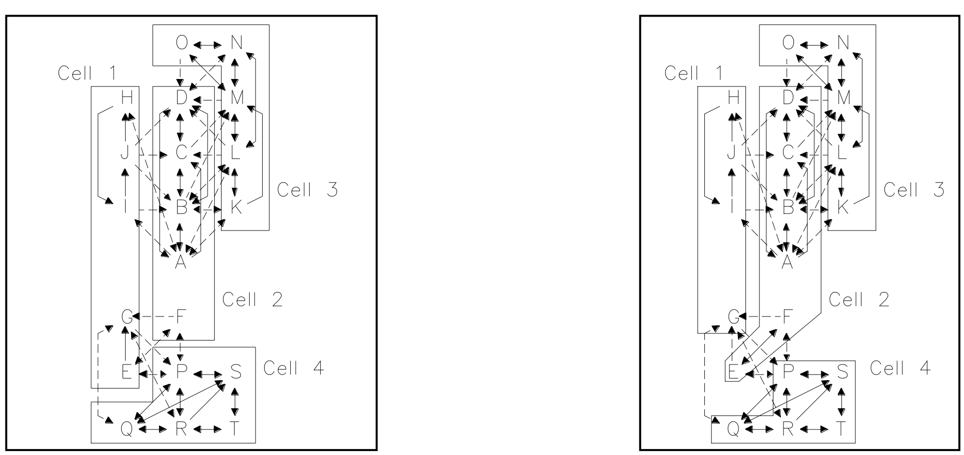
Maximum number of operations	*Cell number*	**Operations assigned to each cell**
6	1	H, J, I, G
	2	D, C, B, A, F, E
	3	O, N, M, L, K
	4	T, S, R, Q, P
5	1	H, J, I, G, E
	2	D, C, B, A, F
	3	O, N, M, L, K
	4	T, S, R, Q, P

TABLE 11: Multiple cell designs obtained for sub-cell 2

Maximum number of operations	Cell number	Operations assigned to each cell
9	1	H, J, I
	2	D, C, B, A
	3	O, N, M, L, K, P, R, S, T
	4	E, F, G, Q
8	1	H, J, I
	2	D, C, B, A
	3	O, N, M, L, K, P, S, T
	4	E, F, G, Q, R
7	1	H, J, I
	2	D, C, B, A
	3	O, N, M, L, K, S, T
	4	E, F, G, Q, R, P
6	1	H, I, J
	2	D, C, B, A, T
	3	O, N, M, L, K, S
	4	E, F, G, Q, R, P
5	1	E, F, G, Q, R
	2	H, J, I, P, S
	3	D, C, B, A, T
	4	O, N, M, L, K

TABLE 12: Multiple cell designs obtained for sub-cell 3

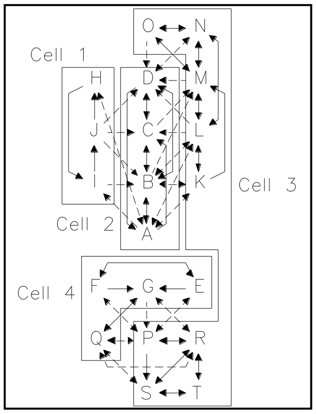
Maximum number of operations	Cell number	Operations assigned to each cell
5	1	H, J, I, A
	2	D, C, B, K
	3	O, N, M, L
	4	F, G, E
	5	T, S, R, Q, P
4	1	H, J, I, A
	2	D, C, B, K
	3	O, N, M, L
	4	F, G, E, P
	5	T, S, R, Q



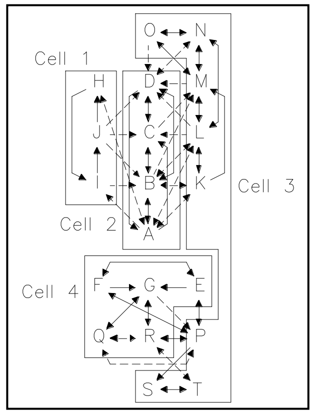
(i) Maximum number of operations in a cell = 5

(ii) Maximum number of operations in a cell = 6

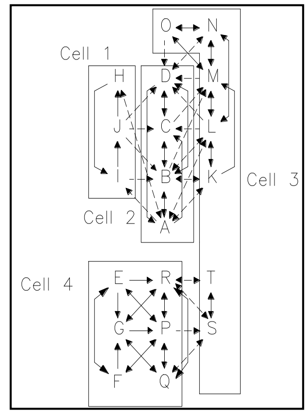
FIGURE 3(a): Network representation of facility layout for sub-cell 1 obtained during Phase 4



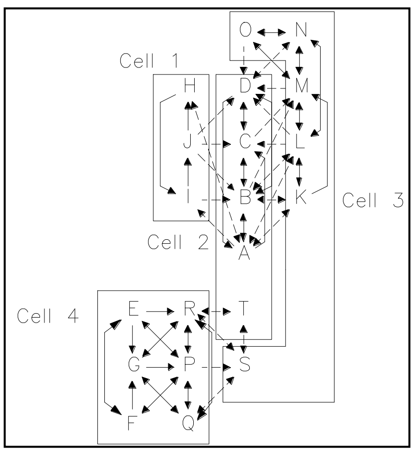
(i) Maximum number of operation in a cell = 9



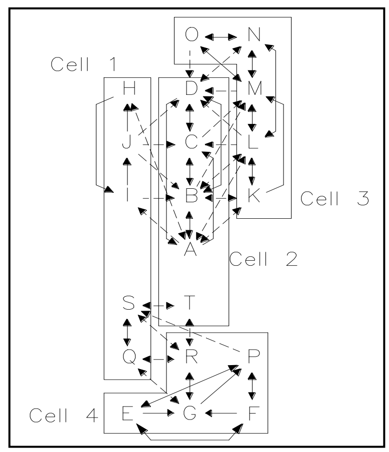
(ii) Maximum number of operations in a cell = 8



(iii) Maximum number of operations in a cell = 7

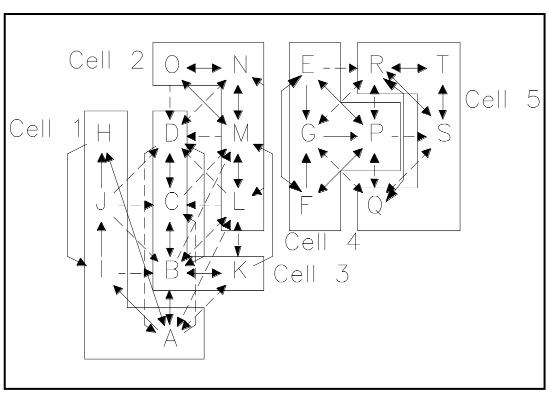


(iv) Maximum number of operations in a cell = 6

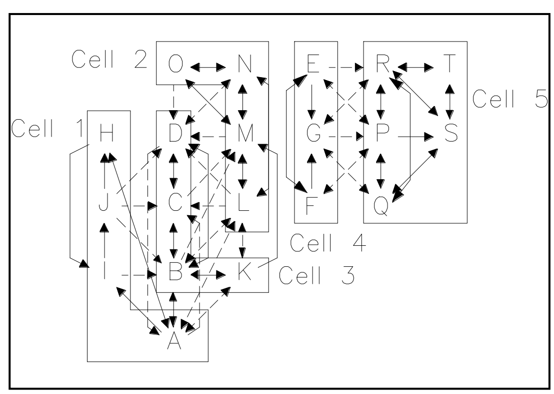


(v) Maximum number of operations in a cell = 5

FIGURE 3(b): Network representation of facility layout for sub-cell 2 obtained during Phase 4



(i) Maximum number of operations in a cell = 4



(ii) Maximum number of operations in a cell = 5

FIGURE 3(c): Network representation of facility layout for sub-cell 3 obtained during Phase 4

7. Conclusions

VCM is a major innovation in the design of production systems. While advantages have been claimed in the past from the implementation, but the methods, which can achieve full benefits of GT still needs to be improved. This paper presents a new approach for virtual cell formation that has four phases. Phase 1 is responsible for formation of primary cells. Phase 2 tries to minimize the flow distances by Model I and addressees the problem of machine duplication by employing Model II. By finding efficiency factor (which judges the contribution of operations towards intercell flows) in terms of cost and time by Model II, the problem of machine duplication was solved. Phase 3 divides primary cells into sub-cells having lesser number of operations. Phase 4 forms multiple cell designs by forced decomposition of the sub-cells. The main objective of this paper is to form cells with minimal procurement of new machines and minimal part movement. The proposed virtual cell formation approach can generate machine groups, identifies flowline layout for each group and minimizes intercell distances and travels. An approximate configuration of the aisles, conveyers or automated guided vehicle grid can also be identified from the flow arcs. It is advisable to minimize or eliminate intracell and intercell travel distances.

The research reported in this paper has demonstrated a useful methodology in the area of facilities design. The methodology identifies groups of machines and sequence of machine arrangements within each cell. In this approach, the decision-maker is provided with multiple cell designs according to maximum number of machines in a cell. It offers the flexibility to assess each alternative against tangible and intangible benefits and criteria. The capability of the methodology was demonstrated through an illustrative example. This virtual cell formulation approach provides a formal framework and starting point for the development of solution methods and heuristics.

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