# A New Concept of Virtual Cellular Manufacturing

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*The research in virtual cellular manufacturing (VCM) systems area gains momentum as markets have become more globalised. This is due to turbulent customer demands, charcterised by frequent changes in product mix and volume. Therefore, if companies are interested in implementing manufacturing systems that can be quickly restructured with minimal cost and time, the approach of virtual cellular manufacturing gives considerable benefits. VCM systems physically resemble the traditional functional layout. Within this setting, group technology (GT) philosophy is used to gain the advantages accompanying with traditional cellular manufacturing (CM) systems. VCM is being used as a philosophy with broad applicability in manufacturing sector to reduce job set-up and flow times. Decisions for pooling of jobs into families, release of part families to the shop, and temporary machine dedication will lead to improvement in shop performance i.e. in terms of job flow time and system utilisation.*
*The goal of this paper is to develop a new concept of VCM and address its operational issues through a numerical illustration. Based on the numerical results, we also outline a factorial design of simulation experiments for future research.*

***Keywords:*** Group technology, cellular manufacturing, virtual cell formation, simulation experiments.

## 1. Introduction

The manufacturing sector has become increasingly competitive as markets become more globalised. Producers of goods are under intense pressure to improve their operations by enhancing productivity, quality, customer-responsiveness and reducing manufacturing costs. Consequently, there have been major shifts in the design of manufacturing systems using innovative concepts. The adoption of cellular manufacturing (CM) has consistently formed a central element for many of these efforts and has received considerable interest from both practitioners and academicians. Cellular manufacturing is known to offer several major advantages, including reduction in lead times and work-in-process inventories and reduction of setup times due to similarity of part types produced (**Burbidge, 1963**).

The concept of dynamic manufacturing cells, where machines are mobile and will be reallocated as soon as production runs are competed can be used to adapt a cellular manufacturing system to turbulent environments (**Rheault *et al.*, 1995**). This concept may reduce some of the negative implications of cell manufacturing while keeping the positive effects. Reorganising the cell layout to meet the changed needs, however, may be time-consuming and costly. Further, if these changes occur very frequently, reconfiguration becomes impracticable or even infeasible (**Thomalla, 2000**).

However, although cellular-manufacturing offers important advantages, there also exist some important reasons why many firms still prefer the 'traditional' functional layout. In contrast to the cellular layout, the functional layout is more robust to

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changes in product mix. It also offers a certain routing flexibility, which may improve shop performance significantly (**Flynn** and **Jacobs, 1986; Suresh** and **Meredith, 1994**). Furthermore, a functional layout tends to foster functional synergies and expertise. At times, they may also provide the economies of scale required for justifying new investments in manu-facturing technology. A functional layout is associated with high machine utilisation and shop flexibility (**Greene** and **Sadowski, 1984**) and superior performance in the queue-related variables (**Flynn** and **Jacobs, 1987**). These are important reasons why a functional layout is still dominant in manufacturing industry and why some firms have shifted from a cellular layout to a functional layout (**Slomp, 1998; Molleman, Slomp** and **Rolefes, 2002**).

In recent years, the concept of "agile manufacturing" has also been explored. This involves facilities that can produce a variety of customised products with minimal reconfiguration and set up. A high degree of volatility in demand, production lots, processing times and set-up times, frequent changes in product mix and/or unique product orders, varying production sequences and presence of a strong competition, all characteristics of a turbulent environment form the rationale for agile manufacturing (**Rheault** ***et al.*****, 1995**). In such an environment, it appears that manufacturers tend to adopt a traditional job shop layout combined with the benefits of cellular manufacturing systems.

A relatively new alternative has been considered in recent years, namely the concept of virtual cellular manufacturing (VCM) systems. Retaining the functional layout, virtual manufacturing cells have been defined as a temporary grouping of machines, jobs and workers to realise the benefits normally associated with cellular-manufacturing. A virtual cell is a logical grouping of workstations that are not necessarily transposed into physical proximity (**McLean** ***et al.*****, 1982**). The logical grouping of jobs, machines and workers is based on a predefined logic and it is only resident in the production control system and in the minds of the workers. Machines are not physically relocated into cells, in other words.

Conventional cellular manufacturing systems involving physical changes to the layout, as stated earlier, possess certain disadvantages relating to the loss of routing flexibility and the inflexibility arising from machine dedication (**Flynn** and **Jacobs, 1986; Suresh, 1991**). VCM concept was proposed primarily as a means to overcome these limitations (**Irani** ***et al.*****, 1993; Drolet** ***et al.*****, 1996; Kannan** and **Ghosh, 1996; Vakharia** ***et al.*****, 1999**).

There has been very little research to date on design of virtual cellular manufacturing systems, which forms the theme of this paper. The main objectives of the paper are to:

(i) Propose a new concept of virtual cellular manufacturing approach along with a numerical example; and

(ii) Outline a factorial design of simulation experiments for future research.

This paper is organised as follows. A review of virtual cellular manufacturing system research is presented in Section 2. In Section 3, a description of the new concept of virtual cellular manufacturing system is considered. A numerical is presented in Section 4 as an illustrative example. Factorial design of simulation experiments for future research is presented in Section 5. This is followed by the conclusions.

## 2. Literature Review

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 (**McLean** ***et al.*****, 1982**). A virtual cell was defined as a logical grouping of products and resources within a controller. 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 allocates machine and other resources to these cells.

Virtual cells may also help to minimise 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. They developed a two-stage, flow-based approach for formation of virtual manufacturing cells with an objective of minimising travel distances. The study addressed the issues of machine-grouping, machine-sharing, intra-cell layout and inter-cell layout.

The impact of utilising part family-oriented scheduling rules within a functional layout was explored in the study of **Suresh** and **Meredith (1994)**. This study showed that a functional layout-system using part family-oriented scheduling (referred to in this work as an "FLP" system), and a first-come, first-serve (FCFS) selection of jobs within each family, fares significantly better than cellular layout systems as well as functional layouts in many parameter ranges. **Kannan** and **Ghosh (1996, 1996a); Kannan (1998)** and **Kannan (1997)** referred to these systems as virtual cellular manufacturing systems.

**Kannan** and **Ghosh (1996, 1996a); Kannan (1997); Kannan (1998)** and **Jensen *et al.* (1996)** extended VCM research stream further, exploring many part family-oriented scheduling rules in FL and showing the superiority of this type of system in which these virtual cells combine the setup benefits of traditional cellular layouts and the routing flexibility of job shops to respond to market changes since machine dedication can be changed without major shop floor modifications. In addition, virtual cells allow the shop to be more responsive to changes in demand and shop load. The study results **(Kannan, 1997)** indicate that VCM configurations yield significantly better job flow time and due date performance over a wide range of common operating conditions, as well as being more robust to demand variability. The model results of **Kannan (1997)** further indicate that virtual cellular manufacturing system is robust to changes in the number and size of families being processed. The approach involves the allocation of machines to part families based on machine idleness and the prevailing production requirements.

**Vakharia *et al.* (1999)** state that a virtual cell simply requires the dedication of individual machines within the current departments to a specific set of part families. Their virtual cell approach mainly dealt with interrelation of the number of machines with the requirements of part families. They compared the performance of virtual cells and multistage flow shops analytically. The results indicate that the ratio of setup time to run time per batch is a major factor that influences the decision to implement virtual cells.

**Ko** and **Egbelu (2000)** illustrate the superiority of a dynamic, cellular-manufacturing system to a static, cellular manufacturing system. The impact of variations in the product mix on the shop performance has been investigated through a comparative study of dynamic and static manufacturing systems. This dynamic cell approach is different from previous approaches **(Kanan** and **Ghosh, 1996a; Vakharia *et al.*, 1999; Hyer** and **Brown, 1999)** and is especially applicable in situations with moveable machines.

The problem of virtual cell formation arises when the product-mix changes frequently **(Thomalla, 2000)**. For higher utilisation of the limited resources, the study proposed an effective grouping of machines into virtual cells through an algorithm. For formation of virtual cells, job travel times, process description and processing time on each machine are considered.

It is apparent from the literature review that much of the literature to date has focused on performance evaluation and comparison of virtual cellular-manufacturing with traditional manufacturing systems. It is evident that there is ample scope to investigate further on design-related issues pertaining to the formation of virtual cells using family-oriented, production-scheduling, depending on changes in product mix. For further reduction in setup times, it may be preferable to pool the jobs into families, keeping families together before releasing to the shop floor and sequencing of jobs within a family. If a group of machines are dedicated to a family temporarily and logically, then there will be a significant improvement in machine utilisation. Apart from this, the following additional benefits can be expected such as further setup advantages, flexibility in release of families based on the family size, increase in due-date performance, and pooling synergy.

Thus, a new concept of virtual cellular manufacturing is proposed here, which is expected to cover other issues such as team production as it is possible to assign job responsibility (from input to output stage) to each team for its timely completion. The new concept of virtual cellular manufacturing is described in the next section.

## 3. A New Concept of Virtual Cellular Manufacturing

The new concept of VCM differs from the existing concept primarily in the creation of virtual cells, nothing but the way of dedication of machines to families. However, the first issue of this approach is according to job similarities; the jobs are pooled into families before their release to the shop. In the second issue, the number of machines that are required per processing department will be decided based on the work content. The third issue deals with the mechanism of family releasing to the production shop. Job-dispatching and temporary dedication of machines to the families is the final issue of the new concept of VCM. However, it is worth to note that sometimes the pre-decided number of machines in each department is not available by the time that the released family reaches the process department. Once a family reaches a departmental buffer and if all the machines of that department are busy with some other family, then the family just arrived will wait in the departmental queue until its turn. If production of a particular family is completed in a cell, then that cell no longer exists and the machines within that cell are free to form another virtual cell. The operational issues of the new VCM concept are summarised in **Table 1** and are illustrated through a numerical in the following section.

## 4. Numerical Illustration

The major issues and the operational procedure of both (existing and new) VCM approaches are explained through an illustrative numerical example. The selected numerical consists of a shop with three process departments. The shop contains a total of nine machines; M1, M2, ..., M9, with three machines in each department. The selected, machine-department configuration is depicted in **Figure 1**. In the numerical, four-part types (a, b, c and d) belonging to two-part families are considered and each part type has to visit all the three departments before leaving the system. The jobs inter-arrival and processing times are presented in **Table 2**. If two consecutive jobs that require processing at a machine do not belong to the same part family, the latter job incurs a major setup. On the other hand, if the latter job belongs to the same part family as the former, no setup is required for the latter job. Job major set-up time is assumed as 1 hr. In the current illustration, job minor set-up is neglected. Also, the move time of a job from one department to another is neglected.

According to existing (**Kannan** and **Ghosh, 1997**) approach of VCM (hereafter referred to as VCM-1), the jobs in the order of their arrival, i.e., d, b, a, c are released to the shop. As soon as Job 'd' approached the Department 1 (Dept.l) buffer, it was loaded over Ml since at that time, all machines of that department are ready for allocation. After a major setup of 1 hr., Job 'd' was processed for 16 mins. on Ml. As per the arrival sequence of jobs to the Dept. l buffer, Job 'b' and Job 'a' are loaded over M2 and M3 respectively. Both jobs took a major setup of 1 hr. on each machine and processed for 14 and 5 mins. respectively. In the meantime, the last arrived Job 'c' waits in Dept. 1 queue since all machines are busy. After completion of processing, Job 'a' has moved to Dept.2. Job 'c' was then loaded over M3, which requires a major setup as it belongs to a different family when compared to Job 'a' that is just moved out. After the processing of Job 'b' and 'd' in Dept. l, they moved to Dept. 2 and loaded over M5 and M6 respectively, as M4 is busy. Again, in Dept. 2, all three jobs need major setup and processed as per the operational schedule (see **Table 2**). Finally, Job 'c' entered the Dept. 2 buffer and has loaded over M4 for major setup. After process completion, all three jobs (a,b and d) moved to the Dept. 3 buffer in the order as shown in **Figure 1** and processed on M7, M8 and M9 respectively with major setups. Later, Job 'c' has loaded over M9. However, Job 'd' and Job 'c' belong to the same family and hence major setup was zero for the latter. Event-by-event description, along with the machine assignment details is presented in **Table 3**. The machine allocation schedule under VCM-1 is represented in a Gantt chart and is depicted in **Figure 2**.

The new concept of virtual, cellular-manufacturing approach (hereafter referred to as VCM-2) illustrates the issues (see **Table 1**) through the selected numerical. The first issue has been resolved through pooling of jobs into families based on processing similarities and release of each family to the shop as soon as formed. Maximum waiting time of jobs in a family is assumed as 9 mins. Only two families are considered for explaining the VCM-2. For instance, Job 'a' and Job 'b' are pooled into Family l (i.e., based on the arrival pattern of the jobs) and was released to the shop. This was followed by Family 2 with Job 'c' and 'd'. The second issue of VCM-2 had been resolved through determination of the number of machines that were required per processing stage. We used work content rule for

**TABLE 1:** *The Operational Issues of the New Concept of VCM*

| Issue | Proposed Approach |
|---|---|
| Pooling of jobs before release to shop | This issue has been considered with an intention to take further setup advantages of the GT concept. |
| Decide number of machines that are required per processing stage | Number of machines ($n_i$) required in the i th process department will be decided before release of a family to the shop floor using, $n_i = (\Sigma_i t_{ij} / \Sigma_i \Sigma_j t_{ij}) * N$ where, $t_{ij}$ = processing time required for j th family in the i th process department and $N$ = Number of machines available in the i th process department. |
| Family-releasing mechanism | When to release a family to the shop can be addressed various thumb rules such as (i) Family size, (ii) Pooling time, (iii) Job priority/due date rule. |
| Machine dedication | 1. Idle machines in each department are dedicated temporarily to families based on the number of machines required per processing stage. For instance, there is a family with batch size of four that requires two machines in a specific department as per a prior computation. If two machines are available in that department by the time it reaches the buffer, then such machines are dedicated to that family.<br>2. In case the idle machines are less than that of the required number of machines, then a partial family will be assigned to such available machine(s) and the rest of the jobs will wait in the queue until availability of machines. For example, in the previous step, instead of two machines if only one machine is available in that case two jobs of that family will be assigned to that machine and the rest will be waiting in the queue.<br>3. Once a machine is assigned to a family, the family retains use of the machine until either of the following conditions are met:<br>(i) None of the jobs of that family remain in the corresponding departmental queue.<br>(ii) None of the jobs of that family remain in the preceding process department. |

*Note:* **GT:** Group technology
**Family:** A group of jobs with similar processing characteristics
**Partial family:** A part of a **Family**
**Machine Dedication:** Temporarily a machine or group of machines is allocated to a **Partial family** or a **Family**

**TABLE 2:** *The Selected Job Inter-arrival and Process Times for Illustration of VCM-1 and VCM-2*

| Family No. | Job | Inter-Arrival Time (mins.) | Processing Time (mins.) | | |
|---|---|---|---|---|---|
| | | | Department 1 | Department 2 | Department 3 |
| 1 | a | 04 | 05 | 11 | 18 |
| 1 | b | 02 | 14 | 08 | 16 |
| 2 | c | 09 | 06 | 04 | 25 |
| 2 | d | 00 | 16 | 09 | 05 |

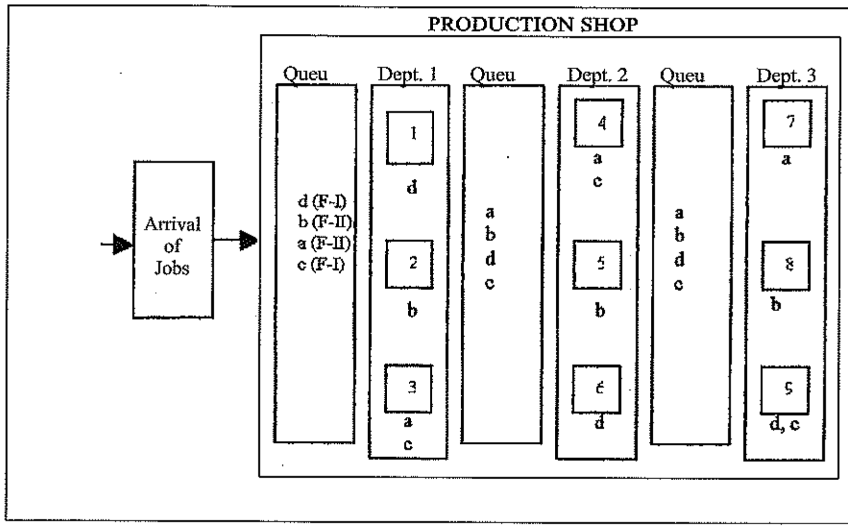
Note: VCM-1: Existing Concept of VCM
VCM-2: New Concept of VCM

estimation of the number of machines needed per processing stage, i.e., in each department. For example, for processing of Family 1, it was decided that one machine each from Dept. 1 and 2 and two machines from Dept. 3 were needed (see **Table 1**). Similarly, two machines from Dept. 1, Dept. 3 and one from Dept. 2 were needed for processing of Family 2. Within each department, machines are dedicated temporarily accordingly. For instance, for processing of Family 1, Ml is dedicated since one machine is sufficient. As per the pre-decided processing sequence, initially, Job 'a' had been loaded over Ml followed by Job 'b'. Though machines M2 and M3 were idle but any of these machines are not assigned to Job 'b' and ultimately, it had to wait in the queue for Ml, i.e., until completion of Job 'a'. Similarly, for processing of Family 2, M2

**TABLE 3:** *Associated Events in VCM-1 Approach*

| Time | Event Description |
|---|---|
| 0 | Job **d** arrived and loaded on M1. |
| 2 | Job **b** arrived and loaded on M2. |
| 4 | Job **a** arrived and loaded on M3. |
| 9 | Job **c** arrived and waiting in the queue in Dept. 1. |
| 69 | Job **a** completed on M3 and moved to Dept. 2 and loaded over M4. Job **c** loaded over M3. |
| 76 | Job **b** and **d** completed and moved to Dept. 2 and loaded over M5 and M6 respectively. |
| 135 | Job **c** completed on M3 and waiting in the queue in Dept. 2. |
| 140 | Job **a** completed on M4 and moved to Dept. 3 and loaded over M7. Job **c** loaded over M4. |
| 144 | Job **b** completed on M5 and moved to Dept. 3 and loaded over M8. |
| 145 | Job **d** completed on M6 and moved to Dept. 3 and loaded over M9. |
| 204 | Job **c** completed on M4 and moved to Dept. 3 and waiting in the queue. |
| 210 | Job **d** completed and released from the shop. Job **c** loaded over M9. |
| 218 | Job **a** completed and released from the shop. |
| 220 | Job **b** completed and released from the shop. |
| 235 | Job **c** completed and released from the shop. |

*Note:* M1, M2, ..., M9: Machine 1, 2, ..., Machine 9.
Dept.: Department




**Legend**

| | |
|---|---|
| Dept.: | Department |
| a, b, c, d: | Jobs |
| F-I: | Family -1 |
| F-II: | Family-2 |
| 1, 2, ..., 9: | Machine 1, Machine 2, ..., Machine 9 |

**FIGURE 1:** *Machine-Department Structure in Job Shop Configuration*

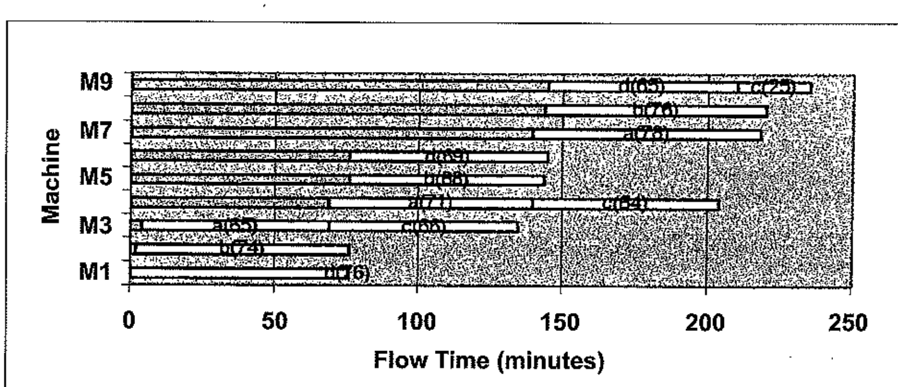



**FIGURE 2:** *Machine versus Job Allocation in VCM-1*

and M3 were assigned to Job 'c' and 'd' respectively from Dept. 1. In Dept.2, M4 was dedicated to Family 1 and M5 to Family 2. In Dept. 3, M7 had been assigned to Job 'c' and M8 and M9 were dedicated to Family 1, but after completion of Job 'a', only Job 'd' was loaded over M8, since for processing of Family 2, it was decided that two machines were required within Dept. 3. The event-description along with the machine dedication details is presented in **Table 4**. Also, the machine allocation scheme to each of the selected families and formation of virtual cells in the VCM-2 are shown in **Figure 3**. In each department, if processing of a dedicated family on a machine or machines is completed, then such a machine or machines are free to form another virtual cell for the next family. Interestingly, in the VCM-2, one machine (M6) was unassigned (see **Figure 4**) when compared with VCM-1 and it can be allocated to some other family.

To provide further evidence for the value of adding or retaining flexibility in manufacturing systems without compromising setup efficiency, it is expected to examine the use and implementation of the VCM-2 in the following context:

(i) Under what parameter range, the VCM-2 is more suitable to operate than traditional manufacturing systems?

(ii) How robust is the VCM-2 to changes in various manufacturing shop conditions?

To answer the above two questions, we now proceed to describe a factorial design of simulation experiments for future research in the area.

## 5. Design of Simulation Experiments: A Future Research Agenda

The study will consist of four experimental factors: shop configuration (SHOPCON), setup time (ST), lot size (LS) and shop load (SL).

### 5.1 *Shop Configuration (SHOPCON)*

The main thrust of the simulation study will be focused on the performance evaluation of various manufacturing systems, ranging from a pure, functional layout through various cellular manufacturing systems, (including conventional to a new concept of virtual cell). Four shop configurations will be included: a pure functional layout (FL), a cell, manufacturing layout (CM) and two virtual, cellular configurations (VCM-1 and VCM-2).

The shop consists of three process departments, where a process department is defined as a set of machines that are functionally identical. The shop contains a total of nine individual machines with three machines in each process department. The shop processes six part types belonging to three part families and each part type has to visit one to two departments before leaving the system. The selected parts routing of this study are shown in **Table 5**.

Each job comprises a lot of certain part types and are generated according to a negative, exponential distribution with a mean inter-arrival time (1A) that is equal to the lot size (LS), divided by the annual demand (d) and are grouped into part families according to processing similarities. The average load on each machine is 3360 hrs., as indicated in **Table 6**. The processing time required for a job is based on a 2-Eriang distribution, with a mean value of 3 hrs. For a job, a major setup value for every operation will be obtained from a 2-Erlang distribution with a mean of 3 hrs. If two consecutive jobs that require processing at a machine did not belong to the same part family, the latter job incurs both the major and minor setups. On the other hand, if the latter job belongs to the same part family as the former, the latter job incurs a minor setup only. Also, if the latter job belongs not only to the same part family but also to the same part type, then both setups are zero. The minor setup is assumed as 30 mins. and is independent of the major setup time. In this study, the move time of a job from one work centre to another will be neglected.

i) **Functional layout (FL)**
In the FL configuration, a standard, job-shop mode of operation will be followed. When a job arrived at a department, if any of the machines belonging to that department is available for processing, it will set up for the operation, and the operation will be performed on the machine. If none of the machines of the department required is available, the job joined a queue of waiting parts at

**TABLE 4:** *Associated Events in VCM-2*

| Time | Event Description |
|---|---|
| 0 | Job **d** arrived [Family of type **(c, d)** starts]. |
| 2 | Job **b** arrived [Family of type **(a, b)** starts]. |
| 4 | • Job **a** arrived [Family of type **(a, b)** completed] . . . say Family-1 formed.<br>• Determination of number of machines required per stage for Family-1 (2 from Dept. 1, 1 from Dept. 2 and 2 from Dept. 3).<br>• Release the Family-1 to the shop in the order of a, b (heuristic). |
| 4 | Job **a** loaded on M1.<br>Job **b** waiting in the queue of Dept. 1. |
| 9 | • Job **c** arrived [Family of type **(c, d)** completed] . . . say Family-2 formed.<br>• Grouping of jobs into a new family started.<br>• Determination of number of machines required per stage for Family-2 (2 from Dept. 1, 1 from Dept. 2 and 2 from Dept. 3).<br>• Release the Family-2 to the shop in the order of c, d (heuristic). |
| 9 | Job **c** loaded on M2.<br>Job **d** loaded on M3. |
| 69 | Job **a** completed and moved to Dept. 2 and loaded over M4.<br>Job **b** loaded over M1. |
| 75 | Job **c** completed and moved to Dept. 2 and loaded over M5. |
| 85 | Job **d** completed and moved to Dept. 2 and waiting in the queue. |
| 139 | Job **c** completed and moved to Dept. 3 and loaded over M7.<br>Job **d** loaded on M5. |
| 140 | Job **a** completed and moved to Dept. 3 and loaded over M8. |
| 148 | Job **b** completed and moved to Dept. 3 and loaded over M9.<br>Job **d** completed and moved to Dept. 3 and waiting in the queue. |
| 218 | Job **a** completed and released from the shop floor.<br>Job **d** loaded on M8. |
| 224 | Job **c** completed and released from the shop.<br>Job **b** completed and released from the shop. |
| 283 | Job **d** completed and released from the shop. |

*Note:* M1, M2, ..., M9: Machine 1, 2, ..., Machine 9.
Dept.: Department

**TABLE 5:** *Selected Part Families and their Processing Routes*

| Part Type | Family Type | # Operations required | Processing Departments | |
|---|---|---|---|---|
| 101 | 1 | 2 | 1 | 2 |
| 102 | 1 | 1 | 1 | |
| 201 | 2 | 2 | 2 | 3 |
| 202 | 2 | 1 | 2 | |
| 301 | 3 | 2 | 3 | 1 |
| 302 | 3 | 1 | 3 | |

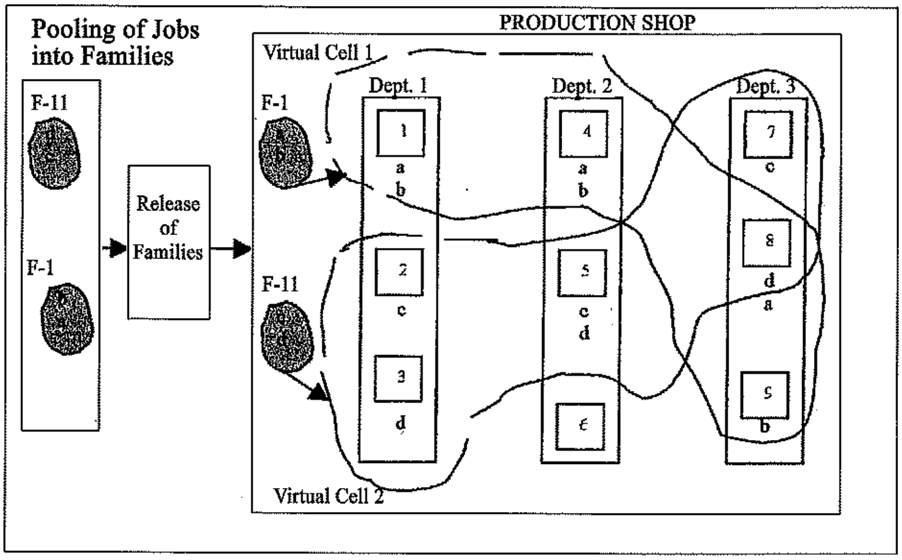
**TABLE 6:** *Selected Machine Configurations*

| | Part Family | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| No. of Jobs | 2 | 2 | 2 |
| Processing Departments | 1, 2 | 2, 3 | 1, 3 |
| # Operations | 3 | 3 | 3 |
| Average Annual Demand ** | 1120 | 1120 | 1120 |

Machine Configurations

| Configurations | Part Family Processed | No. of Machines in each Department 1 | 2 | 3 | Total | Avg. Load on each Machine* (Avg. # parts processed/ machine/year) |
|---|---|---|---|---|---|---|
| FL | 1 to 3 | 3 | 3 | 3 | 9 | 3360 |
| CL | 1 in Cell 1 | 2 | 1 | - | 3 | 3360 |
| | 2 in Cell 2 | - | 2 | 1 | 3 | 3360 |
| | 3 in Cell 3 | 1 | - | 2 | 3 | 3360 |
| VCM-1 | 1 to 3 | 3 | 3 | 3 | 9 | 3360 |
| VCM-2 | 1 to 3 | 3 | 3 | 3 | 9 | 3360 |

* Assumption:
Available hours in a year = 8 (hours per shift) x 3 (shifts in a day) x 200 (days in a year) = 4800 hours
Shop utilisation = 70%; workload per machine per cell = 4800 x 0.70 = 3360 hours
** Average demand calculations per item per year per cell.
No. of items * (Av. No. Operations/No. of Processing Departments Required) * Av. Annual Demand = 3360
i.e., 2 * (3.2) * Average Annual Demand = 3360
Average Annual Demand = 1120




**Legend**

| | |
|---|---|
| Dept.: | Department |
| a, b, c, d: | Jobs |
| F-I: | Family -1 |
| F-II: | Family-2 |
| 1, 2, ..., 9: | Machine 1, Machine 2, ..., Machine 9 |

**FIGURE 3:** *New Concept of Virtual Cells*

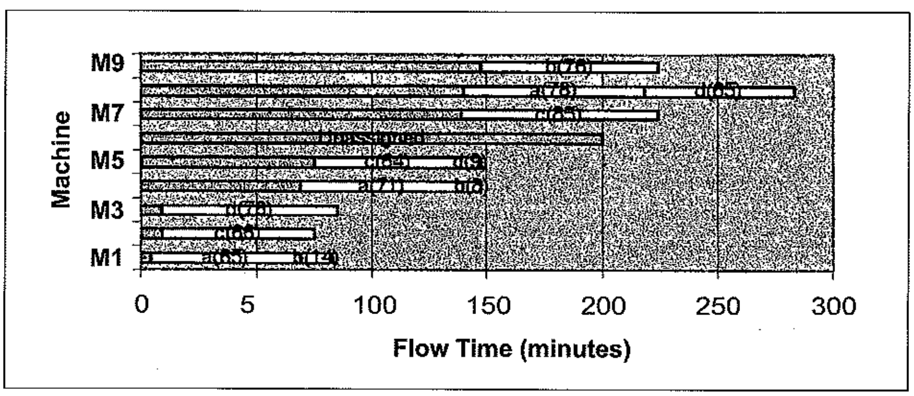



**FIGURE 4:** *Machine versus Job Allocation in VCM-2*

that department. When one of the machines became available, the queue is scanned and a job, if present, will be selected, based on the FCFS rule. If no jobs are present in the queue when a machine became available, the machine simply waited for one to arrive. Upon completion of an operation, the job will be moved to the next department for another operation. At each department where the operation has just been completed, the next job in the queue, if one existed, will be selected from the queue using a FCFS rule. In this way, all the required operations for a job will be completed.

ii) **Cellular layouts**

In the CL, the nine machines are allocated to three cells corresponding to three, part families. Each cell contains one to two machines. The machine configuration in each cell is presented in **Table 6**. In the CL, a newly-arriving job will be processed, if a cell is assigned for that part family. Jobs belong to a particular part family are processed within a single cell that means intercell moves are not permitted. In this configuration, it is assumed that the job-releasing and dispatching mechanisms are similar to that of FL configuration.

VCM configurations physically resemble the functional layout. They differ, however, in how they allocate machines to families to form virtual cells.

*VCM-1:*

The family selected is that containing the most jobs in the current queue.

*VCM-2:*

Machines are dedicated temporarily to families based on the work content.

### 5.2 Setup Time (ST)

This factor is selected basically to verify and to take further setup reduction, especially in the case of VCM-2. Two levels of the setup time are considered: Low setup (1/3 of processing time) and high setup (equal to processing time).

### 5.3 Lot Size (LS)

There must be an optimal, lot size at which flow time and WIP are minimised [**Karmarkar *et al.*, (1985; 1987), Suresh (1991; 1992)**]. To investigate the impact of lot size on the performance of the proposed concept of virtual cell, the lot size issue is considered as one of the experimental factors in this study. The simulation studies will employ three levels of the lot size values: 1, 5 and 10.

### 5.4 Shop Load (SL)

Past research on job shop and cellular-manufacturing have demonstrated that increases in shop load affect shop performance by increasing queue length and bottlenecks (**Baker, 1984; Mahmoodi *et al.*, 1992**). In this study, two levels of shop load will be considered: Low (decrease the arrivals by certain percentage) and high (increase the arrivals by certain percentage). This factor can be fixed based on a prior computation, i.e., before running the simulation model, computations such as load feasibility over the machines can be done in terms of job arrivals and number of operations.

### 5.5 Performance Measures and Factorial Design of Simulation Experiments

The performance of various manufacturing configurations will be measured in terms of mean flow time, WIP and system utilisation. In order to gain a dimensionless measure for the mean job flow time, the job flow ratio will be introduced which is defined as the ratio of the flow time of a specific situation to the flow time of a functional layout performing at its peak. The set of experiments in terms of the selected experimental factors set at various different levels are shown in **Table 7**. It is expected that the proposed, simulation experiments can help to compare the performance of the VCM-2 with other manufacturing systems.

## 6. Conclusions

Past research has shown that it is possible to simultaneously achieve the benefits of traditional, manufacturing systems including cellular and functional layouts by viewing cells not as permanent,

**TABLE 7:** *Factorial Design of Experiments*

| Experiment Number | Level of Experiment Factor | | | |
|---|---|---|---|---|
| | Shop Load | Set Up Time | Lot Size | Shop Configuration |
| 1 | Low | 1/3 of PT | 1 | FL |
| 2 | Low | 1/3 of PT | 1 | CL |
| 3 | Low | 1/3 of PT | 1 | VCM-1 |
| 4 | Low | 1/3 of PT | 1 | VCM-2 |
| 5 | Low | 1/3 of PT | 5 | FL |
| 6 | Low | 1/3 of PT | 5 | CL |
| 7 | Low | 1/3 of PT | 5 | VCM-1 |
| 8 | Low | 1/3 of PT | 5 | VCM-2 |
| 9 | Low | 1/3 of PT | 10 | FL |
| 10 | Low | 1/3 of PT | 10 | CL |
| 11 | Low | 1/3 of PT | 10 | VCM-1 |
| 12 | Low | 1/3 of PT | 10 | VCM-2 |
| 13 | Low | = PT | 1 | FL |
| 14 | Low | = PT | 1 | CL |
| 15 | Low | = PT | 1 | VCM-1 |
| 16 | Low | = PT | 1 | VCM-2 |
| 17 | Low | = PT | 5 | FL |
| 18 | Low | = PT | 5 | CL |
| 19 | Low | = PT | 5 | VCM-1 |
| 20 | Low | = PT | 5 | VCM-2 |
| 21 | Low | = PT | 10 | FL |
| 22 | Low | = PT | 10 | CL |
| 23 | Low | = PT | 10 | VCM-1 |
| 24 | Low | = PT | 10 | VCM-2 |
| 25 | High | 1/3 of PT | 1 | FL |
| 26 | High | 1/3 of PT | 1 | CL |
| 27 | High | 1/3 of PT | 1 | VCM-1 |
| 28 | High | 1/3 of PT | 1 | VCM-2 |
| 29 | High | 1/3 of PT | 5 | FL |
| 30 | High | 1/3 of PT | 5 | CL |
| 31 | High | 1/3 of PT | 5 | VCM-1 |
| 32 | High | 1/3 of PT | 5 | VCM-2 |
| 33 | High | 1/3 of PT | 10 | FL |
| 34 | High | 1/3 of PT | 10 | CL |
| 35 | High | 1/3 of PT | 10 | VCM-1 |
| 36 | High | 1/3 of PT | 10 | VCM-2 |
| 37 | High | = PT | 1 | FL |
| 38 | High | = PT | 1 | CL |
| 39 | High | = PT | 1 | VCM-1 |
| 40 | High | = PT | 1 | VCM-2 |
| 41 | High | = PT | 5 | FL |
| 42 | High | = PT | 5 | CL |
| 43 | High | = PT | 5 | VCM-1 |
| 44 | High | = PT | 5 | VCM-2 |
| 45 | High | = PT | 10 | FL |
| 46 | High | = PT | 10 | CL |
| 47 | High | = PT | 10 | VCM-1 |
| 48 | High | = PT | 10 | VCM-2 |

**Legend:** PT: Processing time, FL: Functional layout, CL: Cellular layout,
VCM-1: Existing approach, VCM-2: New type of VCM.

physical structures, but as temporary, 'virtual' entities. Within the virtual, cell-creation mechanism, right decisions for pooling of jobs into families, release of part families to the shop and dispatching of jobs to individual machines will lead to further improvement in shop performance. The first and main objective of this paper is to develop a new concept of virtual, cellular-manufacturing and to address its operational issues through a numerical illustration.

Interestingly, in the new approach of VCM, one machine can be allocated for processing of some other families. Apart from this benefit, a significant reduction in flow time for Job 'c' was also found in it. The unassigned machine (M6) can be scheduled for different jobs, whereas in the case of VCM-1, all the machines of the shop are engaged for processing of the two families. This shows that by implementing VCM-2, there will be tremendous potential to utilise production resources fully, thereby ample scope for lowering in job flow times and improvement due-date performance. Further, it is believed that the new concept of VCM also simplifies the task of pooling jobs to families by giving manufacturers the flexibility to define families more independently and to change their composition overtime as demand patterns change.

In this paper, the conduct of the future research is elaborated along with a discussion of a factorial design of simulation experiments for comparison of performance of VCM-2 with other traditional approaches in the future. It is expected to provide evidence for the value of adding or retaining flexibility in "cellular" manufacturing systems without compromising setup efficiency and effectively overcomes the limitations of traditional manufacturing, particularly that of responsiveness to change in part mix. Research work in this direction is in progress.

The new concept of virtual cellular manufacturing (VCM-2) may fit into the present-day, industrial practice, especially within the functional layout environment in which the production-planning department periodically reorganises the manufacturing system without any major investment and risk.

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