A Simulation Study of the Cell Operation Impact on Job shop Configuration

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Abstract

Manufacturing organisations have been unable to cope with an increasingly fast changing market. Product life tends to be much shorter than in the past. To survive, companies must try to increase responsiveness, improve flexibility, shorten set-up time and lower their work in process inventory. Traditional manufacturing systems such as job shops are renowned for their high costs of set-ups, high level of inventory and long lead time while well-publicised cellular manufacturing systems can offer just about everything that is required for the present competitive situation. Even with the problems known, most companies are afraid of such a radical change to becoming manufacturing cells. This paper presents an alternative to this drastic change. While maintaining the job shop configuration, the virtual cell system employs logical concepts of cell manufacturing and has been proved to achieve most of the cell benefits.

1. Introduction: Characteristics of batch production

Batch production covers a wide range of manufacturing situations where a number of items have to move together between production facilities until work on them is completed. It has been reported to account for more than 50% of all manufacturing activities [1] and has been estimated that 75% of batch production deals with batch sizes of less than 50 units [2-3]. In a tradition batch production environment, several drawbacks including long lead time, high work in process inventories and complicated production planning and control have been reported. In an attempt to improve the batch production's performance, this study tries to analyse and compare three possibly used configurations of batch production which are traditional job shop, cell manufacturing and virtual cell systems. Their typical characteristics can be presented as follows;

1.1. Job shops

Their layouts feature departments or other functional grouping in which similar kinds of activities are performed (see Figure 1). The same type of machines are, then, grouped together. After being processed in one department, parts in batches are transferred to the next department according to their predefined routes. Although job shop offers a high degree of routing flexibility, they are inefficient with respect to the high level of required set-ups, work-in-process and part delivery.

1.2. Cell Manufacturing Systems (CMS)

The concept of cell manufacturing was born from a need to compromise between the flexibility of job shop and retaining the production management simplicity associated with the transfer line layout to boost productivity in low-to-medium volume and part variety production environments [4]. Manufacturing cell is a type of layout in which machines are grouped into what is referred to as a cell [5]. Groupings are determined by the operations needed to perform work for a set of similar items, or part families, that require similar processing. Having formed machines into cells, the rate of change in product range and part mix becomes essential to its performance. Thus, in general, cell system presents a high degree of set-up efficiency, but is severely constrained by routing inflexibility.

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1.3. Virtual cellular manufacturing systems

A virtual cell is not identifiable as a fixed physical grouping of workstations (like traditional cell manufacturing), but it views manufacturing cells from a different perspective. When an order needs a set of workstations to be put together, a virtual cell controller takes over the control of these required workstations and makes communication possible between them. By scheduling a functionally organised shop using rules that recognise the existence of part families, machines can be temporarily dedicated to families. When a machine becomes available, it can be assigned to a family rather than an individual job. As machines from different process departments are dedicated to a family, a sequence of machines develops through the shop similar to that obtained in traditional cells. The difference is that the machines are not necessarily physically adjacent to one another. Since the machine is already set-up for the family, the need for additional set-ups is reduced [6]. As conditions change and a family no longer needs a machine, the machine can be re-assigned to another family so that as one cell contracts another expands.

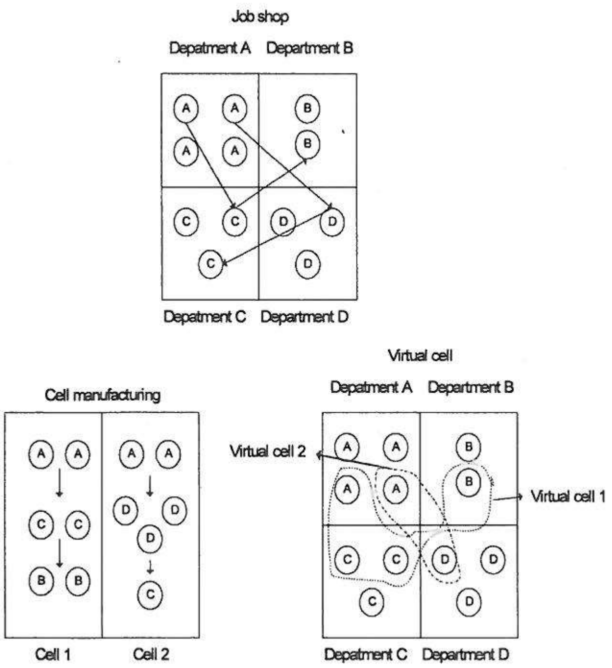


Figure 1: Job Shop, Cell Manufacturing Systems and Virtual Cell Configurations

2. Background of the problem

Manufacturers have been trying for many years to make batch production more efficient and responsive to changes in demand. For this purpose, many innovative methods and techniques have been created to reduce production lead time, enhance product quality, reduce levels of inventory and hence reduce product cost. One of the causes of the problem is the arrangement of the machines. Traditional process layout or the job shop has been sited by a number of researches to cause ineffectiveness and inefficiency in production [7, 8] while a growing number of reports have been published to show the success stories of applying cell concepts [9-14]. However, the fact is that each system has its own advantages and disadvantages. For example, besides poor overall performances, job shop shows a high level of routing flexibility to cope with the rate of change in part mix and product range whereas the formed cells would find it difficult to keep up with such frequent changes.

In addition, forming such cells would require a lot of layout modifications. Each cell must contain all machines necessary to manufacture the parts assigned to that cell. Otherwise, parts must cross cell boundaries and many system benefits are lost. Later, some researches such as Flynn and Jacobs [15], Morris and Tersine [16] have even claimed the negative impact of permanent machine dedication in physical cell layouts. Their findings suggest that cells, in fact, can exploit its advantages only under a limited set of conditions that provides significant opportunities to use its advantages in set-up time reduction and minimum intracell movement.

An attempt to overcome their inherent drawbacks with respect to routing flexibility and imbalances in cell utilisation through allowing intercell transfer has been made without a clear success. Routing parts outside their designated cells reduces problems of unbalanced cell utilisation but at the expense of a loss in material handling efficiency. Garza and Smunt [17] reveal that if a conversion to cells results in intercell flows, performances of the cellular system will likely be worse than that of a traditional job shop. Even small amounts of intercell flow can have a substantially negative impact on mean flow time and WIP level for many conditions, especially those associated with high run time variability and large batch sizes [17].

Another attempt to solve this problem can be made through introducing the concept of the virtual cell, which defines cells as a temporary routing mechanism as opposed to a physical structure. The very first concept of the virtual cell has been proposed by the National Bureau of Standards to address specific control problems in the design of their Automated Manufacturing Research Facility (AMRF) [18]. However, only recently Kannan and Ghosh [19] have made this concept operational. Their finding reveals superior performance from the virtual cell in terms of better flow time and work-in-process than the traditional cell and job shop production methods. In reaching these conclusions, however, certain important issues concerning sequencing rules, batch size and part transfer between processes were not addressed. Thus, their experiment seems to put a good operating virtual cell into the test with poor organised job shop and cell production.

3. Methodology

The overall objective of this study is to compare the performance between job shop, cellular manufacturing and virtual cellular shops. This is to find a more effective way to operate batch production systems. To achieve the objective, each system needs to be tested under various conditions to first determine what factors have the most effect on the performance of each shop and second, to determine what conditions are best suited to them. Due to the complexity of the studied problem, applications of analytical models including mathematical programming are hardly achieved. In addition, the mathematics for such problems is too complex, precluding any possibility of an analytical solution. As a result, simulation modeling is selected as a tool for the study. However, there are pros and cons of using simulation, which can be seen from Law and Kelton [20].

Four experiment factors used in this study are batch size, ratio of set-up time to operation time, demand pattern, and shop operating characteristic. These are factors, which have been used in past researches [15, 16, 19, 21] and have direct significant impact to the batch production's shop performance.

3.1. Batch size

Batch size is used to form parts before delivering to the next process. Three levels of batch size which are 10, 20 and 30 units per batch (denoted as small, medium and large batch) are considered in this study. Small batch size will normally lead to more frequent set-ups and require more trips to deliver and vice versa. These levels of batch size fall within actual practice as addressed in the introduction.

3.2. Set-up ratio

Set-up times are based on the degree of similarity between two successive batches of parts on a particular machine. If the operation, which the machine performs on the parts in the two batches is identical, no set-up is necessary. Major set-ups are required if the successive part is different and not in the same family group. Minor set-ups (50% of the major set-ups) are required when there is a change in the part being processed in a machine but there is no change in the family being processed. This minor to major set-up ratio of 0.5 has been used by several researchers such as Morris and Tersine [16], Yang [21] and a survey of cell users suggests the ratios from 0.05 to 0.98, with an average of about 0.68 [12]. Three levels of the main set-up ratio, which are the ratios between operating time and the major set-up time (1:0.5, 1:1 and 1:1.5), are considered. This represents low set-up, medium set-up and high set-up levels respectively. In general, there is no major set-up in operating under traditional cells while a virtual cell can take the advantage of the family set-up scheme by searching the parts in the same family group to reduce the set-ups.

3.3. Demand pattern

Demand pattern decides the level of part mix variability. Two types of demand pattern, balanced demand pattern and unbalanced demand pattern, are considered. Under balanced part mix conditions, demand is equally distributed among five part families (see the section of shop configuration for more details of part family and cell formation). Under unbalanced part mix conditions, three families account for 70 percent of total demand while 30 percent of demand is equally distributed between the remaining two families. The purpose behind this experiment is to test the effect of unbalanced load on traditional cells.

3.4. Shop operating characteristic

Thirteen shops with 3 layouts (job shop, traditional cell and virtual cell) are considered. The movement of parts through a shop is regulated by the manner in which scheduling decisions are made at individual machines and at the time of actual production. The aim of this study is not to find the best rule. Since these rules can have an important impact on system performances, they are only applied here just to improve system performance. Moreover, most of the related literature suggests that it is unlikely to find a rule that performs best in every measure since the performances are often inconsistent with one another [22]. Under the job shop and traditional cell, four selected rules which are First in First out (FIFO), Maximum Remaining Operation (MRO), Least Remaining Operation (LRO) and Repetitive Lot (RL) rules are applied. These are the rules often used by many researchers. Under the virtual cell, five rules used in Kannan and Ghosh [19] are also used in this study. Thus, the thirteen shops under investigation are:

1. **JF**: Job shop with First in First out (FIFO) rule
2. **JM**: Job shop with Maximum Remaining Operation (MRO) rule
3. **JL**: Job shop with Least Remaining Operation (LRO) rule
4. **JR**: Job shop with Repetitive Lot (RL) rule
5. **CF**: Traditional cell with FIFO rule
6. **CM**: Traditional cell with maximum remaining operation rule
7. **CL**: Traditional cell with the least remaining operation rule
8. **CR**: Traditional cell with repetitive lot rule
9. **VC1**: Virtual cell with the family selected being the one requiring the fewest remaining machines to complete a cell
10. **VC2**: Virtual cell with the family selected being the one with the lowest average slack per job.
11. **VC3**: Virtual cell with the family selected being the one containing the most jobs in the current queue
12. **VC4**: Virtual cell with the family selected being the one currently having members being processed in their predecessor department. If more than one such family exists, the family with the most jobs in current queue is selected
13. **VC5**: If the family that is using the now idle machine has jobs currently being processed in their predecessor department, the machine is not reassigned to a new family and is allowed to remain idle until those jobs are ready to use the machine. If the family does not have jobs en route, then the new family selected is the one with the most jobs in the current queue.

It should be noted that shop 1 to 4 and shop 5 to 8 belong to the job shop and traditional cell respectively. Shop 9 to 13 are those implemented with the virtual cell concept. However, shop 9 to 11 (VC1-VC3) focus solely on processing activity in the process department with machines to assign, while shop 12 and 13 (VC4 and VC5) also consider activity at the other departments in the shop. Even though the job shop model with the RL rule (JR) gives priority to the currently idle machine in selecting identical part, but it does not extend priority to the parts in the same family as applied in the case of the virtual cell. The rules described in VC_1 to VC_5 are used to break the tie when there is no such part in the same family waiting to be processed in the current queue.

4. Shop environment

4.1. Shop configuration

Configurations and part routing are based on the shop used by Morris and Tersine [16] and Kannan and Ghosh [19]. The job shop is a 30-machine, eight-department shop. Each department contains three or four identical machines. Forty different parts are processed within the shops. Parts belong to one of five part families, each family containing between six and ten different parts. To convert into traditional cells, one family type per one cell can be formed so as to avoid any intercell transfer. Each cell contains between four and eight machines, with no more than one machine of the same type. The virtual cell physically resembles the job shop. However, as described earlier, machines are allocated on a temporary basis to specific families.

4.2. Arrival time and processing time

Assuming a make to order environment, a customer order of 30 units is scheduled to arrive at the shop under exponentially distributed mean interarrival time of every 280 minutes. Common random stream numbers are used to reduce variance and set all systems to the same operating condition. Processing time of each process is normally distributed with a mean of 40 minutes and a standard deviation of 10% of its mean. These values were selected from preliminary runs to yield an overall plant utilisation of approximately 60-70% in the base job shop model. This level is below the more typical value of 80-90% used in the other job shop simulation studies [23] but research on CMS suggests that lower machine utilisation may be necessary in a cellular layout. Wemmerlov and Hyer [12] have even reported in their survey that an average shop utilisation of 64% was found and should be expected in the cellular shop.

4.3. Transportation

Three forklift trucks running 25 meters per minute are used for transferring parts to and from departments or cells in all experiments. This number of trucks was tested during preliminary runs to yield a reasonable level of truck utilisation without blocking the systems. In fact, a variation of the number of forklift trucks and their speeds were also tested during the pilot study. However, the results reveal only minor significance to the relative performance of our models. For example, from ANOVA, the effect (F-value) of the truck speed factor compared to the effect of batch size on mean flow time in one of the pilot runs is 8.052 to 1663.92. Thus, to reduce the complexity in interpreting results, the number of trucks and their speed are fixed throughout the experiment.

5. Simulation model description

All shops were written in SIMAN simulation language [24]. With the four experiment factors, data of 234 (3 x 3 x 2 x 13) treatments are collected and analysed. From preliminary runs, the moving average in output analysis reveals that a warm-up period of 410,000 minutes is required to be truncated before normal conditions are built up. Ten replications with 250,000 minutes in each replication are required, yielding independent observations between replications and bringing the confident interval (half-width) of the interested observation (flow time) within 5 percent of our point estimate for this value under 95% confident level.

6. Performance measurement

During each run, data are collected in 4 observations, which are:

1. **Mean flow time**: This is to measure on average how long part spending in each shop.
2. **Total transportation time**: This is to measure total time spent in moving or delivering parts.
3. **Total set-up time**: This is to measure total time used in setting up machines.

4. **Total process waiting time**: This is to measure time that parts spent in queues waiting to be processed (WIP level).

7. Results

Two experiments are performed to give insights into outcomes of differences in configurations and operating policies. The first experiment is to determine which experiment factors (batch size, set-up ratio, demand pattern and type of shops) have the most effect on the selected performance measures. Thus, analysis of variance (ANOVA) was carried out for each of the interested measures to find experimental effect on these system performances. Given the presence of significant factors, the second experiment is then performed to compare the performances of each model in each combination of experimental factors. This can be done to check which type of system performs best under given conditions. Duncan's multiple range test was used for each combination. This allows the impact of changes in family configuration to be more readily examined, as well as facilitating examination of the impact of other interested factors. It should be noted that all statistical analyses in this study are based on 95% confident level.

7.1. First experiment: Experimental factor effect on selected system performance

Based on ANOVA (Table 1), it can be seen that the factors under investigation are not equally significant to the interested performance measures. The factor of batch size has shown to have a significant effect on every performance measure. This supports our decision to bring batch size as experiment factors. However, with a few exceptions, some factors have a little impact on other measures. For example, set-up ratio has shown to have a little impact on transportation time. This is quite obvious since these two are not really related. All these facts are also applied to the effect of the interaction of these factors in which their results are not presented here for the sake of suitable paper length.

Table 1: Multiple Analysis of Variance

Performance measure	Experiment factor	Significant	F-value
Mean flow time	Batch size	Yes	64.97
	Set-up ratio	Yes	584.59
	Demand pattern	No	.0002
	Model	Yes	197.76
Total transportation time	Batch size	Yes	213,220.6
	Set-up ratio	No	1.8
	Demand pattern	Yes	13.3
	Model	Yes	15,205.5
Total set-up time	Batch size	Yes	113,969.3
	Set-up ratio	Yes	189,608.0
	Demand pattern	Yes	33.8
	Model	Yes	25,722.9
Total process waiting time	Batch size	Yes	16.23
	Set-up ratio	Yes	395.99
	Demand pattern	Yes	33.44
	Model	Yes	217.05
Significant values of their interaction do not show in this table			

7.2. Second experiment: Duncan's multiple range test

As an alternative to the first experiment, it is more of value to analyse each scenario of the combination in our interested factors separately. This allows the impact of changes in family configuration to be more readily examined, as well as facilitating examination of the impact of the remaining factors. Duncan's multiple range test is performed to check the significant difference of each model's given means under given conditions. Table 2 to Table 5 show the results from the test.

7.2.1. Performance related to mean flow time and process waiting time

In general, these two-performance measures can be similarly interpreted (see Table 2 and Table 3). It is found that virtual cells (VC_1-VC_4) are always in the group of the relatively better systems. However, VC_5, which needs to hold machines for en route parts to reduce set-ups, shows the worst results. The traditional cells under FIFO (CF), Maximum and Least Remaining Operations (CM and CL) have also shown disappointing performance in nearly all factor levels. The best performance from the cell system always comes from the cell with the Repetitive Lot (CR). When operating with small to medium batch (batch size = 10, 20) and high set-up time (set-up ratio = 1.5) under balanced demand pattern or *scenario code 131 and 231* as shown in Figure 2, CR is clearly the best system, showing the shortest mean flow time. This is due to the fact that benefits of being cells can be fully exploited. However, with the same scenario but under the unbalanced demand pattern, we can see that the effect of unbalanced loading worsens CR performance by pushing the performance of CR back to the same group of other VC models.

Table 2: Relative Performance on Mean Flow Time (Rank from Shortest to Longest)

Performance	Experimental Factor			Rank
	B[1]	S[2]	D[3]	
Mean flowtime	1	1	1	VC1 VC4 VC3 JR JF VC2 JL CR JM CL CM CF VC5
	1	1	2	VC1 VC4 VC3 JF JR VC2 JL CR JM CL CM CF VC5
	1	2	1	CR VC3 VC2 VC1 VC4 JR JF CM CL JL CF JM VC5
	1	2	2	VC3 VC1 VC2 VC4 CR JR JF JL CM CL JM CF VC5
	1	3	1	CR VC2 VC3 VC4 VC1 CM CL JR CF JF JL JM VC5
	1	3	2	CR VC2 VC3 VC4 VC1 JR CM CL CF JF JL JM VC5
	2	1	1	VC1 JR JF VC4 VC3 VC2 JL JM CR CM CL CF VC5
	2	1	2	VC1 JR JF VC4 VC3 VC2 JL JM CR CM CL CF VC5
	2	2	1	VC1 JR JF VC4 VC3 VC2 CR JL JM CM CL CF VC5
	2	2	2	VC1 JF JR VC4 VC3 VC2 JL CR JM CM CL CF VC5
	2	3	1	CR VC1 VC3 VC4 VC2 JF JR JL CM JM CL CF VC5
	2	3	2	CR VC3 VC4 VC1 VC2 JR JF JL JM CM CL CF VC5
	3	1	1	JR JF VC1 VC4 VC3 VC2 JL JM CR CM CL CF VC5
	3	1	2	JF JR VC1 VC4 VC2 VC3 JL JM CR CM CL CF VC5
	3	2	1	VC1 JR JF VC4 VC3 VC2 JL CR JM CM CL CF VC5
	3	2	2	VC1 JF JR VC4 VC3 VC2 JL JM CR CM CL CF VC5
	3	3	1	VC1 CR VC4 VC3 JR JF VC2 JL JM CM CL CF VC5
	3	3	2	VC1 VC4 VC3 JR VC2 JF CR JL JM CM CL CF VC5

B[1] = Batch size (1=batch of 10; 2=batch of 20; 3=bacth of 30):
S[2] = Set-up ratio (1=set-up ratio of 1:0.5; 2=set-up ratio of 1:1, 3=set-up ratio of 1:1.5)
D[3] = Demand pattern (1=balanced demand pattern; 2=unbalanced demand pattern)
Note: Underlined systems denote systems that cannot distinguish their interested performance measure under 95% confident level

Table 3: Relative Performance on Total Process Waiting Time (Rank from Shortest to Longest)

Performance	Experimental Factor			Rank
	B	S	D	
Total process waiting time	1	1	1	VC_1 JF VC_4 VC_3 JR VC_2 JL CR JM CL CM CF VC_5
	1	1	2	JF VC_1 VC_4 VC_3 JR VC_2 JL JM CR CL CM CF VC_5
	1	2	1	VC_3 CR VC_1 VC_2 VC_4 JF JR JL CM CL JM CF VC_5
	1	2	2	VC_4 VC_1 VC_3 VC_2 CR JF JR JL CM JM CL CF VC_5
	1	3	1	CR VC_2 VC_3 VC_4 VC_1 CM CL JR CF JF JL JM VC_5
	1	3	2	CR VC_3 VC_4 VC_2 VC_1 JR CM CL CF JF JL JM VC_5
	2	1	1	JF VC_1 JR VC_4 VC_3 VC_2 JM CR JL CM CL CF VC_5
	2	1	2	VC_4 JF VC_1 JR VC_3 VC_2 JL JM CR CM CL CF VC_5
	2	2	1	JF JR VC_1 VC_4 VC_3 VC_2 CR JL JM CL CM CF VC_5
	2	2	2	VC_4 JF VC_1 JR VC_3 VC_2 JL CR JM CM CL CF VC_5
	2	3	1	CR VC_1 VC_3 VC_4 VC_2 JF JR JL CM JM CL CF VC_5
	2	3	2	VC_4 CR VC_3 VC_1 VC_2 JF JR JL JM CM CL CF VC_5
	3	1	1	JF JR VC_1 VC_4 VC_3 VC_2 JL JM CR CM CF CL VC_5
	3	1	2	VC_4 JF JR VC_1 VC_2 VC_3 JL JM CR CM CL CF VC_5
	3	2	1	JF VC_1 JR VC_3 VC_4 VC_2 JL CR JM CM CL CF VC_5
	3	2	2	VC_4 JF VC_1 JR VC_3 VC_2 JL JM CR CM CL CF VC_5
	3	3	1	VC_1 JF VC_4 CR VC_3 JR VC_2 JL JM CM CL CF VC_5
	3	3	2	VC_4 JF VC_1 JR VC_3 VC_2 CR JL JM CM CL CF VC_5

Results from Figure 2, which shows the relative performance on mean flow time, also reveal that mean flow time of the cell under the unbalanced demand pattern is always longer than the one under the balanced demand pattern. This may be due to the fact that demand patterns that are inconsistent with the capacities of cells lead to severe bottlenecks in some cells and idle machines in others while VC is able to take advantage of family based processing by reducing or increasing number of machines required accordingly.

For systems under traditional job shop, the job shops under simple FIFO (JF) and Repetitive Lot (JR) have shown to give the shortest flow time and waiting time when the condition is best suited to job shop characteristics (big batch size and low set-up). However, there is no statistical evidence to conclude that they are better than the virtual cell shops. When the condition is unsuited to the job shop configuration (small batch, high set-up- *scenario code 131 and 132*), it can be clearly seen that there is quite a big gap between the best job shop system and the rest. It is also interesting to see that the virtual cell's mean flow time is closer to the traditional cells, despite using job shop configuration. This has reinstated benefits of family set-up scheme. Despite different configurations, set-up time of the systems under family set-up scheme from both traditional cell and virtual cell can be tremendously reduced and hence the reduction of their flow time is presented. Thus, this finding also shows that the benefits of cellular manufacturing can be achieved by dedicating machines to families on temporary rather than a permanent basis.

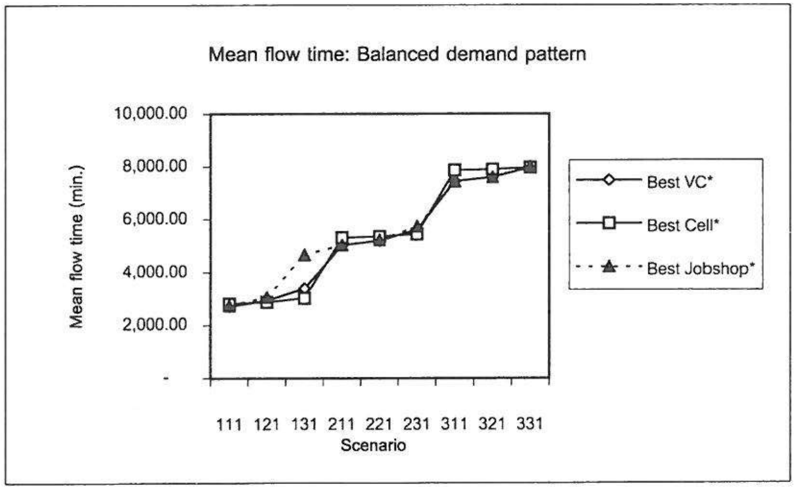
7.2.2. Performance related to total transportation time

It is quite obvious that the system performances on transportation time from Table 4 can be classified into two groups. The first group, which outperforms the second group, is the group from the traditional cell layout. And the second group is the group of job shop and virtual cell. Traditional cells

	Balanced demand pattern	Mean flow time (min.)		
Code	Scenario	Best VC*	Best Cell*	Best Jobshop*
111	Small batch / low set-up	2,690.11	2,796.66	2,721.10
121	Small batch / medium set-up	2,908.94	2,856.47	3,042.22
131	Small batch / high set-up	3,378.93	3,002.94	4,658.26
211	Medium batch / low set-up	5,025.60	5,307.23	5,028.91
221	Medium batch / medium set-up	5,196.72	5,349.82	5,221.79
231	Medium batch / high set-up	5,605.84	5,444.64	5,737.85
311	Large batch / low set-up	7,441.90	7,859.79	7,430.63
321	Large batch / medium set-up	7,596.06	7,892.50	7,602.64
331	Large batch / high set-up	7,957.11	7,965.58	8,001.90

	Unbalanced demand pattern	Mean flow time (min.)		
Code	Scenario	Best VC*	Best Cell*	Best Jobshop*
112	Small batch / low set-up	2,668.93	2,833.81	2,694.07
122	Small batch / medium set-up	2,879.78	2,903.98	3,004.45
132	Small batch / high set-up	3,331.23	3,082.95	4,517.52
212	Medium batch / low set-up	5,009.15	5,362.01	5,012.36
222	Medium batch / medium set-up	5,179.71	5,413.50	5,202.19
232	Medium batch / high set-up	5,575.80	5,523.60	5,713.25
312	Large batch / low set-up	7,391.36	7,913.44	7,382.94
322	Large batch / medium set-up	7,545.10	7,950.64	7,548.19
332	Large batch / high set-up	7,877.29	8,036.72	7,921.08

* Best selected policy can be seen from Table 2



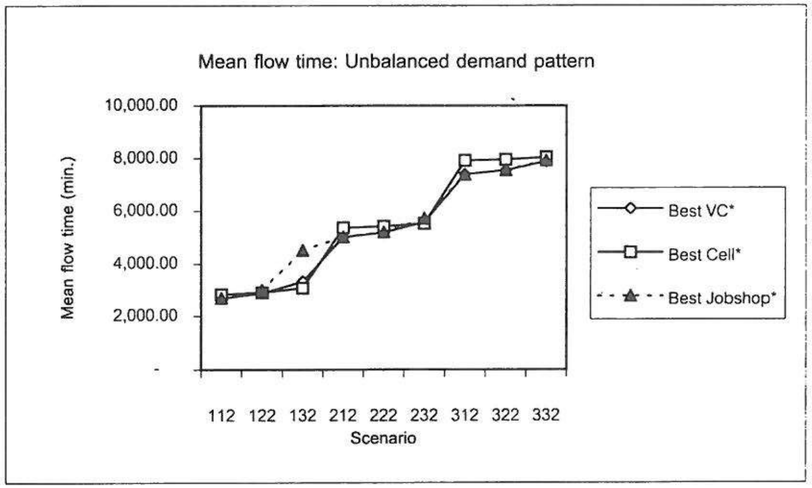


Figure 2: Mean Flow Time from Each System

certainly provide the best performance among all systems since there is no transfer within the cells. The only transfers required are between the cell and the enter/exit station (warehouse). Within cells, all required machines are situated next to each other and the parts can be handed to the next process very quickly (assumed to be negligible in the study). While under the job shop and the virtual cell, both still use the job shop configuration. Thus, transportation times can hardly be distinguished. In fact, under 95% confident level, we cannot distinguish them at all. This is due to the fact that the configuration of the job shop forces parts to be transferred across departments. Thus, there is no much difference in the number of transferring trips and the time used for transferring parts.

Table 4: Relative Performance on Transportation Time (Rank from Shortest to Longest)

Performance	Experimental Factor			Rank
	B	S	D	
Transportation	1	1	1	CR CL CM CF VC_4 VC_3 VC_1 JM JF VC_2 JL VC_5 JR
	1	1	2	CR CL CM CF VC_3 VC_4 VC_2 JM JR JF VC_1 JL VC_5
	1	2	1	CL CM CF CR VC_3 VC_2 VC_4 VC_1 JF JM JL VC_5 JR
	1	2	2	CR CM CL CF VC_3 VC_4 VC_2 VC_1 JM JR JF JL VC_5
	1	3	1	CF CR CM CL JL JM JF VC_3 VC_4 VC_1 VC_5 JR VC_2
	1	3	2	CF CR CM CL JL JF JM VC_2 VC_3 VC_4 VC_1 JR VC_5
	2	1	1	CR CL CM CF JR JM VC_2 JF VC_3 VC_4 VC_1 JL VC_5
	2	1	2	CR CM CL CF VC_3 VC_2 JF JR VC_4 VC_1 JM JL VC_5
	2	2	1	CR CL CM CF JR VC_4 VC_3 JF VC_1 JM VC_2 JR VC_5
	2	2	2	CR CM CL CF VC_2 JF VC_3 JR VC_1 VC_4 JM JL VC_5
	2	3	1	CR CM CL CF VC_4 VC_2 VC_3 VC_1 JF JR JM JL VC_5
	2	3	2	CF CR CM CL VC_4 VC_2 VC_3 VC_1 JR JF JM JL VC_5
	3	1	1	CR CL CM CF JM VC_3 JR VC_2 VC_4 JF VC_1 JL VC_5
	3	1	2	CR CF CL CM VC_5 JF VC_2 JR VC_4 VC_1 VC_3 JM JL
	3	2	1	CF CR CM CL JM VC_1 VC_3 VC_4 JF VC_2 JR JL VC_5
	3	2	2	CR CM CL CF VC_4 VC_1 JR JM VC_2 JF VC_3 JL VC_5
	3	3	1	CF CR CM CL VC_5 JM VC_4 VC_3 VC_1 JF VC_2 JR JL
	3	3	2	CF CR CM CL VC_2 VC_3 VC_1 JR JM JF VC_4 JL VC_5

7.2.3. Performance related to total set-up time

The traditional cell is anticipated to perform best under this category since only minor set-ups are required. From Table 5, it can be seen that the cellular layout with Repetitive Lot (RL) performs best under this performance measure since the rule allows the shop to search for identical parts just processed to be processed first even when it has just arrived at the shop. This obviously reduces the time required for setting up machines for a new part. It is also found that even though the virtual cell, especially VC_5, tries to reduce set-up time by searching predecessor departments for parts in the same family, it still cannot reduce set-up time as much as the traditional cell can offer. Traditional job shop performs worst in this study. Even when using the repetitive lot rule, the performance of this layout type shows no difference from when using simple FIFO rule. This may be due to the fact that there is no family set-up scheme in the job shop. Thus, an idle machine only searches for the same identical part, ignoring parts from the same family group. Under randomly part generating, possibility of having identical parts waiting to be processed in the same queue from different batches is far less than the possibility of having waiting parts from the same family group. Figure 3, presenting a comparative set-up time from the best model from each system, highlights the time saved from family set-up scheme of the virtual cell shop compared to that of the traditional job shop. Especially when the batch size is small, we can see that more time can be saved on set-up just by employing a concept of a logical cell. In addition, variation of the interested factors (batch size, set-up ratio, and demand pattern) seems to have no effect on relative performance from different shops on the total set-up time.

Table 5: Relative Performance on Total Set-up Time (Rank from Shortest to Longest)

Performance	Experimental Factor			Rank
	B	S	D	
Total set-up time	1	1	1	CR CM CL CF VC_5 VC_2 VC_3 VC_4 VC_1 JR JF JM JL
	1	1	2	CR CM CL CF VC_5 VC_2 VC_3 VC_4 VC_1 JR JF JM JL
	1	2	1	CR CM CL CF VC_5 VC_2 VC_3 VC_4 VC_1 JR JF JM JL
	1	2	2	CR CM CL CF VC_5 VC_2 VC_3 VC_4 VC_1 JR JF JM JL
	1	3	1	CR CM VC_5 CL CF VC_2 VC_3 VC_4 VC_1 JR JF JL JM
	1	3	2	CR CM VC_5 CL CF VC_2 VC_3 VC_4 VC_1 JR JF JL JM
	2	1	1	CR CM CL CF VC_5 VC_2 VC_3 VC_4 VC_1 JF JR JM JL
	2	1	2	CR CM CL VC_5 CF VC_3 VC_2 VC_4 VC_1 JR JF JM JL
	2	2	1	CR CM CL VC_5 CF VC_3 VC_2 VC_4 VC_1 JR JF JM JL
	2	2	2	CR CM CL VC_5 CF VC_3 VC_2 VC_4 VC_1 JR JF JM JL
	2	3	1	CR CM VC_5 CL CF VC_3 VC_2 VC_4 VC_1 JF JR JM JL
	2	3	2	CR CM VC_5 CL CF VC_3 VC_2 VC_4 VC_1 JR JF JM JL
	3	1	1	CR CM VC_5 CL CF VC_3 VC_2 VC_4 VC_1 JR JF JM JL
	3	1	2	CR CM CL VC_5 CF VC_3 VC_2 VC_4 VC_1 JR JF JL JM
	3	2	1	CR CM VC_5 CL CF VC_3 VC_2 VC_4 VC_1 JR JF JM JL
	3	2	2	CR CM VC_5 CL CF VC_3 VC_2 VC_4 VC_1 JF JR JL JM
	3	3	1	CR VC_5 CM CL CF VC_3 VC_2 VC_4 VC_1 JF JR JM JL
	3	3	2	CR CM VC_5 CL CF VC_3 VC_2 VC_4 VC_1 JR JF JM JL

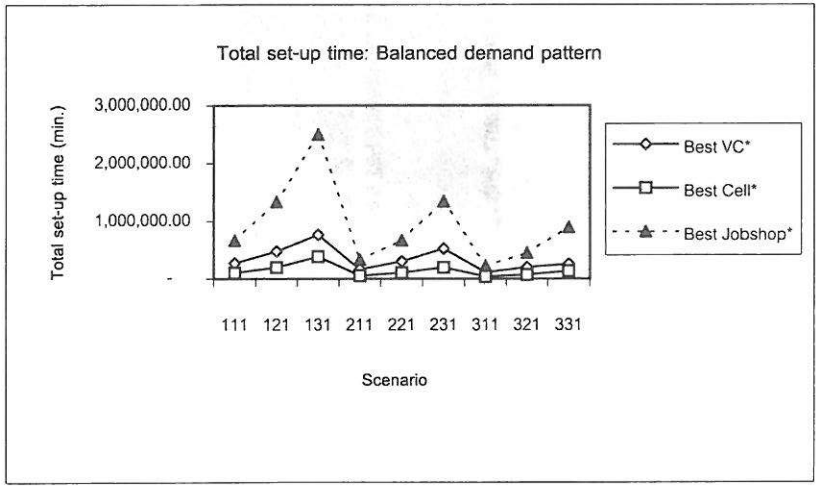
8. Overall discussion on the selected scheduling rules

Even though there is no scheduling rule that performs best in every situation, the Repetitive Lot (RL) works very well in this study. In fact, the appropriate sequencing rule has proved to play an important role in deciding the best system or configuration, especially with the traditional cells and job shops. Apart from VC_5, there is no much difference among other four rules implemented on the virtual cell. VC_5, which tries to save the amount of set-ups, has failed to make sufficient positive impact since it wastes too much time on doing that saving. The significant advantages of the virtual cell as suggested by Kannan and Ghosh [19] may stem from comparing the simple cell and job shop with the well organised virtual cell. Nevertheless, this study also confirms the advantages of the virtual cell over the tradition cell and job shop. However, only when the condition is best suited to the traditional cell and job shop, then the best policy from both shops can slightly outperform the virtual cell.

	Balanced demand pattern	Set-up time (min.)		
Code	Scenario	Best VC*	Best Cell*	Best Jobshop*
111	Small batch / low set-up	272,139.20	101,021.00	667,264.80
121	Small batch / medium set-up	476,032.50	196,550.20	1,333,047.00
131	Small batch / high set-up	764,754.10	385,859.30	2,499,771.00
211	Medium batch / low set-up	160,684.40	51,830.39	335,341.20
221	Medium batch / medium set-up	302,866.20	101,347.20	670,208.70
231	Medium batch / high set-up	523,385.30	197,553.40	1,342,608.00
311	Large batch / low set-up	108,829.60	34,842.18	223,319.40
321	Large batch / medium set-up	198,151.40	68,451.20	447,458.70
331	Large batch / high set-up	254,544.80	133,147.40	895,953.90

	Unbalanced demand pattern	Set-up time (min.)		
Code	Scenario	Best VC*	Best Cell*	Best Jobshop*
112	Small batch / low set-up	296,081.10	99,375.67	658,357.40
122	Small batch / medium set-up	513,192.40	193,880.50	1,314,619.00
132	Small batch / high set-up	688,411.40	379,477.80	2,453,633.00
212	Medium batch / low set-up	141,182.70	51,442.68	330,545.50
222	Medium batch / medium set-up	296,983.50	100,495.20	661,144.30
232	Medium batch / high set-up	438,967.30	195,600.50	1,326,625.00
312	Large batch / low set-up	106,750.70	34,470.67	219,973.80
322	Large batch / medium set-up	212,460.40	67,833.41	440,418.00
332	Large batch / high set-up	371,200.40	131,997.60	880,318.40

* Best selected policy can be seen from Table 5



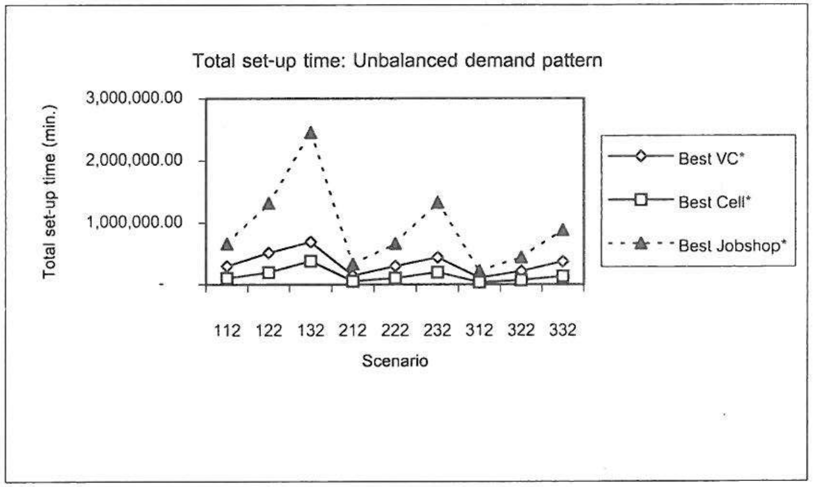


Figure 3: Set-up Time from Each System

9. Conclusions

The results demonstrated the impact of temporary machine dedication. Even though, the virtual cell does not provide the lowest set-up time and shortest transportation time, it offers the shortest process waiting time (lowest WIP level) and hence the shortest mean flow time. This advantage is achieved without any permanent physical rearrangement of the process layout or any trouble from forming such cells, but simply by employing the concept of logical cells on an existing job shop configuration. In the current market situation, where the competitions become so intense that the life cycle of the product becomes much shorter, the management must search for advantages that can improve a company's competitive position. Thus, the production process must respond to the situation by offering the ability to process in smaller batches with greater part varieties.

Under the wide variety of the tested scenarios, the virtual cell has shown its flexibility to respond well in all conditions, absorbing all the deficit areas of set-up time efficiency, material handing and production control. This can make batch production more efficient and responsive to changes in demand. The results from this paper present a small step towards improving batch production by introducing another type of shop configurations, the virtual cell. The study will also be extended to include more varieties of system variables and family searched scheduling methods on temporary machine dedication to further improve the performance of the shop.

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