

Chapter 17

Flexibility via Virtual Cellular System for Variability

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1 Introduction

The manufacturing industry produces a large variety of products in order to satisfy the diverse needs of markets. This is due to the dynamic environment in which we live, informed customers who desire goods with closer tolerances (DeGarmo et al. 1997) and demand additional features (Evans and Lindsay 2005). Hence, customer satisfaction (Mason-Jones et al. 2000) is of utmost importance. As a result, manufacturing operations must be flexible to accommodate varying needs of customers. Flexible operations are responsive; they are able to react when customers make unexpected demands (Szwejczewski and Cousens 2007). It has become one of the most sought after properties in modern manufacturing systems (Shewchuk 1999) in order to handle uncertainties and variations (Ramaseh and Jayakumar 1991) in both internal and external environments.

Customers require goods and services which must be easily available with short lead time and of a high quality at competitive prices. Field trips were undertaken and discussions held with members of Trinidad and Tobago Manufacturers Association and the above is apparent within the manufacturing industry in Trinidad and Tobago (TT). The product variety which is produced in the manufacturing industries within TT is accomplished through Job Shop (JS), Flow Shop, Project, and Continuous Processes. Customers demand small quantities and in most cases one of a kind from a large variety (DeGarmo et al. 1997); hence, in today's environment the JS manufacturing operation becomes critical.

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Manufacturers must be competitive and flexible in all aspects for their survival due to the turbulent environment in which they operate. They are encountering extreme difficulties (Nomden and Van Der Zee 2008; Tay and Ho 2008) such as product reliability, quality assurance, and on-time delivery (Karim et al. 2008). The competitive market place of varying demand and product mix from one period to another requires manufacturers to improve their operations and decrease their manufacturing cost (Khilwani et al. 2011; Kesen and Gungor 2011). They must improve at a faster rate if they are to become leaders in the industry. The key to their survival is getting the right product, at the right price and at the right time to the consumer (Mason-Jones et al. 2000). There has to be a shift to meet market requirement with respect to flexibility, quality, and delivery performance due to an increase in global competition. Hence, it is critical for the success of any manufacturing organization to maximize the utilization of workers, materials, and machines (DeGarmo et al. 1997).

As a result, the elimination of waste (Evans and Lindsay 2005) is a major strategy being pursued by manufactures globally. Ohno (1998) postulated that waste is what drives up cost. Waste is anything which does not add value to the product or manufacturing activity and which the customer is not willing to pay for (Womack et al. 1990), for example, jobs on a machine to be processed while major setup is being undertaken or products waiting in a queue to be processed or inspected. The elimination of these wastes is being undertaken by a culture of continuous improvement (kaizen, kanban), “pull” production, mistake proofing (poka-yoke), just in time, value stream mapping, cellular manufacturing (CM), and virtual cellular manufacturing (VCM).

Additionally, to bring about competitive advantage, flexibility together with cost, quality, and time (Szwejcjewski and Cousens 2007) is now a strategic objective being pursued by international manufacturers. More so, flexibility through reconfiguration of manufacturing systems can be accomplished with low additional cost (Kesen and Gungor 2011). Therefore, for longevity and profitability of the local manufactures, more so for the JS manufactures, this practice of flexibility must be incorporated within their respective plants. It must be embedded in their operational plan and diligently followed as a strategic objective. VCM as outlined by Chowdary et al. (2005) and Slomp et al. (2005) demonstrated this flexibility and now in this research it will be further tested through a case study.

Therefore, the objective of this research is a comparison of the JS performance with the traditional CM and the new concept of VCM. This will be evaluated against shop performance measures, such as waiting time (WT), setup time (ST), and flow time (FT). This reconfiguration for flexibility will be accomplished during the shortest time and at the lowest cost, by varying the methods of production with a minimum interruption to the manufacturer.

In order to meet the objective of this research, the remainder of this chapter is arranged as follows: Sect. 2 gives a brief synopsis of manufacturing systems – JS and VCM. An overview of the manufacturing industry is highlighted in Sect. 3. A case which widely represents JS manufacturing sector in TT is evaluated in Sects. 4 and 5 adopts strategies to alleviate the problems identified. A discussion follows in Sect. 6 and the chapter ends with a conclusion in Sect. 7.

2 Manufacturing Systems

2.1 Job Shop

When manufacturers are required to produce a large variety of products, a number of different machinery are essential. The JS distinguishing feature is when similar production machines are grouped together according to their functionality and arranged into different departments within a plant layout (Irani and Huang 1998; Herage 1994; Shafer and Charnes 1993). Maximum flexibility can be achieved with JS layout. This is evident when products of small lot sizes are required to be manufactured from a large variety. However, during major setup on the machines, waste is incurred in the form of time when dissimilar parts are manufactured utilizing the same machine. Based on a review (Bansee 2012), the advantages and disadvantages associated with JS layout are identified beneath.

Advantages associated with JS are:

- Production of large variety of products in small quantities
- High utilization of machines through overlapping
- High flexibility in allocating operations to alternative machines
- Flexibility to adapt to changes in customer requirement
- Quick adjustment to the manufacturing of new products

However, the disadvantages associated with JS are:

- Long wait time (WT)
- Long setup time (ST)
- Long flow time (FT) due to material flows through complicated routes
- High work-in-process (WIP) levels
- High material handling costs

2.2 Virtual Cellular Manufacturing

VCM follows on from CM; hence, it utilizes the principles and philosophy of group technology (GT) (Chang et al. 1998) for the formation of families of parts. In the formation of these families, there should be the avoidance to the addition of new machinery while at the same time the existing machinery within the JS should be efficiently utilized. VCM affords us to minimize job ST through pooling synergy of machines (Kesen and Gungor 2011; Suresh and Meredith 1994). Implementation of the VCM layout will resemble the traditional JS layout which still exists in majority of companies globally. There is no reconfiguration of the machines and departments; they remain in the same physical location (Kesen and Gungor 2011; Chowdhary et al. 2005). That is, the machines within the existing department are retained. Accessibility to machines is available to more than one cell, hence, the efficient utilization of resources through machine overlapping (Khilwani et al. 2011).

Based on the processing requirements for the family of parts, the appropriate machinery will be identified for the virtual cells. Remember these cells configuration will only be in the minds of the workers. The machines are only temporarily dedicated to the cells. Once the part family processing has been completed, the cells are disbanded and are free to associate themselves with other cells for the processing of other families. This reformatting of cells facilitates quick changes in customer's requirement at relatively no cost to the manufacture in terms of plant layout, thus affording them the benefits of volume and mix flexibility (Szwejcjewski and Cousens 2007). The VCM concept utilized the steps within the model by Bansee and Chowdary (2007).

3 Industry Overview

In order to assist in the identification of common problems and a basis for the generation of common solutions, interviews and discussions were held. Additionally, observations were made to the actual way in which firms operated in TT. As a result of the various processes which were being undertaken by the respective manufacturers, it was observed that wastage was being incurred on the shop floor. We can conclude that the majority of customers were not satisfied due to delays, to which the customers are asked to pay more prices. This conclusion is further reinforced by the first author who has over 20 years of personal experience working in a JS environment at a state company. However, based on an extensive literature search and field visits, factors which contribute to a number of difficulties inclusive of delays are categorized as management and operational levels issues and are listed below.

3.1 Management Issues

- No documented or adopted policy that is strictly followed in terms of job scheduling (Flynn and Jacobs 1987)
- Lack of strategic planning for machinery replacement and upgrades (Shafer and Charnes 1993)
- Low reliability of plant and machinery due to lack of any scientific maintenance program which results in equipment breakdown and unavailability and leads to additional waiting time (Conner 2001)
- Insufficient training pertaining to new operational techniques and advancement of skills for employees (Conner 2001)
- No strategic succession program for continuity of effective and efficient operations
- A low level of employee moral due to an absence of motivation and compensation (Shafer and Charnes 1993)

3.2 *Operational Issues*

- Due to implementation of the nonscientific methods of material handling and the arrangement of facilities within JS, delays in movement of materials occur.
- Due to insufficient information on the job sheet, consequently operators often seek clarification, resulting in delays.
- The amount of time taken to setup jobs is resulting in further job delays and leads to high WIP inventory.

All these delays lead to a high FT and low system utilization. An evaluation of the above issues within the local manufacturing industry demonstrates that there is wastage in resources, inclusive of time. All of the above contribute to the frustration which customers have to incur – when they have to suspend their individual operations. This results in difficulties to their own consumers and intricacy in retaining them. Additionally, there is loss of revenue and profit to both customers and manufacturers. Hence, to mitigate these issues an alternative mode of JS operation like VCM which facilitates configuration flexibility is taken up in this research for investigation purposes. Recognizing across the manufacturing industry that most of the customer's order delays occurred at the operational level, it will be a good starting point to reduce such delays at this level, in order to improve the shop performance through machine scheduling flexibility.

4 **Evaluation of Case Study**

4.1 *Job Shop Layout*

For this research, a manufacturer operation, which widely represents the JS manufacturing sector in TT, is evaluated. The manufacturing operation within the existing JS is accomplished by 21 machines arranged in nine (9) functional departments. Eight (8) machines are currently not in operation and are not included in this research. Table 17.1 identifies the quantity of machines to each department and a schematic layout of the arrangement of the existing machines is shown in Fig. 17.1.

4.2 *Processing Operation*

All jobs are held in a waiting queue when they arrive in the JS. The jobs are then accessed in order to determine their operational requirements. Thereafter, the jobs are sequenced through the appropriate departments based on their operational requirements. The scheduling of the jobs is determined on the basis of first in, first out (FIFO), otherwise on job criticality.

Table 17.1 Machine allocation to departments

Departments (D)	Machine type		Machine code used in the study
	Name	Number	
1	Lathe	10	M3, M4, M5, M6, M7, M8, M9, M10, M11, M12
2	Drills	1	M15
3	Milling	3	M17, M18, 19
4	Boring	2	M20, M21
5	Grinding	1	M25
6	Shapers	1	M26
7	Band saw	1	M27
8	Slotting machine	1	M28
9	Reblading machine	1	M29
Total		21	

Legend: M3, M4... M29 – Machine3, Machine 4... Machine 29

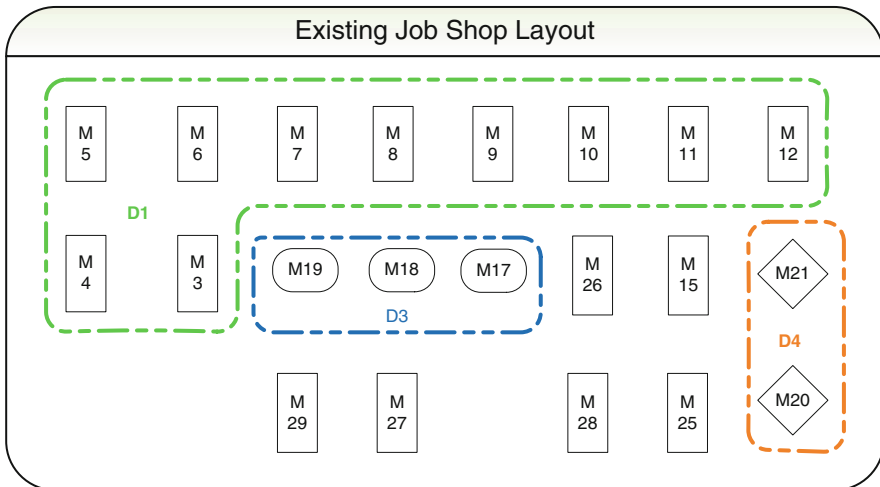


Fig. 17.1 Job Shop layout (Departments 1, 2 ...9, and M3, M4... M29, corresponds to Table 17.1)

The first available machine within a department is utilized for jobs which have been sequenced for manufacturing operation. If required, the job then proceeds to the next sequence department for its second operation and again uses the first free machine which is available in that department and continues so until all the manufacturing operations are completed. When a second operation is required and a machine is available, scheduling is based on the initial job which was scheduled to the first operation, and not necessarily the job which arrive to JS first. However, this does not apply if a latter schedule job can be completed in its second processing department before the earlier job arrives in that department.

Prior to any processing operation, some ST is encountered as jobs enter a department. However, if the same machine is used for a subsequent job which is similar to the first job, no major setup is required. On the other hand if the job is dissimilar to the first one, a major setup is required prior to processing. This continues for all jobs, using a range of machines within the functional departments. For the jobs considered in this research, job setup times and processing times are given in Appendix 6. In this research no minor setup time is considered and job handling time is ignored.

4.3 Data Acquisition and Analysis

Job requests were acquired from the company records which were placed by clients from October 1, 2010, to September 30, 2011. A 12-month period was chosen because it is most likely that the company will receive similar type of jobs in the following 12 months. For the period identified, 1,325 job requests were made by clients. This data was filtered to represent the jobs that were specifically assigned to the JS. The number of jobs that were assigned to the JS was 696.

The company management emphasized that efforts should be concentrated where the most financial benefit can be derived. Hence, the jobs were ranked according to their Annual Revenue Value (ARV). Eighteen jobs, which contributed more than \$50,000 of revenue towards the company, were chosen for evaluation purposes. These jobs are identified as J-1 to J-18 in Appendix 6 and will form the basis of this research.

The 18 jobs to be manufactured required processing in 1–3 departments. The sequences of processing through their respective departments are shown in Appendix 6. For example, for J-1 the number of processing departments is three and the sequence of departments at which processing takes place is from 7 to 1 to 4. The progression of events follow the same format as described. For the 18 jobs selected, the ST and PT are given in Appendix 6. The JS under review operated 5 days per week for 8 h per day and 1 day for 4 h. The resulting calculation gives jobs inter-arrival time of approximately 3 h. The 18 jobs will be rearranged based on their actual arrival order for scheduling within the JS, as shown in Appendix 6.

These 18 jobs under study are scheduled through the existing JS system at an inter-arrival rate of three hours and the processing activities are presented in Appendix 6. A sample description of these activities is at row 4 and column 14 for J-3: the cell represents that at 20 h J-3 setup and processing is completed on M27 in department 7 and move to department 4 and loaded on M20; and at row 7 and column 1, J-6 is loaded on M3 in department 1. The progression of activities follow the same format as described. The results (the average times in hours) for the 18 jobs that were processed through the existing JS system are shown in Table 17.2.

In order to improve the existing system, two cellular strategies will be adopted and analyzed for the data in the next section.

Table 17.2 Results of the existing JS system

Description	Average time (hours)
Wait time	11.11
Setup time	5.67
Processing time	18.72
Flow time	35.5

5 Adoption of Strategies

The company's operational efficiency must increase for improvement of customer satisfaction. In order to achieve this and the objectives previously set, there must be adoption of new strategies. These strategies will be explained and then evaluated.

5.1 Cellular Manufacturing

CM involves the processing of jobs within dedicated cells. As a result the existing JS layout at the company will have to be reconfigured to a cellular layout. Utilizing the principles and philosophy of GT, the individual jobs will be classified. This classification into families will be based on similarities in the processing requirement for the jobs. The machines required to accomplish the processing requirement will be determined. Hence, the requirement for the cell configuration will be established.

Within the physical layout, the various cells location will be identified, and the previously established cell configuration will be installed. That is, the existing JS layout will be reconfigured to accommodate the cells. With CM the machines are permanently dedicated to the assigned cell. Based on the scheduling policy, the various jobs will be dispatch to the appropriate cells for manufacturing utilizing the concept of processing families of parts. The scheduling policy adopted is FIFO; therefore, this will be used in this research.

In analyzing the data, the 18 jobs were grouped into four families and were assigned into four cells. For the families of parts, the machines have been identified based on the departments at which processing takes place. It will be considered that all machines within the same category have the same capability. This will avoid variation in cycle time and prevent the desire to duplicate machines of the same category of various capabilities within the same cell.

Based on the configuration developed, it is recognized that there is a need for additional machines. However, there will be excess machines within some department. In order to create the cells with the appropriate machines, where additional machines are required, they will be introduced. By following this methodology, the four families and machines were allocated to four cells as shown in Table 17.3.

The three (3) additional machines which will be needed to facilitate the formation of the respective cells are Cell-B one band saw and Cell-C and Cell-D one boring machine each. These additional machines are referred as M32, M30, and M31.

Table 17.3 Allocation of families and machines to cells

Family	Cell	Machines
A	Cell-A	M27, M3, M20
B	Cell-B	M21, M32, M4
C	Cell-C	M30, M5
D	Cell-D	M6, M17, M31, M15

Legend: M3, M4... M29 – existing machines
M30, M31, M32 – new machines

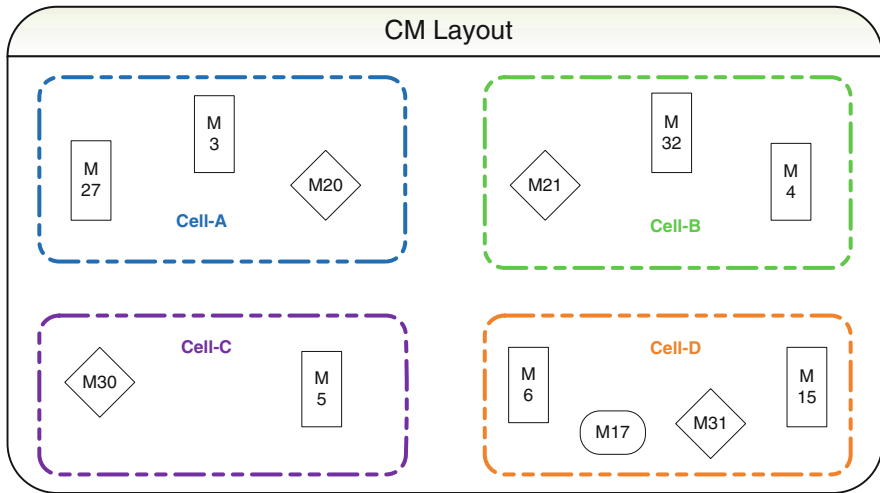


Fig. 17.2 Machine allocation in cellular layout

The seven (7) unutilized machines in the cell formation are six lathes (M7, M8, M9, M10, M11, and M12) and one milling machine (M11). These machines can be used for other purposes. The cellular layout with the respective machines assigned to cells is shown in Fig. 17.2.

Using the data for ST and PT and with an inter-arrival time for the jobs of three hours, these 18 jobs will be scheduled through the cellular layout based on the strategy adopted in the preceding section and the result are observed. Again, this scheduling will be based on the actual arrival pattern of the jobs. It should be recalled that ST only occurs the very first time the part family is processed on the machine within a cell. These results for the processing activities for the CM system for the jobs are shown in Appendix 7. A sample description of these activities is at row 2 and column 8 for J-1; the cell represents that at 3 h J-1 setup and processing is completed on M27 in Cell-A and move to M3 in Cell-A; and at row 5 and column 1 for J-4, the cell represents that at 9 h J-4 is loaded on M30 in Cell-C. The progression of activities follow the same format as described. The results (the average times in hours) for the 18 jobs that were processed through the CM system are shown in Table 17.4.

Table 17.4 Results for the CM system

Description	Average time (hours)
Wait time	9.5
Setup time	1.44
Processing time	18.72
Flow time	29.67

Table 17.5 Allocation of families and machines to virtual cells

Family	Virtual cell	Machines
AB	VC-AB	M27, M3, M4, M5, M6, M7, M20
CD	VC-CD	M21, M8, M9, M10, M11, M12, M17, M15

Legend: M3, M4..., M29 corresponds to Table 17.1

5.2 Virtual Cellular Manufacturing

The utilization of the concept of VCM affords us with a number of options for the formation of families for the various jobs to be process. These options can be based on the number of families, pooling time of families, size of families, similarities in the processing requirement, due date, and family releasing mechanism. For this research, the formation of families is based on similarities in the processing requirement.

Since VCM follows CM, the family formation used for CM will initially be the same for VCM. However, as it pertains to pooling synergy of machines, the 18 jobs were classified only into two families of parts, as our strategy, compared to CM where four families have been created. These two families resulted from the merging of the families of parts. Family type B were merged with A to form virtual cell AB (VC-AB), and family type D were merged with C to form virtual cell CD (VC-CD). This resulted in two families and two virtual cells. The reduction in families with VCM affords us to minimize job ST. Also, the configuration risk will be reduced due to minimum disruption to the JS operations. By following this methodology and with the emphasis on maximum utilization of machinery, these families will be assigned to VC-AB and VC-CD, as shown in Table 17.5.

The layout with the respective machines assigned to VC-AB and VC-CD is shown in Fig. 17.3.

Families will be released to the JS virtual cells for processing when they are formed. That is, when jobs arrive into the shop, they are evaluated to determine which family they belong to and are assigned to their respective family queue. The minimum size of the family considered for this study is two jobs. The company consented for the size of the family to have a minimum of two jobs. However, the maximum WT for the formation of a family from when the job first arrives in the shop until it is released to the JS is 9 h.

The initial order of arrival will be used together with the ST and PT for the manufacturing of jobs. As it pertains to the addition of jobs to the formed family – if a family has been scheduled and is processing within the virtual cells and another family

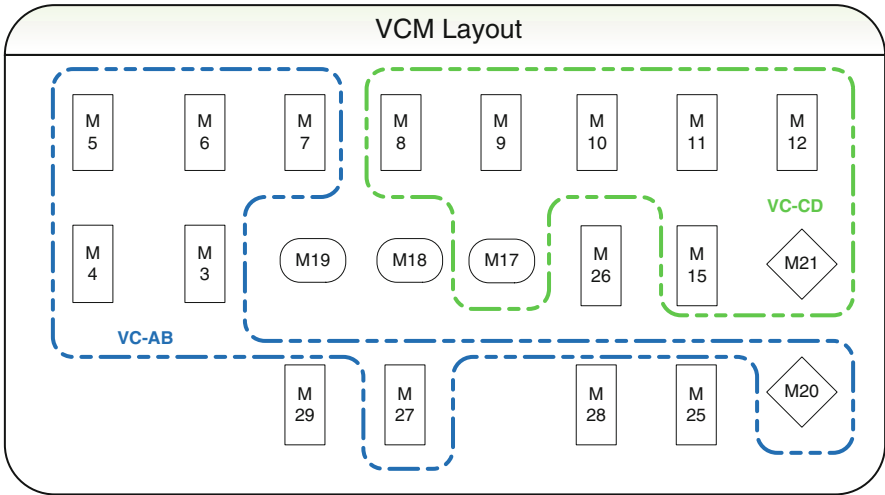


Fig. 17.3 Virtual cellular layout (Departments 1, 2 ...6 and M3, M4... M29 corresponds to Table 17.1)

Table 17.6 Results for the VCM system

Description	Average time (hours)
Wait time	7.89
Setup time	1.28
Processing time	18.72
Flow time	27.89

part arrives in the shop – it joins the family for processing to save ST. With respect to re-routing – if a latter job can be completed in the second process before the earlier job arrives to the workstation within the cell – the latter job can be processed.

For the VCM system the processing activities is presented in Appendix 8 for the 18 jobs. A sample description of these activities is at row 3 and column 9 for J-2; the cell represents that at 19 h J-2 setup and processing is completed on M8 in VC-CD and move to M17 within the same cell; and at row 5 and column 6, J-4 is loaded on M21 in VC-CD. The progression of activities follow the same format as described. The results (the average times in hours) for the 18 jobs that were processed through the VCM system are shown in Table 17.6.

6 Discussion

A summary of the results derived from an assessment of the strategies adopted, together with the present strategy being followed by the company, is shown in Fig. 17.4. This summary is based on the following shop performance measures:

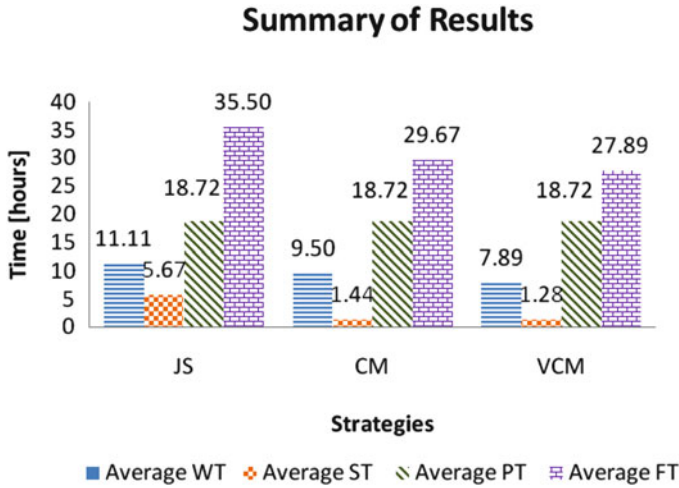


Fig. 17.4 Summary of results

Table 17.7 Analysis of results in terms of percentage

Items	Shop performance measures	Strategies		
		CM vs. JS	VCM vs. JS	VCM vs. CM
1	Waiting time	14.5 % decrease	29 % decrease	17 % decrease
2	Setup time	74.5 % decrease	77.5 %	11.5 %
3	Processing time	Same	Same	Same
4	Flow time	16.4 % decrease	21.4 % decrease	6 % decrease

WT, ST, PT, and FT. Corresponding to Fig. 17.4, the average WT for the 18 jobs for the existing strategy is 11.11 h, whereas for the adopted strategies of CM, 9.5 h and VCM 7.89 h, respectively.

An analysis of the above results is shown in a tabulated format in Table 17.7. Both ST and WT showed a decrease of 74.5 % and 14.5 % for CM when compared with the JS. The effect of this resulted in a decrease of the FT by 16.4 % with the CM strategy. However, as described previously, there are problems with the implementation of CM strategy. Foremost is a considerable amount of capital which must be invested. This will be used for shop reconfiguration and the purchase of additional machines. With CM the machines are permanently dedicated to the cells (Irani and Huang 1998). Every time the products mix changes, the CM layout will have to be reconfigured. Therefore, this type of manufacturing system is impractical (Flynn and Jacobs 1987).

The VCM system showed a decrease with the ST and WT of 77.5 % and 29 %, respectively, when compared with JS. The cumulative effect of this resulted in a decrease of the FT by 21.4 % with the VCM strategy. With VCM there is no

reconfiguration of the JS. The existing JS layout remains the same when implementation of VCM occurs. No new machinery is purchased and added to the current shop. Comparing the VCM system with the CM system, as the data shows, also resulted in decreases in ST, WT, and FT by 11.5 %, 17 %, and 6 %, respectively. These results verify that between the VCM and the CM layouts, the VCM layout is superior as supported by Bansee (2012). As a result, the existing strategy must clearly be changed in order to enhance customer satisfaction.

7 Conclusion

Due to delays in the delivery of customer's orders by JS manufacturers, the customers are dissatisfied. This is felt in terms of inconvenience to their respective customers and in their balance sheet in terms of profit. The main driver of the economy of TT is the energy sector. They are the major revenue earners for the JS manufacturers. As a result, the JS manufacturers must change their existing strategy and adopt an alternative mode of JS operation, such as VCM for their survival.

As a study, a JS setup was analyzed and two cellular strategies were adapted. The results were compared. The comparison revealed superior results for both the CM and VCM strategies in terms of ST when compared against the existing JS strategy. Additionally, there was a reduction in WT and hence an overall decrease in FT for the CM and VCM. Furthermore, the results also revealed that the VCM strategy was better than the CM strategy and which makes it very attractive for manufacturers to adopt.

Successful implementation of VCM to an existing JS layout brings benefits such as reduction in WT, ST, and FT. The effects of this reduction result in a drastic decline in WIP and afford the availability of the system, that is, increase in system utilization. Furthermore, reliability with customer due date delivery is enhanced. Additionally, the existing JS layout is retained. There is no capital investment for reconfiguration of the shop as compared to CM. VCM is flexible in assigning jobs and the virtual cells can be rearranged very rapidly. Additionally, this system affords the quick adaptation to changes in both product mix and volume.

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