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Impact of Cellular Manufacturing on Flexibility of Manufacturing Systems

by
Virender K. Ambwani. B. Eng. (Honours) 1987

A thesis submitted to
the faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of

Master of Management Studies.

School of Business
Carleton University
Ottawa, Ontario

May 1996

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ISBN 0-612-13855-0

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submitted by Virender K. Ambwani. B. Eng. (Hons.)
in partial fulfilment of the requirements for the
degree of Master of Management Studies

Thesis Co-Supervisor

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Carleton University
May 14, 1996

This thesis is dedicated to my Guru
Sant Kalyan Mayi Ji Maharaj

Abstract

Manufacturing flexibility has been identified as a strategic and operational tool for regaining competitiveness. Among many factors, cellular manufacturing (CM) is said to contribute towards flexibility of manufacturing systems. This study examines the changes in different flexibility types upon conversion from a job shop layout to a cellular layout. An instrument has been constructed to measure the change in different flexibility types as a result of the implementation of CM to test the propositions examining these changes. The data for this study was collected through a fax survey of seventeen plants in the electronics and telecommunications industry in Canada. The results reveal that implementation of CM contributed towards improvement in different flexibility types. Plants realized an improvement in their responsiveness to the following: delivery of products on time, introduction of new products, introduction of design changes in existing products and respond to fluctuations in product demand.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my thesis advisors, Professor Vinod Kumar and Professor Donald Gerwin for their guidance, instruction and encouragement during this study. They were extremely patient and helpful in guiding and supporting me throughout the period of this work from conception to the completion stage. Without their selfless assistance, financially and morally, this thesis would not have materialized. I am also grateful to Professor Siva Pal for his valuable feedback and constructive criticism, especially during conception stage of this study, which significantly contributed to shaping this work.

Financial support was provided in part by the Research Program in Managing Technological Change in Manufacturing.

This research would not have been possible without the assistance of the seventeen participating firms. I thank all the executives who so generously contributed their time to this project.

Also thanks to faculty and staff at the School of Business especially Professor Uma Kumar, Greg Schmidt, Jean Blair and Pam Norris, for their support during my stint at school.

Dheerja, Ajit, Utsav and Avni, thank you for providing me a home away from home. You provided me refuge in times of stress and helped me during tough times. Karl, Vibhor and Shobhna, your support was always timely.

Ian and Khalil, thank you for reviewing the drafts of the thesis. Sincere thanks to all my friends, especially Rajeev, Sunil, Sandeep, Ajit and Madhuri, you were there whenever I needed you.

Kaajal, thanks for your understanding and patience during final stages of this thesis. Probably, this thesis could only be completed after you joined me in Ottawa.

Finally, I owe a great debt to my parents and brother who have been a source of constant love and support at all times. Mum and Dad, you have sacrificed a lot for me.

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CHAPTER 1

INTRODUCTION

Cell manufacture is becoming an integral part of more and more manufacturing strategies because it allows radically new concepts of organization from top to bottom. By breaking down business into manageable and distinct, if not stand alone units, it allows a modular approach to manufacturing organization structure. This creates a step change improvement in flexibility and the ability to alter direction in response to developments in market and economic environment.

(Jones, 1993)

Over the past few years, there has been a considerable emphasis on achieving flexibility in manufacturing systems. The importance of flexibility in manufacturing systems has been emphasized in the manufacturing literature for achieving operational effectiveness and competitiveness in manufacturing (Gerwin, 1993; Slack, 1984; Jaikumar, 1986; Kim, 1991). In view of the trend towards shorter product life cycles, the need for a broader product line and an increased responsiveness of the system to changes in the product demand, the strategic need for flexibility in manufacturing systems is on the rise.

Apart from the strategic need for manufacturing flexibility, the operational need for flexibility in the manufacturing system is also of paramount importance if a business is to be competitive (Kim, 1991). According to Kumar and Kumar (1987), manufacturing flexibility is necessary in order to meet uncertainties in the inputs, outputs, processes and external environment of the manufacturing system. Thus, flexibility is required by the manufacturers not only to respond to and bring about changes in the external environment for strategic reasons, but also to respond to changes in their internal environment

for strategic reasons, but also to respond to changes in their internal environment for operational reasons (Pal and Saleh, 1993).

Although there has been an emphasis on capital intensive flexible automation in order to achieve manufacturing flexibility in U.S. (Keller, 1989), advanced manufacturing technologies are only one of the many ways of achieving manufacturing flexibility. There are a variety of methods other than production equipment, such as: product design, work organization, planning and control procedures, material management and information technology, that are available to meet the needs of flexibility (Gerwin, 1993). All these methods synergistically provide flexibility in manufacturing systems. Therefore, one of the major challenges facing a manufacturing system is to effectively manage the available methods to improve manufacturing flexibility.

Once a production system has been acquired, the only way to enhance flexibility is by improving the system's operational structures, control procedures, work organization and product design. Thus, management of manufacturing flexibility through these methods becomes the key issue.

Cellular Manufacturing (CM) is a manufacturing management approach that groups machines, tooling, people and materials into dedicated clusters of manufacturing cells (Gaither et al., 1990). The most common applications of CM involve establishing these cells in an existing job shop configuration; this means rearrangement of some of the machines from functional to product focused layouts.

In recent years, there has been a trend towards the adoption of CM in an attempt to obtain operational efficiencies such as -low inventory, simplified material handling and short lead times. Furthermore, CM seems to provide flexibility without having to invest extensively in facilities, since rearranging existing machines in cells is a less expensive and less risky solution than buying a Flexible Manufacturing System (FMS) (Gerwin and Kolodny, 1992).

The importance of CM in achieving flexibility in the manufacturing system has been emphasized in the manufacturing literature. In comparison to job shops, CM offers more flexibility by changing the layout of facilities, work structures, job design, and production planning and control structures (Gerwin and Kolodny, 1992). Bessant (1991) observes that a cellular layout allows for flexibility in both the volume and variety of products. Cross (1984), similarly, points out that CM provides more flexibility than job shop manufacturing systems since it can respond to changes in production schedules more quickly. These observations indicate that CM offers considerable improvements in flexibility in comparison to job shop manufacturing system.

There are, however, contradictory views and some researchers believe that CM reduces flexibility when implemented within a job shop. For example, Hayes and Wheelwright (1984) suggest that in comparison to job shops, CM offers less flexibility in terms of the range of products that can be manufactured by the system. Vakharia and Kaku (1993) also suggest that CM reduces flexibility in a job shop manufacturing system. The studies, both for and against the viewpoint that CM enhances flexibility, will be

discussed in greater detail in Section 2.3.

As yet, there is no comprehensive study that explores the changes in flexibility when CM is implemented in a job shop manufacturing system. In almost all existing studies, the benefits associated with the introduction of CM have been appraised primarily in terms of economic and technical gains such as -shorter throughput time, reduction of work in progress, and rationalization of machine utilization. In contrast, research on changes in flexibility achieved in a manufacturing system as a result of the implementation of CM is practically nonexistent.

In this study, CM is defined as the rearrangement of an existing plant and its equipment into cells, each of which produces a family of parts with similar processing requirements. This study investigates the effect of CM implementation on various flexibility types in a manufacturing system which had previously been organized as a job shop. It also provides an insight into the extent of implementation of human factors in cells namely -training, team work and job enrichment.

This thesis is organized as follows: Chapter 2 reviews the literature in the area of manufacturing flexibility and cellular manufacturing, suggests a framework for identifying various flexibility types in the manufacturing system, and hypothesizes the impact of CM on the flexibility of a manufacturing system that had previously been organized as a job shop; Chapter 3 considers the research questions and propositions which this study intends to investigate; Chapter 4 discusses the research methodology which was adopted for this study; Chapter 5 presents the results of the data analyses; Chapter 6 discusses the findings,

benefits and limitations of the study. It also discusses possible implications for future research.

CHAPTER 2

LITERATURE REVIEW

This chapter reviews literature in the area of manufacturing flexibility and cellular manufacturing. In the following section, a framework for identifying different flexibility types in a manufacturing system has been suggested. In order to classify the different flexibility types studied in this research, an *a-priori* taxonomy of flexibility in manufacturing systems consisting of mix flexibility, changeover flexibility, modification flexibility, volume flexibility, delivery flexibility and flexibility responsiveness has been suggested.

Section 2.2 introduces the concept of cellular manufacturing (CM). It explains the different definitions of CM and the advantages and disadvantages of CM which are cited in the literature. Section 2.3 hypothesizes changes in different flexibility types after the implementation of CM in manufacturing systems which earlier had been organized in the form of job shops. This section also hypothesizes the effect of extent of human factors in cells such as- training, team work and job enrichment on flexibility. The last section presents a summary of the literature review.

2.1. Manufacturing Flexibility

2.1.1. Concept of Flexibility

Flexibility has been defined as the ability of a system to respond effectively to changing circumstances (Buzacott, 1982; Mandelbaum, 1985). According to Upton (1993), flexibility is the ability of a system to change or react with little penalties in time, effort, cost or performance.

In the literature on manufacturing, there are diverse definitions of flexibility to explain the concept of flexibility. Sethi and Sethi (1991) define flexibility in manufacturing as the ability to reconfigure manufacturing resources and efficiently produce different products with acceptable quality. This means that a flexible manufacturer can quickly adapt its operations to changes in demands for its products, changes in consumer tastes, variations in supplier quality and lead times and it can also adapt to the emergence of new products and process technologies. According to Kim (1991), manufacturing flexibility is not only about how quickly a manufacturer can adapt to changing conditions and environments, but also about how well a manufacturer can lead in changing such conditions and environments.

In the context of this research, flexibility can be defined as the ability of the manufacturing facility to quickly adapt its operations to respond to external or internal changes as a result of change in product mix, product design, production volumes and

delivery times.

2.1.2. Taxonomy of Flexibility

There are various taxonomies of flexibility in the literature that describe different types of flexibility in a manufacturing system. A partial list of the various flexibility types proposed by different authors can be found in Appendix 1 and a detailed review of the literature on flexibility can be found in Hyun and Ahn (1992), Suarez et al.(1991), and Sethi and Sethi (1990). In order to identify various flexibility types for this research, it is necessary to first develop an appropriate taxonomy.

There is confusion about the "concept of flexibility because of overlapping definitions of different flexibility types in different taxonomies in the literature. For example, Gerwin's (1993) definition of "mix flexibility" as the ability of a system to produce diverse products is the same as the definition of "process flexibility" conceived by Browne et al.(1986) and Sethi and Sethi (1991). Buzacott (1982) uses the term "job flexibility" to describe the ability of a system to produce diverse products and relates "job flexibility" to the ability of the system to cope with changes in the jobs to be processed by the system.

There are different flexibility types in the taxonomies, based on the different contexts of researchers; some of these contexts represent different hierarchical levels in

the organization, the time-horizon of change and the type of industry. The use of a taxonomy with broad definitions of different flexibility types, which are applicable to different hierarchical levels and industries, can be helpful in grouping various interpretations of the managers of different types of flexibility.

The discussion in this research will follow Gerwin's (1993) classification of manufacturing flexibility. According to this classification, there are seven flexibility types: mix, changeover, modification, volume, material, rerouting and flexibility responsiveness (for definitions, please see Appendix 1). The discussion is based on Gerwin's classification because of broad definition of different flexibility types in this classification. These definitions can be applied to different hierarchical levels within an organization, including the corporate, factory/ business unit and cell levels. These definitions can also be applied to different types of industries and technologies, such as -process, textile, metal working, and electronics assembly industries.

In this classification, from a manufacturing systems' viewpoint, "rerouting flexibility" and "material flexibility" are related to delivery time and thus can be considered together under the concept of "delivery flexibility". The definitions of "rerouting flexibility" and "material flexibility" are narrow, from a system's viewpoint, as they do not give an overall view of the system's ability to meet customers' product quality and due-date expectations. Apart from material input variations and machine

breakdowns, other process-related uncertainties, such as -employee absenteeism, irregular material supplies, and lack of skill- also may affect the customers' due-dates. The concept of "delivery flexibility" is broader than the concept of "rerouting flexibility" and "material flexibility" and for it includes interacting technological, organizational and human elements.

In this research, the following six flexibility types are considered:

1. Mix Flexibility
2. Changeover Flexibility
3. Modification Flexibility
4. Volume Flexibility
5. Delivery Flexibility
6. Flexibility Responsiveness

2.1.2.1. Mix Flexibility

Mix flexibility is the ability of a system to produce diverse products within a given time period. This flexibility enables the manufacturer to respond to distinct customer tastes by producing a greater variety of products to meet demands of different market segments (Suarez et al., 1991).

In the context of this research, mix flexibility is the ability of a system to produce

different models of an existing product line in a given time period. It assumes an already existing mix of different models of a product line when no new models are introduced.

The major determinants of the mix flexibility in a manufacturing system are the process technology and the overall design of the production system (Slack, 1984). The overall design of a production system includes production planning and control procedures, production layout and work organization.

2.1.2.2. Changeover Flexibility

Changeover flexibility is the ability of a system to introduce new products or substitute products over a given period of time. This type of flexibility enables a manufacturer to quickly introduce newly- designed products to the market (Gerwin and Tarondeau, 1989).

In the context of this research, changeover flexibility is the ability of a production system to introduce new models of a product in an existing product line.

Changeover flexibility is dependent upon labour skills, product design, job design, and the capabilities of process technology (Slack, 1984). Flexible automation, design for manufacturability and broader workforce skills also improve changeover flexibility of the system (Suarez et al., 1991).

2.1.2.3. Modification Flexibility

Modification flexibility is the ability of a system to implement design changes in an existing product. In the context of this research, modification flexibility is the ability of the system to implement engineering change orders on existing products without any significant changes in the process requirement of the product.

Modification flexibility depends on the ability of the workforce to adapt to changed operating procedures in order to meet comparatively new conditions within a short period of time. The responsiveness to change is faster for product-focused teams (Gerwin and Kolodny, 1992). This type of flexibility also depends upon the ability of production equipment to undergo retooling and a modest amount of reprogramming.

2.1.2.4. Volume flexibility

Volume Flexibility is the ability of a system to vary the production level of a manufacturing process in response to fluctuating demand for the products and allows increases or decreases in the aggregate production levels.

In the context of this research, volume flexibility is the ability of a system to implement changes in overall production levels on a daily, weekly and monthly basis.

Since volume flexibility is the accommodation of shifts in volume for a given part mix, in the short term, it requires either very high capacity units or subcontracting

(Gerwin and Kolodny, 1992). In the long term, it requires flexible layouts which can adapt easily to the addition or subtraction of machine tools (Frazelle, 1986). This type of flexibility is also dependent upon adjustable production equipment, a high degree of workforce flexibility and a flexible labour policy that will allow the manufacturer to vary the number of workers (Suarez et al., 1991).

2.1.2.5. Delivery flexibility

In the context of this research, delivery flexibility is defined as the ability of a system to vary the sequencing and scheduling of products at the time of production in order to meet customer due-dates. The ability of a manufacturer to deliver products on time is very critical if customers' needs are to be met.

Delivery flexibility may be required to overcome unpredictable and sporadic problems that are usually internal to the system such as -machine breakdowns, material problems, and workforce absenteeism, and are encountered during plant operations. This type of flexibility may also be required if customers frequently and continually change their due dates.

Delivery flexibility is strongly affected by production management techniques, such as the "just in time system" (JIT), as well by production technology if the setups require long preparations. This flexibility type is also dependent upon the degree to which

machine sequence and operator assignments can be changed to meet operational exigencies in the manufacturing system.

2.1.2.6. Flexibility Responsiveness

"Flexibility responsiveness" is the system's ability to respond to unknown changes by changing the required flexibility types or amounts of a given type of flexibility. In other words, it is the ability of a system to alter existing capabilities for flexibility through reconfiguration of the manufacturing process (Gerwin and Kolodny, 1992). The ability of the manufacturing system to adapt to future changes in product design and manufacturing processes indicates the flexibility responsiveness of the system.

Flexibility responsiveness is facilitated by modular systems design, machinery that does not require special foundations and material transport that can be easily rerouted. Continuous improvement in processes also leads to increased flexibility responsiveness in the system (Suarez et al., 1991).

2.1.3. Time context of flexibility

According to Upton (1993), each of the above types of flexibility can be classified as operational, tactical or strategic flexibility, depending upon the time horizon over which changes are required in the system. In order to better understand the actual nature of each

of the flexibility types, it is necessary to know the time context for each of the flexibility types.

The time context of flexibility may be industry-specific, since it may vary depending upon the process requirements and different environmental uncertainties associated with different industries. The time context of flexibility can be linked to various decision levels in the organization which are responsible for managing flexibility in accordance with Anthony's model (1965). This association of decision levels is based on the assumption that managers at different organizational levels have different perspectives on process technology (Hayes and Wheelwright, 1984) and that they are concerned with different types of flexibility depending upon their positions and responsibilities. The link between time-context and decision levels in the organization will also help to integrate different flexibility types within a unified framework by relating them to the decision levels in the organizations (Mahalanabis, 1993). The different time contexts of flexibility are as follows:

1. Operational Flexibility
2. Tactical Flexibility
3. Strategic Flexibility

2.1.3.1. Operational Flexibility

When a system must respond to frequent changes -such as hourly, daily or weekly, it requires "operational flexibility". Operational flexibility may be associated with the operational control level of decision making in the organization, according to Anthony's model (1965). At the operational control level, technical specialists are concerned with the efficient operation of the plants considering the short-term environmental uncertainties. For example, the system requires mix flexibility and delivery flexibility to respond to changes in daily operations; therefore, the time context of mix flexibility and delivery time flexibility is operational. Similarly, the volume flexibility can be considered in the operational time context when the system must respond to daily changes in production levels.

2.1.3.2. Tactical Flexibility

When the system must respond to changes occasionally, such as quarterly or half-yearly, and requires some effort and commitment, it requires tactical flexibility. This type of flexibility may be associated with the management control level of decision making in the organization, according to Anthony's model (1965). At this level, operations managers must effectively cope with expected midterm environmental changes. For example, modification flexibility facilitates system's quick response to occasional

changes in the product design; therefore, the time context of modification flexibility is tactical. Changeover flexibility and volume flexibility may also be considered in the tactical time context when the system is required to respond to occasional changes due to new product introductions or changes in production levels.

2.1.3.3. Strategic Flexibility

When the system must respond to changes over a long term, say every few years, and requires significant commitment, it requires strategic flexibility. This type of flexibility may be associated with the top level of decision-making in the organization. At this level, corporate managers are concerned with the introduction of new products, and changes in the competitive environment, customers' needs and long-term production capacity. For example, the system requires flexibility responsiveness in order to respond to long term changes; therefore, the time context of flexibility responsiveness is strategic. Changeover flexibility may also be considered in the strategic time context when the system must respond to long term changes as a result of new product introductions.

Apparently, specifying the time context for a particular type of flexibility helps to understand the exact nature of flexibility. Each of the flexibility types may or may not be considered in each of the three time contexts. For example, mix and delivery flexibility can just be considered in the operational time context, while changeover flexibility may

be considered in the tactical and strategic time context. Alternately, volume flexibility may be considered in all the three time contexts, depending upon whether the changes required in volume are daily, seasonal or long term capacity related. Table 1 summarizes the different time contexts by which various flexibility types can be considered.

Table 1- Time Context of Flexibility

	OPERATIONAL	TACTICAL	STRATEGIC
Mix Flexibility	***		
Changeover Flexibility		***	***
Modification Flexibility		***	
Volume Flexibility	***	***	***
Delivery Flexibility	***		
Flexibility Responsiveness			***

2.1.4. Elements of Flexibility

Much of the literature on manufacturing flexibility suggests that each of the flexibility types is associated with one or more elements. Different researchers have identified these elements in their own terminologies.

Slack (1987) has identified three elements of flexibility namely: the *range* of states a system can adopt, the *cost* of moving from one state to another, and the *time* which is necessary to move from one state to another. He refers to these elements as the three dimensions of flexibility.

In contrast, Kumar (1987) identifies two elements of flexibility represented by variables *n* and *x* in his measures of flexibility. In his theory, *n* represents the range in terms of the number of options available, and variable *x* signifies the ease of change from one option to another -which may be measured in terms of time, cost or effort required for this change.

Upton (1993) has defined three elements of each of the flexibility types: *range*, *mobility* and *uniformity of performance* across the range. His *range* element is the same as that identified by Slack (1987), and the variable *n* defined by Kumar (1987), representing the number of available options. Upton's *mobility* element is the same as variable *x* defined by Kumar. This terminology encompasses the context of the time and cost elements identified by Slack, but is more explicit. The *uniformity of performance* is the extent of the differential performance across the range of the manufacturing system.

In the context of this research, two elements of flexibility will be considered: *range* and *mobility*. This research contends that, whenever a flexibility type is considered, the element of *uniformity of performance* is inherent in the range and a flexible system

should signify uniformity of performance within reasonable limits across the range of products with similar processing requirements.

2.1.4.1. Range

Range refers to the variation that is possible within a given type of flexibility.

Examples of range include the following:

- the number of models in a particular product family which can be processed by a given cell, and diversity between the products;
- the range of volumes of output for which a plant is profitable;
- the range of sizes of products that can be produced.

Increased range is generally seen as providing increased flexibility. The range element of mix flexibility can be measured by the variety of products handled by the system in a given time period and the diversity between the different products. The range element of changeover flexibility can be measured by the range of products for which the system has the manufacturing capabilities (Slack, 1984). The range element of modification flexibility can also be measured by the number of different types of minor design changes that are possible in the manufacturing system. The extent of fluctuations in the production levels that can be handled profitably by the system reflects the range

element of volume flexibility. This means that the break-even point for the production system should be low, in order to allow larger fluctuations in production levels. The range element of delivery flexibility can be measured by the extent of possible variation in sequencing and scheduling to meet customers' due dates. The range element of flexibility responsiveness can be measured by the extent of changes in different flexibility types in the system.

2.1.4.2. Mobility

The mobility element of each of the flexibility types is the ability of the system to make the transition from one state to another with minimal penalties of time. Kumar (1987) refers to mobility element in terms of the degree of freedom or ease in making the change. For example, a system which can move quickly from state A to state B is more flexible than one which takes longer to make the same change. The mobility element of flexibility implies responsiveness to change and can be measured in terms of the time or cost which is required to change from one state to another. According to Upton (1993), time (when used as a measure of mobility) is a proxy for the cost or difficulty of a change. This research will consider only time as a measure of the mobility element. It contends that, though cost can be a measure of the mobility element, in practice it is very difficult to isolate as an independent variable, the true cost required to bring about change

in the production system. In practice, cost is usually measured as a function of changeover time and, thus, is a reflection of the time which is required for the change to occur.

The mobility element of mix flexibility can be measured by set-up time or changeover time between the products. The mobility element of changeover flexibility can be measured by the manufacturing start-up time which is required for new product introduction (Gerwin and Kolodny, 1992). The mobility element of modification flexibility is reflected in the time which is required to implement minor design changes in the product (Gerwin, 1993). The mobility element of volume flexibility is represented by the time taken by the system to respond to the fluctuations in the production level (Gerwin, 1993). The mobility element of delivery flexibility can be measured by the average number of days by which jobs get delayed. This element may also depend upon the particular change of state: for example in the case of volume flexibility, increasing volume by one hundred units versus one thousand units.

In the flexibility framework discussed above, each of the six types of flexibility in the taxonomy to be followed in this research has been classified in terms of its time-context. Each of the flexibility types has two elements: range and mobility. This framework can be applied in the field to understand the different managerial perceptions and interpretations of flexibility. This complete framework helps to provide a more explicit definition, focus and measurability for each of the flexibility types.

2.1.5. Potential and Actual Flexibility:

In order to evaluate and measure changes in the flexibility of operations, one must differentiate between potential and actual flexibility for each of the flexibility types (Gerwin, 1993). Potential flexibility indicates what can occur, given the existing plant design, if external conditions are appropriate. Actual flexibility is the flexibility which is achieved in practice and is determined on the basis of experience.

In the context of this research, change in the potential of a flexibility type is measured by the change that could be achieved in the indicator for that flexibility type. In other words, potential flexibility is the change in the potential capability of the system. In this research, the actual change in a flexibility type is measured by the actual change in the indicator for that flexibility type. For example, potential change in the range element of mix flexibility is measured by the change that could be achieved in the variety of parts which are produced in the plant. In contrast, the actual change in the range element of mix flexibility is measured by the actual change in the number of parts which are produced in the plant. As another example, the potential reduction in setup time measures the potential change in the mobility element of mix flexibility, and actual reduction in setup time measures the actual change in the mobility element of mix flexibility.

2.1.6. Flexibility Sources

The flexibility of a manufacturing system is the result of several contributing factors which can be grouped into three broad categories: process technology, product design technology and organizational infrastructure (Swamidass, 1988).

Process technology encompasses factors which are associated with the application of advanced manufacturing processes technology related to machines and equipment to realize manufacturing flexibility. Examples of advanced process technology include numerically controlled equipment (NC, CNC), flexible manufacturing systems (FMS), robots, automated guided vehicles (AGV) and automated storage and retrieval systems (ASRS). Factors which are associated with product design include design techniques and processes used in product development, such as -computer aided design (CAD), computer aided engineering (CAE), design for manufacturability (DFM), and modular design of products. Factors which are associated with infrastructure refer to production management techniques -such as application of Just in Time (JIT) and Total Quality Management (TQM) practices; information systems related to planning, scheduling and control; human resource practices such as training of workforce; and labour policies related to hiring and workforce wage structure. Infrastructural factors are associated with people, procedures, information systems and decision-making systems and allow for the integration of design and process technology related factors.

In order to enhance the flexibility in a manufacturing system, there has to be a coordinated effort to address process technology, product design technology and organizational infrastructure (Swamidass, 1988). Cellular manufacturing is one of the infrastructure techniques which are used to attain flexibility in manufacturing systems. The following sections introduce the concept of CM and the underlying characteristics which may contribute towards improving different types of flexibility in a manufacturing system.

2.2. Cellular Manufacturing

2.2.1. Introduction

Cellular Manufacturing is a form of production that groups machines, tooling, people and materials into manufacturing cells (Gaither et al., 1990). A manufacturing cell is a group of dissimilar machines or processes located in close proximity to one another and dedicated to the manufacture of a family of parts that are similar in their processing requirements.

Hyer and Wemmerlov (1984), define CM as an application of the Group Technology (GT) philosophy, whereby at least part of a firm's plant has been converted to cells. GT is a manufacturing management philosophy which groups together and standardizes families of parts which are similar design characteristics and require similar machining operations (Burbidge, 1975; Hyer, 1984).

CM represents a hybrid production system with a mixture of job shop characteristics (a large variety of parts) and flow shop characteristics (mass production of one type of product) (Hyer and Wemmerlov, 1984). The difference between a production line and cells is that, while a line is associated with the production of a single product and is characterized by repetitive manufacture, cells are associated with mixed model or multi model manufacturing and focus on variety rather than repetition. Cells are primarily suited to mid-volume and mid-variety production (Bessant, 1991, Wemmerlov and Hyer, 1989).

There are two basic types of cells: process-based cells and product-based cells. The process-based cells are defined by the processes that go on in the cell and the product-based cells are defined by the products that require similar processes. An example of process-based cell is a wave-soldering cell to which printed circuit boards for different products come for wave soldering. In contrast, an assembly cell for a product that assembles different models of a product line is an example of a product-based cell.

The composition of cells may vary widely depending upon the manufacturing requirements of an industry, but CM can be implemented in almost any industry such as - electronics, textiles, hospitals, medical equipment, and defence products. Most applications of CM involve establishing manufacturing cells from existing job shop operations without any major investments in new equipment or machinery. In other words, the introduction

of CM usually involves reorganizing the machines which are required to produce a family of parts in a job shop and placing them in the same work area or cell and operating these machines in a flow line for the production of a variety of parts (Gaither, 1990). In other applications, companies introduce production in cells at the same time that they introduce new product lines, and invest in new equipment to set up these cells.

In this research, the context of CM refers to the grouping of equipment in close proximity to produce either a family of parts which have similar production processes or different model variants of a product line.

The objective of CM is to achieve many of the efficiencies associated with mass production in less-repetitive job shop environments. Some of the documented reasons for establishing cells are as follows:

- reduction in work in progress (WIP) inventory, setup time, throughput time and material handling,;
- improvement in quality control, scheduling and flexibility;
- creation of a more stimulating work environment.

Wemmerlov and Hyer (1989) found that firms implementing CM showed an average reduction in setup time by 41.4%, in material handling by 21.0% and in the amount of work in progress (WIP) by 19.4%.

CM implementation has organizational and behavioural implications too. At least two studies have found that cells are conducive to team work in the organizations and this leads to an environment of continuous improvements (Fazarkley, 1976; Huber and Hyer, 1985).

There are also some disadvantages which are associated with CM. One of these is the fact that CM implementation may result in increased capital investment. This is because each cell must contain all the machines which are necessary to manufacture the parts which are assigned to that cell. This may require the purchase of additional machines, but the justification for this is that long-term benefits eventually outweigh the capital investment in additional machines. Additionally, CM may result in a lower machine utilization, due to overall increase in the number of machines which are required in a cellular layout as compared that in a job shop.

2.2.2. Variations in CM Implementation

Cellular Manufacturing can be implemented in different ways according to a multitude of different factors, some of which may be unique to a given company.

The extent of the implementation of cellular manufacturing or the degree of cell usage may vary from firm to firm. The degree of cell usage can be measured by the

percentage of all machine hours in the plant that are expended annually in the cells.

Wemmerlov and Hyer (1989) found that this measure ranged from 0.2% to 88%.

The plants may also implement production management practices other than CM, such as -design for manufacturability, group technology and kan-ban production control. These plant practices may vary from plant to plant.

The extent of the implementation of human factors in the cells -such as work structures, job design and training of staff- may also vary from company to company. The extent of training, team work, and job enrichment may differ from one firm to another.

2.3. Cellular Manufacturing and Manufacturing Flexibility

In the literature on manufacturing, there are contradictory views of the impact of CM on the flexibility of manufacturing systems which had previously been organized as job shops. Hayes and Wheelwright (1984), in their product-process matrix, suggest that CM offers less flexibility than job shop manufacturing. These researchers are implying the range element of mix flexibility. Vakharia and Kaku (1993) also argue that a CM system is less flexible than a job shop manufacturing system. They have defined flexibility as the ability of the cellular system to completely process different parts in the existing

mix of parts in more than one cell. They also see flexibility as the ability to deal with long-term changes in the product demand, and are implying the range element of the mix and the changeover flexibility.

Other researchers emphasize that CM helps to achieve different flexibility types in comparison to a job shop. In a recent survey of firms in the American Midwest (Knudsen et al., 1994), for example, it was found that implementation of CM allowed manufacturers to produce a greater number of products and more models of existing products. This implies that CM offers mix and changeover flexibility but, in the literature, the evidence of a link between CM and flexibility is mostly conceptual and anecdotal. For example, Bessant (1991) suggests that a cellular layout allows for flexibility in both the volume and variety of products being made. Similarly, Cross (1984) suggests that cellular manufacturing offers greater flexibility because of its responsiveness to schedule changes, product changes and process changes with little disruption to the entire line. Wemmerlov and Hyer (1989) also suggest that there is a change in the composition of part families in the cells over a period of time; this implies that the implementation of cellular manufacturing improves changeover flexibility.

According to Gerwin and Kolodny (1992), CM offers more flexible facility layouts, organizational work structures, job designs, production planning and control structures. All these factors contribute towards making the system more responsive to

changes in products and processes and suggest that CM should improve the mobility element of different flexibility types in a manufacturing system.

Evidently, there are various interpretations of the impact of CM on the flexibility of manufacturing systems. This seems primarily a result of different definitions of flexibility and the context in which the term flexibility has been used by different researchers. As Alford (1994) concludes, because interpretations of flexibility differ, it is difficult to identify the type of change in flexibility.

2.3.1. Effect of CM on Manufacturing Flexibility

Since the review of literature in the field of CM does not specifically state the impact of CM implementation on different flexibility types, this section discusses the characteristics of CM in order to hypothesize the impact of CM on changes in different flexibility types. The objective of this study is to investigate the effect of CM implementation on different flexibility types at the plant level.

Since the underlying characteristic of CM is the grouping of equipment in order to process a specific family of parts, this has a direct impact -in many ways- on the flexibility of these manufacturing systems which had previously been organized as job shops. CM also leads to some benefits that may lead to changes in different flexibility

types. For example, according to Gupta et. al (1991), reduced lead times and work in progress (WIP) improve mix flexibility and operational flexibility. Here, the researchers are implying the mobility element of flexibility. The influence of the underlying characteristics of CM and their effects on the different flexibility types of manufacturing systems which had previously been organized as job shops can be described by following four factors:

1. Grouping of Equipment
2. Reduced Setup Time
3. Reduced WIP Inventory
4. Reduced Material Handling

Grouping of Equipment

In CM, the production equipment in each cell is dedicated to the processing of a specific family of parts. This restricts the ability of the system to completely process any new part which does not belong to one of the families and may result in *reduced mix flexibility* and *changeover flexibility* at the plant level in the context of range element.

The grouping of equipment also restricts the ability of the manufacturer to modify parts, because the plant cannot process parts which have processing requirements that different from the processing capabilities of cells within the plant. This may result in

reduced modification flexibility in the context of range element.

The grouping of equipment in cells may also lead to *reduced volume flexibility* in the context of range element because the capacity of the cell limits the extent of volume fluctuations for a part which is currently in the product mix, though excess capacity may exist elsewhere in the system.

Reduced Setup Time

Since CM involves the processing of a group of parts that require similar processing and similar tooling in the same cell, it leads to reductions in setup time (Afzulpurkar et al., 1993; Hyer and Wemmerlov, 1984). As evidence of this, it can be noted that, in a survey, Wemmerlov and Hyer (1989) observed that companies implementing CM achieved an average 41.1% reduction in setup time. As a result of reduced setup time, reduction in setup time allows the manufacturing system to economically produce goods in smaller batch sizes. Furthermore, as a result of short cycle times and smaller batch sizes, short setup time leads to faster throughput .

Reduced setup times also mean that the production runs are shortened and the system is thus able to respond rapidly to unexpected customer demands. Alternatively, long production runs require the customers to wait until the end of the long run before

their demands can be satisfied. Since setup time reduction is a measure of the mobility element of mix flexibility (Gerwin, 1993), a reduction in set up time implies an improvement in this element of *mix flexibility*.

A reduction in unproductive setup time also improves the manufacturer's ability to vary batch sizes in the cells -which may contribute towards improved responsiveness to volume changes and delivery times. This discussion suggests that a reduction in setup time should also contribute towards improvements in the mobility elements of *volume flexibility* and *delivery flexibility*.

Reduced WIP Inventory

CM achieves low work in progress (WIP) because of its smaller batch sizes, shorter production runs and more continual flow of parts (Afzulpurkar et al., 1993). The smaller batch sizes are achieved in CM through reduced setup times. A continuous flow of parts in CM results in reduced WIP as the parts spend less time waiting in line for the subsequent process. In a survey of thirty two firms, Wemmerlov and Hyer (1989) observed that the firms achieved an average 19.4% reduction in WIP inventory after CM introduction.

Due to reduced WIP, the system can quickly complete work in progress and then

switch over to a new part, resulting in a reduced throughput time (time to completely process a part) which in turn enables the manufacturing system to quickly respond to changes in the product demand (Wacker, 1987). This suggests that CM should contribute towards improvements in the mobility elements of *mix flexibility*, *changeover flexibility*, *modification flexibility*, *volume flexibility*, and *delivery flexibility*.

Reduced Material Handling

CM also leads to a reduction in material handling as a result of its simplified workflow and smaller WIP inventory (Welke and Overbeeke, 1988). Simplified workflow is achieved through the reduced travel distances which result both from the grouping of machines in close proximity to one another and from smaller lot sizes. It also reduces the need for sophisticated material handling equipment to transport, stock, retrieve and distribute parts across the plant.

Additionally, a reduction in material handling simplifies the scheduling procedures in manufacturing systems which, in turn, should also result in improvements in the responsiveness of the system to changes in production schedules. Consequently, the reduction in material handling may also contribute towards improvements in the mobility element of *mix flexibility* and *volume flexibility*. Furthermore, the improved responsiveness of the system to changes in production schedules should lead to improvements in the

range and mobility elements of *delivery flexibility*.

Based on the above arguments, expectations for changes in different flexibility types after the conversion of a job shop layout to a cellular layout have been summarized in Table 2.

Table 2- Impact of CM Implementation on the Six Flexibility Types

Flexibility Type	Physical grouping of Equipment	Reduced setup time	Reduced WIP inventory	Reduced material handling	Aggregate Effect
Mix	-(R)	+(M)	+(M)	+(M)	-(R), ++(M)
Changeover	-(R)	O	+(M)	O	-(R), +(M)
Modification	-(R)	O	+(M)	O	-(R), +(M)
Volume	-(R)	+(M)	+(M)	+(M)	-(R), ++(M)
Delivery	O	+(M)	+(R), +(M)	+(R), +(M)	++(R), ++(M)
Flexibility Responsiveness	*	*	*	*	*

Keys - = positive influence, ++ = strong positive influence, * = influence unknown, O = no influence - = negative influence, R = Range, M = Mobility

2.3.2. Effect of Extent of Human Factors in Cells

Apart from the direct benefits of CM that result in changes in different flexibility types over the operational time-context, the extent of the implementation of human factors in the cells -namely extent of training, team work and job enrichment in cells- may also

influence the change which is achieved in different flexibility types as a result of the implementation of CM. The following section hypothesizes the influence of extent of implementation of training, team work and job enrichment on the change in flexibility which is achieved through the CM approach.

Training

Training improves the skills and knowledge which are already possessed by the operators and provides personnel with the ability to perform new tasks and activities which are introduced in the cell environment. Researchers suggest that firms provide training to employees at the time of introduction of cells. The extent of training and the training practices themselves vary widely from company to company in terms of the type of skills which are imparted during the training. The type of training in new skills and knowledge required by the supervisors, operators and support staff varies depending upon the skill requirement of the job. This training may be highly formalized, involving off-the-job training techniques like lectures and workshops- or it may take the form of informal instruction involving such on-the-job techniques as job rotation.

Although, the effect of training of employees on flexibility may not be direct, it does enhance the effectiveness of the workforce in adapting to changes which are associated with team work and job enrichment. Logically, this should improve mix

flexibility, changeover flexibility, volume flexibility, delivery flexibility and flexibility responsiveness.

Team work

Manufacturing cells facilitate the implementation of team-based structures and provide opportunities for social interaction. This, in turn, promotes the formation of a cohesive and integrated working group (Gerwin and Kolodny, 1992), for team work requires a high degree of cooperation among the operators in performing a job. The extent of team work in various cells may differ from company to company, depending upon the type of activities which are allocated to the teams: such as -solving production problems within the cell, training new group members, task scheduling, coordinating with other groups, monitoring performance within the cell, allocating jobs within the group, scheduling tasks, and scheduling days off for group members.

The extent of team-based work structures in the cells may thus influence the change in flexibility which is achieved through CM implementation. The teams approach to work results in greater flexibility in dealing with breakdowns, schedule changes and product changes because workers cooperate closely to solve problems. Thus, team work may improve mix flexibility, volume flexibility, delivery flexibility, modification flexibility, changeover flexibility and flexibility responsiveness in the system.

Job Enrichment

The organization of work in cells may also influence the changes in flexibility which are result from CM implementation. Job enrichment is measured by the extent of job autonomy, job variety and the degree of identification of operators with the jobs which they perform (Hackman and Oldham, 1980).

The term "job autonomy" is defined as the degree to which the job provides substantial freedom, independence and discretion to the individual in scheduling the work and to determine the procedure to be used in carrying it out (Hackman and Oldham, 1980). Since, the cells facilitate greater independence and the participation of operators in decision making, the increased awareness of the cell workers about the processes in which they are involved enables them to take responsibility for planning their own activities, controlling their own processes, recognizing problems and managing their own areas efficiently. Additionally, operators in cells can also be made responsible for the day to day control and planning of work.

"Job variety" is defined as the degree to which a variety of different activities are performed by an operator in carrying out his or her work, involving the use of a number of different skills and talents (Hackman and Oldham, 1980). With increased job variety for operators, the number and type of jobs performed by an operator at a given time can

be increased or decreased as needed, thus offering considerable adaptability to variations in the product mix (Gerwin and Kolodny, 1992). Job variety therefore contributes towards improvement in the mobility and range elements of mix flexibility. The fact that the variety in the jobs of operators enables the workforce to quickly adapt to operating procedures to meet new conditions, may thus improve modification flexibility, changeover flexibility, and the flexibility responsiveness of the manufacturing system. The flexible allocation of operators in the system can facilitate quick adaption to machine breakdowns, operator absenteeism and to changes in volume and product-mix. This, in turn, may improve the volume flexibility, mix flexibility and delivery flexibility of the manufacturing system.

"Job identification" is the degree to which a job requires completion of a "whole" and identifiable piece of work -that is- doing a job from beginning to end with a visible outcome (Hackman and Oldham, 1980). Cells offer considerable opportunities for job identification to the operators (Cross, 1984).

"Job enrichment" in cells due to greater job autonomy, job variety and job identification- should thus lead to an improved responsiveness to breakdowns, schedule changes and product changes as a result of the increased involvement of the operators in their jobs and their readiness to learn new skills. Therefore, job enrichment may contribute towards improvements in mix flexibility, changeover flexibility, modification

flexibility and delivery flexibility and flexibility responsiveness.

2.4. Summary

We have suggested an *a-priori* taxonomy of six generic flexibility types in the manufacturing systems that are explored in this research: mix flexibility, modification flexibility, changeover flexibility, volume flexibility, delivery flexibility and flexibility responsiveness. In addition, a framework has been constructed in order to consider the time-context of each of the flexibility types and, within this framework, each of the six types of flexibility has been classified in the operational, tactical or strategic time context. Also each of the flexibility types has two elements: range and mobility. To analyze the change in flexibility of a manufacturing system, it is necessary to know the change achieved in practice and the change achieved in potential capabilities.

The context of this research is those applications of CM which primarily involve the relocation of existing equipment to a product-focused layout for existing products. Further, the effect of characteristics of CM on different flexibility types has been hypothesized. In addition, the influence of extent of human factors in cells -namely training, team work and job enrichment- on the change in flexibility achieved through CM implementation has also been hypothesized.

It appears that CM should contribute towards improvements in the *mobility*

elements of mix flexibility, changeover flexibility, modification flexibility, volume flexibility and delivery flexibility. While CM should also improve the *range element of delivery flexibility*, there should be a reduction in the *range elements of mix flexibility, changeover flexibility, modification flexibility and volume flexibility.*

The next chapter will develop the research question and propositions which arise from the literature review.

CHAPTER 3

RESEARCH QUESTIONS

The preceding literature review suggests that the implementation of cellular manufacturing affects different flexibility types in a manufacturing system. The research question posed in this study is motivated by a previous lack of research on the impact of implementing cellular manufacturing on the flexibility of a manufacturing system which had previously been organized as a job shop. This study seeks to address the following question:

RQ What is the effect of the implementation of CM on the following flexibility types in a manufacturing system which had previously been organized as a job shop?

- a) Mix Flexibility**
- b) Modification Flexibility**
- c) Changeover Flexibility**
- d) Volume Flexibility**
- e) Delivery Flexibility**
- f) Flexibility Responsiveness**

Apart from focusing on the impact of CM on different flexibility types, this study also attempts to explore some factors that will help in understanding relative changes in different flexibility types. For example, the relative priorities which are given to different flexibility types by the senior management and the facility should help to explain the changes that are achieved in different flexibility types. It should be noted, however, that the emphasis which is given to different flexibility types may vary from industry to industry.

Apart from the contribution of CM to flexibility, other plant practices -namely design for manufacturability, kan-ban production control, and group technology- may contribute towards changes in flexibility. This research also attempts to study the contribution of CM to each of the flexibility types versus the contribution of design for manufacturability, kan-ban production control, and group technology, to each of the flexibility types. This research also studies the extent of implementation of human factors in cells -namely training, team work and job enrichment.

Propositions

To reach an objective decision as to whether a proposition should be rejected or accepted with the help of the collected data, the propositions are expressed in null form, which implies a proposition of "no effect or greater (less)." The propositions which follow

in this section have been developed in order to investigate the impact of cellular manufacturing on different flexibility types.

Mix Flexibility

As discussed in section 2.3, CM implementation leads to reductions in setup time due to part similarities, shorter production runs as a result of reduced WIP inventory, and simplified scheduling and shopfloor control as a result of reduced material handling. This could thus reduce the average time which is required to switch production to a different model. In other words, it is expected that CM implementation improves the mobility element of mix flexibility.

In previous research on this subject, it is argued that CM reduces the range element of mix flexibility in the job shop (Hayes and Wheelwright, 1984; Vakharia and Kaku, 1993). While Hayes and Wheelwright (1984) make a conceptual statement, Vakharia and Kaku (1993) base their statement on the findings of a computer simulation study. Based on the discussion in section 2.3, it is also expected that CM should result in a reduction in the range element of mix flexibility.

The propositions to investigate the change in the mobility and the range element of mix flexibility are as follows:

#1a There is no change in the average time required to switch production from one model to another model in the manufacturing system upon conversion of a job shop layout to a cellular layout.

#1b There is no change in the variety of models produced in the manufacturing system upon conversion of a job shop layout to a cellular layout.

Changeover Flexibility

Based on the discussion in section 2.3, it can be concluded that CM should improve the responsiveness of a plant to new product introductions. This is because reduced WIP inventory results in quicker introduction of full scale production of new models in the production system, as the system can quickly complete work in progress and switch over to a new part. Moreover, product orientation in cells improves the system's ability to respond to new product introductions (Cross, 1984). Thus, it can be expected that CM improves the mobility element of changeover flexibility.

However, a CM layout may make it difficult to produce a new part that does not belong to any of the cell families because of the dedication of production equipment to cells and this should result in a reduced range element of changeover flexibility as per expectations developed in Section 2.3. The propositions to investigate changes in the

mobility and range elements of changeover flexibility are as follows:

#2a There is no change in the average time required to start a full scale production of a new model, upon conversion of a job shop layout to a cellular layout.

#2b There is no change in the variety of new models introduced by the manufacturing system upon conversion of a job shop layout to a cellular layout.

Modification Flexibility

As discussed in Section 2.3, CM should improve the mobility element of modification flexibility. This is because a CM system's reduced WIP inventory reduces the waiting time to start production after minor design changes are made to the model. In contrast, a job shop has a longer waiting time to start production due to its larger WIP inventory.

As a result of the dedication of production equipment in CM, the different types of minor changes that can be incorporated in an existing model should be fewer than those which can be incorporated into an existing model in a job shop. Thus, as expected in Section 2.3, CM should result in a reduced range element of modification flexibility when compared to that of a job shop.

The propositions to investigate changes in the mobility and the range elements of modification flexibility are as follows:

#3a *There is no change in the average time required to implement a minor design change in an existing model upon conversion of a job shop layout to a cellular layout.*

#3b *There is no change in the number of minor design changes in existing models upon conversion of a job shop layout to a cellular layout.*

Volume Flexibility

As discussed in section 2.3, CM implementation should reduce the average time which is required to introduce changes in the production levels because of reduced setup times, shorter production runs, simplified scheduling, and simpler shopfloor control. In other words, it is expected that CM implementation should improve the mobility element of volume flexibility. Although the dedication of equipment in the cells limits the maximum production level of a product (unless this has been taken into consideration by redundant equipment), excess capacity may still exist elsewhere in the system. This should limit the range of production levels in a CM system in comparison to those of a job shop system. In other words, CM should reduce the range element of volume flexibility as per the expectations developed in Section 2.3.

The propositions to investigate changes in the mobility and range elements of volume flexibility are as follows:

#4a There is no change in the average time which is required to change the production levels of models upon conversion of job shop layout to a cellular layout.

#4b There is no change in the extent of fluctuation in the production levels of different models upon conversion of a job shop layout to a cellular layout.

Delivery Flexibility

As a result of simplified production scheduling, simplified controls, and small batch sizes in CM, it is easier to make changes in the production plans in order to ensure on-time delivery of products than it is in a job shop (Cross, 1984; Welke and Overbeeke, 1988). Therefore, as discussed in section 2.3, CM implementation should improve on-time delivery performance; in other words, both the range and mobility elements of delivery flexibility should improve.

The propositions to investigate changes in the mobility and range elements of delivery flexibility are as follows:

#5a There is no change in the percentage of orders delivered on schedule upon conversion of a job shop layout to a cellular layout.

#5b There is no change in the average number of days by which delivery of a product is delayed upon conversion of a job shop layout to a cellular layout.

Flexibility Responsiveness

The impact of the implementation of CM on flexibility responsiveness could not be hypothesized in section 2.3. However, literature suggests that product familiarity and the wider skill-set of employees in the cells makes the workers more competent in managing and adapting to future changes in the product designs and manufacturing processes (Hyun and Ahn, 1992). Thus CM implementation should improve the flexibility responsiveness of the plant when compared to a job shop layout.

The proposition to investigate the impact of CM implementation on flexibility responsiveness is as follows:

#6 There is no change in the ability of the manufacturing system to adapt to future changes in product designs and manufacturing processes upon conversion of a job shop layout to a cellular layout.

CHAPTER 4

RESEARCH DESIGN

This is an exploratory study, since there has been little prior research on this topic. The research design is *ex post facto*, as there is not enough information about the independent variables and, therefore, these variables cannot be manipulated. Nevertheless, the literature search in the manufacturing field facilitated the design of the questionnaire.

This chapter describes the research methodology employed in this study. A field study was carried out in plants that had implemented cellular manufacturing (CM) in the electronics and telecommunication industry. The data was collected through a structured questionnaire. A copy of the questionnaire appears in Appendix 2.

4.1. Sampling Design

4.1.1 Population

The population for this study consisted of manufacturing companies in the electronics and telecommunication industry that had implemented CM. The firms in the electronics and telecommunication industry were selected, first, because market environment in this industry is characterized by short product life cycles and quick change and the firms in this industry are looking for ways to improve flexibility in their manufacturing systems in order to meet the competition. Secondly, CM offers an exceptional opportunity to achieve such key performance objectives in the high-tech

manufacturing as low WIP, improved quality and flexibility (Cross, 1984): Thirdly, a sample from one type of industry provides control over some of the extraneous variables and macroeconomic conditions are roughly the same for all firms in one type of industry. Finally, concentration of firms in the electronics and telecommunications industry in Ottawa area facilitated preliminary research on this topic.

The respondents were senior executives of the company in the manufacturing department such as: vice president of manufacturing, director of manufacturing or production manager. The study primarily considered senior executives since they would have a better overall perspective of changes in the performance of the manufacturing system as a result of CM implementation. Moreover, they would be more concerned about flexibility and as a result more aware of the performance indicators related to flexibility.

The selection criteria for the population was those manufacturing plants that had

- a) reorganized a majority of their production shop layouts into cells, such that each cell either produced several models of a product line or the cell produced parts with similar processing requirements:

- b) the investment in new equipment for an existing product line was not more than 20% of the total investment in equipment for that product line. This criteria was intended to minimize the impact of new equipment on the change in flexibility.

4.1.2. Sampling Selection

The sample was selected based on judgement and convenience sampling. Random

sampling was not possible because of the lack of a large identifiable population. The companies were identified using the following methods:

1. A listing of manufacturing companies in the electronics and telecommunications industry in Canada with an annual sales turnover of more than Can. \$500,000 was obtained from the Business Opportunities and Sourcing System (BOSS) of Industry Canada (I.C.). Out of eighty-two companies in the list, thirty-eight companies that could have implemented CM were identified using judgement sampling. The criterion for selection of the companies from this list was the companies that manufactured the products that were likely to be of mid-variety, mid-volume production. This is because the product lines with mid-volume and mid-variety production are highly suitable for production in cells (Bessant, 1991).
2. Two manufacturing consultants and some members of the Manufacturing Managers' Network in Ottawa were contacted to establish a liaison and encourage the identified companies to participate in the study.
3. A brief introduction to the study was also posted on the Internet in the news group "sci.engr.manufacturing", to seek involvement of the companies. However, this approach did not yield any results.

A brief introduction explaining the purpose of the study, along with a cover letter, was sent to the companies which were identified in the sample. This was followed by a phone call to enquire whether or not the company had implemented CM. If the companies met the criteria of selection, their willingness to participate in the study was solicited.

A total of thirty-two companies were contacted, out of which twenty-four had implemented CM. However, only nineteen companies agreed to participate in the study. In the end, seventeen companies responded to the questionnaire; two companies did not respond to the survey due to an inability of their respondents to spare time to answer the questionnaire.

4.2. Field Study

The field study was conducted through a structured questionnaire that was designed to elicit responses from senior manufacturing executives. A copy of the questionnaire was faxed to the companies which had agreed to participate in the study, along with a cover letter. These respondents were then contacted by telephone to clarify any ambiguities in their responses to the questionnaire. Data for this study was collected during January 1995 and February 1995.

4.3. Design of Survey Instrument

The survey instrument used for this study appears in Appendix 2. This instrument was developed based on the research in the field of manufacturing, and preliminary visits to two companies in the Ottawa area that had introduced CM. The objective of the questionnaire was to elicit information on the nature and extent of CM implementation in each company and the subsequent influence of CM on changes in different types of flexibility.

The questionnaire is divided into two sections. The aim of first section of the questionnaire was to get company-specific information on the nature and extent of cellular manufacturing operations in the company. This section also elicits information on the extent of training, team work and job enrichment in the cells. The objective of questions in the first section of the questionnaire is shown in Table 3.

Table 3- Objective of Questions in Section I of the Questionnaire

Question Numbers	Objective
1 to 5	CM operations in the company
6	Training to employees. (extent & type)
7	Level of job autonomy of operators in cells
8	Extent of variety in operators' jobs
9	Extent of operators' job as an identifiable piece of work
10 and 11	Extent of teamwork

The objective of the second section of the questionnaire was to get information on changes which were achieved in different flexibility types after the implementation of CM. The objective of questions in the second section of the questionnaire is shown in Table 4.

Table 4- Objective of Questions in Section II of the Questionnaire

Question Numbers	Objective
1 and 2	Impact of CM on different flexibility types
3	Changes in product market environment
4	Contribution of plant practices to different flexibility types
5	Changes in plant performance indicators
6 and 7	Emphasis on flexibility

Question number one is aimed to elicit information on the change achieved in parameters which indicate overall change in different flexibility types as a result of the introduction of CM. The data for overall change in different flexibility types is intended to be a reliability check of the data for change in different elements of flexibility and the contribution of CM to flexibility when compared to other plant practices. Overall change in different flexibility types is indicated by respondents' perceptions of change in their plants' ability to manage change in indicators of the respective flexibility types. For example overall change in mix flexibility is measured by the change in a plant's ability to manage the production of a variety of models as a result of the introduction of CM.

Question number two elicits information on changes which were achieved in different production parameters to indicate actual and potential changes in different flexibility types. These production parameters were conceptualized for each of the flexibility types based on existing literature in the field of manufacturing flexibility. The extent of change in these parameters indicates change in the flexibility. For example,

change in the number of products produced indicates actual change in the range element of mix flexibility. The respondents were asked to indicate their perception of the actual and potential change in each of these indicators on a five-point Likert scale. Table 5 shows the indicators which were used to measure changes in each of the flexibility types that have been previously identified in the taxonomy.

Question number three was intended to elicit information on changes in the market environment since the introduction of CM. As the market environment plays a significant role in determining emphasis on different flexibility types, this data is intended to explore possible reasons for difference in emphasis which was placed on different flexibility types. Question number four was intended to compare the contribution of plant practices to the different flexibility types under study. This is because plant practices other than CM (such as -design for manufacturability, group technology and kan-ban production control) which were implemented at the same time or after the implementation of CM, could also have affected different types of flexibility. Question number five was exploratory, attempting to understand changes in overall plant performance indicators, such as lot size, work in progress turns, machine idle times, and group-coordination, as a result of CM introduction. Question number six in the questionnaire helped to identify the importance placed by the plant on different types of flexibility. Question number seven was designed to reveal the priorities for different flexibility types which are perceived by the senior management.

Table 5- Indicators for Different Flexibility Types Used in the Questionnaire

Flexibility Indicators	Flexibility Element	Question Number
<i>Mix Flexibility</i> Ability to manage production of diverse models Setup time to switch production Variety of models produced Diversity in design among various models	Overall Mobility Range Range	1(a) 2(b) 2(a) 2(c)
<i>Changeover Flexibility</i> Ability to manage production of new models Startup time for full scale production of new models Number of new models produced Diversity in design of new models	Overall Mobility Range Range	1(b) 2(f) 2(d) 2(e)
<i>Modification Flexibility</i> Ability to manage introduction of minor design changes in existing models Time to introduce minor design changes Average number of minor design changes in existing model	Overall Mobility Range	1(c) 2(g) 2(h)
<i>Delivery Flexibility</i> Ability to manage timeliness in delivery of products Delay time for products delivered late Percentage of orders delivered on schedule	Overall Mobility Range	1(e) 2(l) 2(k)
<i>Volume Flexibility</i> Ability to manage fluctuation in production levels Time to change the production level Amount of fluctuation in production levels	Overall Mobility Range	1(d) 2(j) 2(i)
<i>Flexibility Responsiveness</i> Ability to manage adaptation of facility to future changes in product designs and manufacturing processes	Overall	1(f)

The second section of the questionnaire was intended to be answered separately by two respondents. One of the respondents was targeted to be a senior manufacturing executive in the firm -such as the vice president of manufacturing, director of manufacturing, or a production manager who is responsible for overall production

activities. The second respondent was to be a manufacturing executive familiar with overall production operations in the plant.

Validity and Reliability

Validity refers to the crucial relationship between a concept and its indicators. It is the degree to which the instrument measures the constructs for which it is intended. For most managerial concepts, there are no rules for specifying the complete domain and there are no rigorous methods for assessing the content validity. Only the subjective evaluation of knowledgeable individuals ensures that relevant items are included and irrelevant items are excluded from the scale (Gerwin and Kolodny, 1992).

As regards the validity, the survey instrument was developed after interviews with two senior personnel in the industry and feedback by four academics. The results of their input were used to ensure clarity of the questions, ease of comprehension, and to eliminate any ambiguities.

The question of the reliability of an instrument concerns whether or not the scale consistently indicates what is being measured. Since indicators are based on the perceptions of individuals and the scales are subjective, it was intended to investigate the reliability of the study through a check for inter-rater consistency of two respondents for the second section of the questionnaire. However, only one company responded with two responses for Section II. The rating of the two respondents was found to be consistent.

The maximum difference in rating was limited to one point on a five point Likert scale. Moreover, since the respondents from other firms were in senior positions in manufacturing and had considerable experience in manufacturing, the responses in the questionnaire can be considered to be reliable.

Also multiple questions were asked in the questionnaire to measure the same concept and ensure reliability of the responses. Prior to the analysis of the data, responses within each section of the questionnaire were analysed for any contradictions. If any contradictions were found, respondents were contacted by telephone to confirm the responses and to elicit the reason for these differences. The data was analysed quantitatively, using the SPSS for Windows software package.

CHAPTER 5

RESULTS

This chapter examines the results of the study. The results are presented in the following sections: section one discusses the demographic profile of the participant companies; section two discusses the characteristics of CM implementation in the participating firms; section three reveals the emphasis placed on flexibility by the senior management and the facility; the fourth section analyzes the impact of implementation of CM on different flexibility types; section five discusses the contribution of plant practices to changes in different flexibility types; section six presents the impact of the implementation of CM on plant performance indicators; section seven summarizes the extent of the implementation of human factors in cells - namely training, team work and job enrichment; finally, section eight summarizes the findings of the study.

5.1. Demographic Profile

5.1.1. Size of the Respondent Companies

The firms that participated in the study can be classified as medium to large sized, based on the number of employees in the plant and the annual sales revenue. The average annual sales revenue of the sample was Cdn. \$ 365 million, with a minimum of Cdn. \$ 15 million and maximum of Cdn. \$ 2500 million. The average workforce size of

the sample was 746 employees; the minimum workforce size in a plant was 86 and maximum workforce size was 3500 employees. Table 6 presents a summary of the size of the respondent companies in the sample.

Table 6 - Size of Respondent Companies (N=17)

Company size indicators	
Number of Employees	
Mean	746
Minimum	86
Maximum	3500
Less than 500	9
Greater than 500	8
Annual Sales Revenue (In million Cdn. \$)	
Mean	365
Minimum	15
Maximum	2500
Less than 100	7
From 100 to 500	8
Greater than 500	2

5.1.2. Profile of Respondents

The respondents to the questionnaire were senior manufacturing executives of the firms. Table 7 presents the statistics for the respondents in terms of their experience in manufacturing and their years of association with their respective companies.

Table 7 - Respondent Statistics (N=17)

Respondent's	Mean	Minimum	Maximum
Tenure of employment with the company (Number of years)	17	6	30
Experience in manufacturing (Number of years)	18	7	30

The respondents to the questionnaire occupied senior positions in the manufacturing field such as -vice president manufacturing, director manufacturing or plant manager. They all had considerable experience in the manufacturing field ranging from a minimum of seven years to a maximum of thirty years, with an average of eighteen years. The individual respondents had all been working with their respective firms for a considerable period of time and were involved in the implementation of CM in their plants. The average tenure of employment of the respondents with their respective companies was seventeen years, with a minimum of six years and a maximum of thirty years. The long association of respondents with their companies ensured that they were aware of the changes in the manufacturing systems from an overall systems perspective.

5.2. Cellular Manufacturing Characteristics of the Participating Firms

The extent of cellularization and characteristics of cells such as -number of employees in a cell, type of equipment in the cells and the types of manufacturing

activities carried out in the cells- varied from company to company.

5.2.1. Extent of Cellularization

The plants in the sample had a high level of cellularization. The extent of the cellularization of plant operations was measured by the fraction of total machine hours in the plant which were expended in the cells and the percentage of each plant's total production in terms of the variety of parts which are produced in the cells (Hyer and Wemmerlov, 1988).

Many firms in the sample (75%) had more than sixty percent of their total production hours spent in cells. The average percentage of the total number of parts produced within the cells was in the range of 80% - 90% of total plant production. This implies that the sample population consisted of those plants which had converted the operations into cells to a considerable extent.

5.2.2. Characteristics of Cells

The number of manufacturing cells in the firms in the sample ranged from two to forty, with a population average of ten cells per company. All cells were manned cells with an average of ten operators per cell.

Manufacturing activities carried out in the assembly cells were mainly product assembly, mechanical assembly of systems, PCB assembly, testing and packaging. In contrast, manufacturing activities carried out in the process cells were mainly surface

mounting, wave soldering and welding.

Most of the equipment in the process cells consisted of such computerized numerically controlled machines (CNC) such as -surface mount machines and wave soldering machines. The equipment in the assembly cells consisted mainly of hand tools, specific test benches and personal computers for software loading. The majority of the cells were formed using existing equipment for existing products but, in some of the cases, new equipment was purchased to set up cells for new product lines.

5.3. Emphasis on Flexibility

The market environment plays a significant role in determining the emphasis on different flexibility types. This section describes the emphasis which is placed on different flexibility types by the senior management (Section II, Q.7), and the importance which is given to different flexibility types for the production facility (Section II, Q.6). Before analyzing the emphasis on different flexibility types, one should consider changes in the market environment of the electronics and telecommunication industry as they are perceived by the participant firms. In the study, the respondents were asked to list changes in the market environment which demanded changes in the flexibility (Section II, Q.3).

Table 8 presents the summary of these changes in the market environment indicators which facilitate understanding the importance of different types of flexibility in the electronics and telecommunication industry.

Table 8- Changes in Market Environment (N=17)

Market environment indicators in terms of increased need for:	% responses
Delivery of products on time	93.8%
Quick introduction of new models	93.8%
Meeting frequent fluctuations in demand	93.8%
Wide variety of models	62.5%
Frequent changes in product design	56.3%

Overall, the results suggest an increased need for all types of flexibility. Over ninety-three percent of the firms thought they must deliver products on schedule, indicating a need for improved delivery flexibility. More than ninety-three percent of the firms in the sample saw the need for a quicker introduction of new products, which required higher changeover flexibility. Also, most of the respondent firms (93.8%) felt higher volatility in market demand, which required higher volume flexibility. For the respondent firms, change in the need for a broader product line and the frequency of product design changes was not as critical as the above three dimensions. From the results, it seems that delivery flexibility, changeover flexibility and volume flexibility are more critical in the electronics and telecommunication industry to respond to changes in the market environment.

5.3.1. Senior Management's Perspective

Table 9 presents the Senior Management's perception of the priorities for flexibility types. The flexibility types are ranked on the basis of mean score for priority rankings.

Table 9- Priority Rankings for Different Flexibility Types by Senior Management (N=17)

Flexibility Type	Rank by Mean	Mean	Std. Dev.	% of responses for 5 & 6
Delivery	1	5.71 ^{***}	0.99	94.1%
Changeover	2	4.88 ^{**}	1.27	58.9%
Flexibility Responsiveness	3	4.71	1.69	70.6%
Volume	4	4.59	1.46	58.8%
Modification	5	4.47	1.5	58.8%
Mix	6	4.29	1.65	58.8%

Six-point scale used 6=Highest Priority, 1=Lowest Priority. ^{**} $\alpha \leq 0.01$. ^{***} $\alpha \leq 0.001$.

Senior management placed the highest priority on delivery flexibility, followed by changeover flexibility. Over ninety-four percent of respondents ranked delivery of products on schedule to the customer among the top two rankings (5 and 6) on a six-point¹ scale of different flexibility types. Frequent introduction of new products was the second highest priority for the senior management, with a mean score of 4.88. More than fifty-eight percent of respondents gave it the top two rankings (5 and 6) on a six-point scale. These results also revealed that the t-statistics for the mean scores for delivery flexibility priority and changeover flexibility priority were significantly greater when compared to 4 as the reference point ($\alpha \leq 0.001$). The average scores for priority ranking for other flexibility types show that these flexibility types were also a high priority for the senior management (minimum mean score is 4.29). The t-statistics for these flexibility types did not reveal any significant difference in the mean score when compared to 4 as

¹ A six point scale was used in this question as the respondents were asked to rank the priorities given to six flexibility types.

the reference point. However, the mean scores were significantly higher when compared to 3 as the reference point. Also, there was no statistically significant difference between mean scores for delivery flexibility and changeover flexibility. Senior Management's emphasis on delivery and changeover flexibility is consistent with changes in the market environment in the electronics and telecommunication industry which placed greater emphasis on the delivery of products on schedule and also emphasizes shorter product life cycles.

5.3.2. Plant Perspective

The importance of different flexibility types for the facility may influence the change which is achieved in different flexibility types. Also there may be a difference in the emphasis of senior management and the facility on different flexibility types. The data on the importance of flexibility for the facility was intended to illustrate the difference in perspectives of senior management and the plant on the importance of different flexibility types. Table 10 presents a summary of results, indicating the importance of different types of flexibilities for the facility.

Table 10- Importance of Different Flexibility Types for the Facility (N=17)

DESCRIPTION Flexibility Type	Rank by Mean	Mean	Std. Dev.	% of responses for 4 & 5
Delivery	1	4.94***	0.24	94.1%
Changeover	2	4.53***	0.72	88.2%
Modification	3	4.47***	0.51	100%
Volume - Monthly Change	4	4.24***	0.97	76.4%
Mix	5	4.18***	1.07	82.4%
Volume - Weekly Change	6	3.88	1.32	76.5%
Flexibility Responsiveness	7	3.35	1.32	47%
Volume - Daily Change	8	3.18	1.32	41.2%

Five-point scale used 5=Extremely Important, 1=Not Important, ** $\alpha \leq 0.01$, *** $\alpha \leq 0.001$

The firms placed highest priority on the delivery flexibility of the plant. The mean score for the importance of the plant's ability to deliver products on schedule was found to be significantly greater than 3 ($\alpha \leq 0.001$). Over ninety-four percent of respondents rated the plant's ability to deliver products on schedule as considerably important or extremely important (4 or 5) on a five-point scale. The emphasis of the facility on delivering its products on time conforms with the finding that senior management places highest priority on delivery flexibility. Also, the market environment requires greater emphasis on reliability in the timely delivery of products.

The importance of changeover flexibility, indicated by the ability of the facility to frequently introduce new models, was also ranked high by the respondent firms. Most of the respondents (88.2%) regarded it as considerably important to extremely important

(4 or 5) on a five-point scale with a mean score of 4.53 ($\alpha \leq 0.001$, when compared to 3 as the reference point). This finding is in conformity with senior management's high priority on quickly introducing new products and also conforms with a greater emphasis in the market on frequently introducing new products.

These results also reveal that the respondent firms considered modification flexibility to be significantly important for their plants, indicated by the plant's ability to introduce minor changes in the existing products. This indicator was statistically significant ($\alpha \leq 0.001$) with a mean score of 4.47. All of the respondents ranked their plants' ability to introduce minor design changes as either considerably important or extremely important (4 or 5).

It can also be observed that the mix flexibility of plants was considered significantly important by the respondents, with a mean score of 4.18 ($\alpha \leq 0.001$). Over eighty-two percent of the firms regarded their plant's ability to produce a wide variety of models as either considerably important or extremely important (4 or 5 rank on a five-point scale).

One interesting result of this survey is the difference in the relative ranking for flexibility responsiveness priority as perceived by senior management and the importance of flexibility responsiveness for the production facility relative to other flexibility types. Flexibility Responsiveness was ranked third by the senior management while it was regarded as least important for the facility compared to other flexibility types. The probable explanation for this variation is that, while, the focus of the senior management

is strategic, the plant itself is focused more towards more immediate operational priorities.

5.4. Impact of CM on Flexibility

In this section, the effect of CM on different flexibility types is discussed. Different production parameters were identified through the literature search. The change in each of these parameters indicates changes in a specific type of flexibility.

The data collected was mostly quantitative, although there were some qualitative responses. Descriptive statistics such as mean, standard deviations and relative / absolute frequencies by category were used. All the quantitative scores for changes in different flexibility types were calculated on a five-point Likert scale. The respondents were asked to indicate changes in these flexibility indicators on a five-point scale from 1 to 5, with 3 (mid point of the scale) indicating no change, while 1 indicated a considerable decrease and 5 indicated a considerable increase in the indicator (Section II, Q.1 and 2). Due to a dearth of appropriate non parametric tests for analysis, Student t-statistics were used to determine the statistical significance of mean observations, indicating the extent of change in flexibility as a result of CM implementation. A Student t-test was performed with 3 as the reference point, in order to determine whether the mean was significantly greater than the mid-point of the scale. The propositions developed in Chapter 3 to investigate the change in different flexibility types were accepted or rejected based on the results of the t-test. The small sample size limits the conclusions that can be drawn from the results.

Table 12 presents the mean of actual and potential changes in indicators of

different flexibility types as a result of CM introduction. Since a decrease in the value of the indicators to measure the mobility element of different flexibility types indicates an increase in the mobility element, the scale shown in Table 11 for the mobility element has been adjusted accordingly.

The averages for potential changes in flexibility were numerically greater than the averages for actual changes. The results of the t-tests however, show that the differences for any of the pairs of actual and potential changes in flexibility were not significant statistically. One manager remarked that the numerical difference could be attributed to managers' perception that there could be an improvement in different flexibility types in the future as a result of an improvement in plant practices. The following sections will discuss the actual change in indicators for each of the flexibility types.

Table 11- Means of Changes in Different Flexibility Types as a Result of CM Implementation.
(Sample size is shown in parenthesis)

Elements Flexibility Types	Overall	Range		Mobility	
		Potential	Actual	Potential	Actual
MIX	3.82** (17)	4.12	3.71*** (17)	4.25	4.12*** (16)
CHANGEOVER	4.12*** (17)	4.00	3.58** (17)	4.20	4.11*** (15)
MODIFICATION	3.82*** (17)	3.47	3.32 (15)	4.06	3.76** (17)
VOLUME	3.82** (17)	3.87	3.67* (16)	4.25	4.06*** (16)
DELIVERY	4.06*** (17)	4.38	4.06*** (16)	4.36	4.07*** (16)
FLEXIBILITY RESPONSIVENESS	4.00** (16)				

Five-point scale used. 5=Considerable Increase, 1=Considerable Decrease. * $\alpha \leq 0.05$ ** $\alpha \leq 0.01$ *** $\alpha \leq 0.001$

5.4.1. Mix Flexibility

Over seventy percent of the firms improved their ability to manage the production of a wide variety of products as a result of CM introduction. The mean for this variable was 3.82 (t-statistics significant at $\alpha \leq 0.01$ compared to 3 as the reference point), with more than seventy percent of the respondents finding an increase (rating of 4 or 5).

Table 12 presents the change in mix flexibility indicators as a result of CM implementation.

Table 12 - Actual changes in Mix Flexibility

Indicators	Flexibility Element	Mean	Std. Dev.	% of responses
Ability to manage production of diverse models (N=17)	Overall	3.82**	0.95	70.6%
Setup time to switch production (N=17)	Mobility	1.88***	0.62	87.5%
Variety of models produced (N=16)	Range	3.71***	0.85	58.8%
Diversity in design among different models (N=15)	Range	3.40	0.84	40%

Five-point scale used: 5=Considerable Increase, 1=Considerable Decrease. ** $\alpha \leq 0.01$ *** $\alpha \leq 0.001$

The following proposition was tested in order to understand the impact of CM implementation on mobility element of mix flexibility:

#1a *There is no change in the average time required to switch production from one model to another model in the manufacturing system upon conversion of a job shop layout to a cellular layout.*

This proposition can not be accepted because results reveal that the mean score for the change in setup time to switch production was 1.88 ($\alpha \leq 0.001$). Analysis suggests that there is a reduction in the average time to switch production from one model to another upon conversion to a cellular layout. Over eighty-seven percent of the firms observed a

reduction in the set up time which is required to switch production to a different model. In other words, plants improved the mobility element of mix flexibility upon conversion to a cellular layout. This finding is consistent with that of Wemmerlov and Hyer (1989), who found that CM results in a reduction in setup time. This result is in conformity with the list of expectations in section 2.3.

The proposition to test the change in the range element of mix flexibility is as follows:

#1b There is no change in the variety of models produced in the manufacturing system upon conversion of a job shop layout to a cellular layout.

The mean score for change in the variety of models which were produced upon conversion to a cellular layout was 3.71 ($\alpha \leq 0.001$). Therefore, the proposition can be rejected. This shows that firms observed an increase in the variety of models which are produced as a result of conversion to a cellular layout. This finding is inconsistent with that of Vakharia and Kaku (1993), that there is a reduction in the range element of mix flexibility upon conversion to a cellular layout is converted to a job shop layout. (Note that Vakharia and Kaku's analysis was based on the results of a computer simulation.) Also, this finding is contrary to the expectation in Section 2.3, wherein it was expected that there should be a reduction in the range element of mix flexibility.

One interesting finding is that, whereas more models were produced after conversion to a cellular layout, the diversity in the design of models did not change. The mean score

indicating change in diversity in design among different models was 3.40, but t-statistics were not found to be significant when compared to 3 as the reference point. This implies that the models introduced in cells had a high similarity in design.

5.4.2. Changeover Flexibility

Table 13 presents results which indicate changes in changeover flexibility. The results show that plants improved their ability to manage the production of new models (mean=3.82, $\alpha \leq 0.001$). Over seventy percent of the firms observed some increase to a considerable increase (4 or 5) in their ability to manage the production of new models after the introduction of CM, indicating an increase in changeover flexibility.

Table 13 - Actual changes in **Changeover Flexibility**

Indicators	Flexibility element	Mean	Std. Dev.	% of responses
Ability to manage production of new models (N=17)	Overall	4.12***	0.86	82.4%
Startup time for full scale production of new models (N=17)	Mobility	1.89***	0.64	86.7%
Number of new models produced (N=15)	Range	3.58**	0.79	53%
Diversity in design of new models (N=15)	Range	3.40	0.83	33.3%

Five-point scale used 5=Considerable Increase 1=Considerable Decrease ** $\alpha \leq 0.01$ *** $\alpha \leq 0.001$

The following proposition tested change in the mobility element of changeover flexibility:

#2a *There is no change in the average time required to start a full scale production of a new model, upon conversion of a job shop layout to a cellular layout.*

The results of the t-test imply that this proposition can be rejected, as the mean score indicating change in startup time was statistically significant (Mean Score = 1.89, $\alpha \leq 0.001$) when compared to 3 as the reference point. Over eighty-six percent of the firms reduced the time needed to start production of a new product as a result of conversion to a cellular layout. As the reduction in startup time indicates an increase in the mobility element of changeover flexibility, it can be said that the firms achieved an increase in the mobility element of changeover flexibility after the introduction of CM. This result is consistent with the expectation developed in section 2.3.

The following proposition was tested to determine change in the range element of changeover flexibility:

#2b *There is no change in the variety of new models introduced by the manufacturing system upon conversion of a job shop layout to a cellular layout.*

This proposition can be rejected, as the results show that the mean score for the change in the number of new models which are introduced after conversion to a cellular layout from a job shop layout was 3.58 and the t-statistics was significant ($\alpha \leq 0.01$) when compared to 3 as the reference point. On the basis of this analysis, it can be concluded

that the firms improved their range element of changeover flexibility after the implementation of CM. This result is contrary to the expectation in section 2.3 that there will be a reduction in the range element of changeover flexibility due to the physical grouping of equipment in cells.

The results show that there was no change in the diversity in design of the new models which were introduced after conversion to a cellular layout. This implies that the new models which were introduced after conversion to a cellular layout were similar in design.

5.4.3. Modification Flexibility

The plants improved their ability to manage the introduction of minor design changes in the existing products, indicating an increase in their modification flexibility. Table 14 presents changes in the indicators for modification flexibility after the introduction of CM. The mean score for this indicator was 3.82 with the t-statistics significant at $\alpha = 0.001$. Over eighty-two percent of the firms observed an increase (ratings 4 and 5) in their ability to manage the introduction of minor design changes in their existing products.

Table 14 - Actual changes in **Modification Flexibility**

Indicators	Flexibility element	Mean	Std. Dev.	% of responses
Ability to manage introduction of minor design changes in existing models (N=17)	Overall	3.82***	0.88	64.7%
Time to introduce minor design changes (N=17)	Mobility	2.24**	0.9	64.7%
Average number of changes in existing design of a model (N=15)	Range	3.32	0.66	33.3%

Five-point scale used: 5=Considerable Increase, 1=Considerable Decrease; ** $\alpha \leq 0.01$, *** $\alpha \leq 0.001$

The following proposition tests the mobility element of modification flexibility:

#3a *There is no change in the average time required to implement a minor design change in an existing model upon conversion of a job shop layout to a cellular layout.*

Analysis reveals that there was a reduction in the average time required to implement minor design changes in existing models (Mean Score=3.76, $\alpha \leq 0.01$) and, therefore, the proposition can be rejected. It can be concluded that there is an increase in the mobility element of modification flexibility after the introduction of CM. This result is consistent with the expectation which was developed in Section 2.3, that CM should improve the mobility element of modification flexibility.

The following proposition tests change in the range element of modification flexibility:

#3b *There is no change in the number of minor design changes in existing models upon conversion of a job shop layout to a cellular layout.*

The results reveal that the above proposition can not be rejected: the mean score for change in the number of minor design changes in the existing models was 3.33 but t-statistics was not found significant. It can thus be said that there was no change in the range element of modification flexibility. This result is contrary to the expectation in Section 2.3, that the physical grouping of equipment in CM should lead to a reduction in the range element of modification flexibility.

5.4.4. Volume Flexibility

Over seventy percent of the respondent firms improved their plant's ability to manage fluctuation in production levels due to changes in market demand as a result of CM introduction. The mean score for this indicator was 3.82, significantly greater than 3 ($\alpha \leq 0.01$). More than seventy percent of the firms observed an increase in their plant's ability to operate at varying levels of production. Table 15 presents changes in different indicators measuring actual change in the different elements of volume flexibility.

Table 15 - Actual changes in Volume Flexibility

Indicators	Flexibility element	Mean	Std. Dev.	% of responses
Ability to manage fluctuation in production levels (N=17)	Overall	3.82**	1.07	70.6%
Amount of fluctuation in production levels (N=16)	Range	3.67*	1.05	56.4%
Time for the facility to change the production level (N=16)	Mobility	1.94***	0.68	81.3%

Five-point scale used 5=Considerable Increase, 1=Considerable Decrease. * $\alpha \leq 0.05$, ** $\alpha \leq 0.01$, *** $\alpha \leq 0.001$.

The following proposition investigates change in the mobility element of volume flexibility.

#4a *There is no change in the average time which is required to change the production levels of models upon conversion of a job shop layout to a cellular layout.*

The results show that the above proposition can be rejected because there was a reduction in the average time required to change the production levels of models in the facility. The mean score of this indicator was 4.06 and t-statistics was significant at $\alpha \leq 0.01$. Over eighty-seven percent of the respondents observed a reduction in the time required to adapt their manufacturing systems to changes in demand. This observation was consistent with the expectation in Section 2.3, that the mobility element of volume flexibility in a plant shall improve as a result of CM implementation.

The following proposition tests change in the range element of volume flexibility:

#4b *There is no change in the extent of fluctuation in the production levels of different models upon conversion of a job shop layout to a cellular layout.*

The results imply that the above proposition can be rejected because it was found that there was an increase in the extent of fluctuation in the production levels for different models. The mean score for the indicator was 3.67, significantly greater when compared to the mid point of the scale ($\alpha \leq 0.05$). It can be concluded that the range element of volume flexibility of the plants improved as a result of CM implementation. Over fifty-six percent of the firms observed an increase in the fluctuations of their production levels.

5.4.5. Delivery Flexibility

It was found that the ability of the plants to manage the delivery of products on schedule improved after the introduction of CM. Table 16 presents a summary of changes in the indicators which measure actual changes in delivery flexibility. The mean score for the indicator measuring change in the plant's ability to manage the delivery of products on time was 4.06 ($\alpha \leq 0.001$). Over eighty-eight percent of the respondents observed an increase (ratings 4 and 5) in their plants' ability to manage on-time delivery of products.

Table 16 - Actual changes in **Delivery Flexibility**

Indicators	Flexibility element	Mean	Std. Dev.	% of responses
Ability to manage timeliness in delivery of products (N=17)	Overall	4.06***	0.90	88.2%
Percentage of orders delivered on schedule (N=16)	Range	4.06***	0.77	87.5%
Delay time for products delivered late (N=16)	Mobility	1.93***	0.47	92.9%

Five-point scale used 5=Considerable Increase, 1=Considerable Decrease, ** $\alpha \leq 0.01$, *** $\alpha \leq 0.001$.

The following proposition tested the range element of delivery flexibility:

#5a *There is no change in the percentage of orders delivered on schedule upon conversion of a job shop layout to a cellular layout.*

The findings reveal that the above proposition can be rejected, as the mean score for change in the percentage of orders delivered on schedule was 4.06 ($\alpha \leq 0.001$). Over eighty-seven percent of the firms observed an increase in the percentage of their orders delivered on schedule. It can thus be concluded that there is an improvement in the range element of delivery flexibility after the implementation of CM. This result is in conformity with the expectation in section 2.3 that CM should improve the range element of delivery flexibility.

The following proposition investigates change in the mobility element of delivery flexibility:

#5b *There is no change in the average number of days by which delivery of a product is delayed upon conversion of a job shop layout to a cellular layout.*

Analysis reveals that the above proposition can be rejected because the mean score for the reduction in the delay of products delivered late was 4.07 with the t-statistics significant at $\alpha \leq 0.001$. Over ninety-two percent of the firms achieved an increase in the mobility element of delivery flexibility. This observation is in conformity with the expectation in section 2.3 that CM should improve the mobility element of delivery flexibility. The mean scores for production parameters, indicating changes in delivery flexibility, are high and reflect an increase in delivery flexibility as a result of the implementation of CM. This conforms with a high priority on delivery flexibility on the part of the senior management and the high degree of importance which is placed by the plant on the delivery of their products as per schedule.

5.4.6. Flexibility Responsiveness

Table 17 presents changes in the flexibility responsiveness indicators of the plant after the introduction of CM. Over seventy-five percent of the respondent firms improved their flexibility responsiveness as a result of CM introduction. This is indicated by the plants' ability to adapt to changes in product designs and manufacturing processes in the future.

Table 17- Actual Changes in Flexibility Responsiveness

Indicators	Mean	Std. Dev.	% of responses
Ability to manage adaptation of facility to future changes in product designs and manufacturing processes (N=16)	4.00***	0.89	75.1%

Five-point Likert scale used 5=Considerable Increase, 1=Considerable Decrease, ** $\alpha \leq 0.01$, *** $\alpha \leq 0.001$.

The following proposition investigates change in flexibility responsiveness of the plants:

#6 *There is no change in the ability of the manufacturing system to adapt to future changes in product designs and manufacturing processes upon conversion from a job shop layout to a cellular layout.*

This proposition can be rejected, as the results show a significant improvement in plants' ability to manage adaptation to future changes in product designs and manufacturing processes. The mean score for this variable was 4 with t-statistics significant at $\alpha \leq 0.001$.

5.5. Contribution of Plant Practices to Changes in Flexibility

Some of the plants implemented plant practices other than CM such as -design for manufacturability, group technology and kan-ban production control- at the same time as CM. Apart from the contribution of CM to flexibility, these plant practices may have

contributed towards changes in flexibility. This study also attempted to investigate the contribution of CM to the changes in different flexibility types versus the contribution of other plant practices.

The respondents were asked to rate their perception of the contribution made to different flexibility types by the four plant practices: design for manufacturability, group technology, kan-ban production control and cellular manufacturing (Section 3.1, Q.4). A five-point Likert scale was used to elicit the responses with 1 representing some contribution and 5 representing a significant contribution to the parameter, indicating a specific type of flexibility. A Student t-test was performed with 3 as the reference point in order to determine whether the mean was significantly greater (smaller) than the mid-point of scale 3.

Table 18 presents a summary of the contribution of plant practices to change in the indicators for different flexibility types.

2 OF 2

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Table 18 - Contribution of Plant Practices to Changes in different Flexibility Types

Plant Practices Flexibility	Cellular Manufacturing (N=13)	Design for Manufacturability (N=13)	Group Technology (N=8)	Kan-ban (N=11)
MIX	3.71* (57.1%)	3.00 (38.5%)	3.62 (50.0%)	2.54 (36.4%)
CHANGEOVER	3.57 (57.23%)	3.08 (30.8%)	2.62 (12.5%)	2.54 (09.1%)
MODIFICATION	3.43 (64.3%)	3.31 (46.2%)	2.25 (25.0%)	2.54 (18.2%)
VOLUME	4.14*** (78.6%)	2.61** (47.7%)	3.12 (50.0%)	3.36 (54.6%)
DELIVERY	4.29*** (78.6%)	3.00 (38.5%)	2.87 (3.5%)	3.64 (35.2%)

Five-point scale: 5= Large contribution, 1= no contribution * $\alpha \leq 0.05$ ** $\alpha \leq 0.01$ *** $\alpha \leq 0.001$

From the results, it seems that CM made a major contribution to an improvement in different flexibility types, as compared to the contribution made by other plant practices.

Table 19 presents a summary of the contribution of CM to different flexibility types.

Table 19- Contribution of Cellular Manufacturing to Different Flexibility Types (N=13)

Indicators	Rank By Mean	Mean	Std. Dev.	% of responses for 4 & 5
Delivery	1	4.29***	0.83	78.6%
Volume	2	4.14***	0.77	78.6%
Mix	3	3.71*	1.27	57.1%
Changeover	4	3.57	1.22	57.2%
Modification	5	3.43	1.40	64.3%

Five-point scale used 5=Large contribution, 1=No Contribution, * $\alpha \leq 0.05$, ** $\alpha \leq 0.01$, *** $\alpha \leq 0.001$

CM contributed greatly to delivery flexibility, with a mean score of 4.29 ($\alpha \leq 0.001$). Over seventy-eight percent of the firms observed an above average contribution of CM to delivery flexibility. This finding also supports the results in Section 5.4. that the plants improved their delivery flexibility as a result of the introduction of CM. These findings are also justified by the results in Section 5.3. that senior management gives highest priority to delivery flexibility compared to other flexibility types. Also, at the plant level, delivery flexibility was given highest importance.

It was found that CM also contributed greatly to volume flexibility and mix flexibility as compared to other plant practices. These results also support the findings in section 5.4. that plants achieved an improvement in indicators of volume flexibility and mix flexibility. All other plant practices had an average contribution to different flexibility types (average ratings for indicators between 2 and 3 on a five-point scale).

Statistical analysis shows that Design for Manufacturability resulted in a reduction of indicators for volume flexibility. The mean score indicating contribution of design for

manufacturability to volume flexibility was 2.61 and t-statistics was found to be significantly greater when compared to the mid point of scale ($\alpha \leq 0.001$).

5.6. Impact of CM on plant performance indicators

Table 20 presents a summary of the effect of CM implementation on various plant performance indicators.

The results show that over eighty-eight percent of respondent firms considerably reduced the travel times for jobs between the workstations (job flow time) and waiting time for jobs between the work stations (job waiting time), since the mean scores for the variables of job flow time and job waiting time were 4.41 and 4.25 respectively ($\alpha \leq 0.001$). Over eighty-eight percent of the respondent firms observed a decrease in the job flow times and over ninety-three percent of the respondent firms observed a reduction in job waiting time. A reduction in job flow time and job waiting time results in reduced throughput time. As discussed in Section 2.3, this should contribute towards improvements in the mobility element of different flexibility types.

The results reveal that there was statistically significant reduction in lot size as a result of CM implementation. As discussed in Section 2.3, lot size reduction should contribute towards the mobility element of mix flexibility, volume flexibility and delivery flexibility.

Table 20 - Influence of Cellular Manufacturing on Plant Performance Indicators

Plant Performance Indicators	Rank by Mean	Mean	Std. Dev.	% of responses for 1 & 2
Reduction in Job Flow Time (N=17)	1	4.41***	0.87	88.2%
Reduction in Job Waiting Time (N=16)	2	4.25***	0.77	93.8%
Reduction in Lot size (N=17)	3	4.00**	1.17	76.5%
Group Coordination (N=17)	4	4.00***	1.17	76.5%
Operator Utilization Time (N=16)	5	3.94***	0.93	81.3%
Resource Pooling(N=17)	6	3.88**	1.27	76.5%
Reduced New Product Launch Time (N=16)	7	3.81**	0.91	75.1%
Machine Utilization Time (N=16)	8	3.75**	1.06	75.1%
Ease in Production Control (N=17)	9	3.65*	1.32	64.7%
Improved Scheduling (N=17)	10	3.59	1.28	64.7%
Material Handling Reduction (N=16)	11	3.50	1.37	56.3%
Tooling Setup Cost Reduction (N=15)	12	3.33	0.98	53.4%
Stock Inventory Turnover (N=17)	13	3.29	1.40	52.9%
WIP Turnover (N=17)	14	3.29	1.11	46.7%
Stability in Production Costs (N=16)	15	3.20	1.08	33.4%
Reduction in Downtime (N=15)	16	3.00	1.00	46.7%

Five-point scale used 5=Increased a lot, 1=Decreased a lot. * $\alpha \leq 0.05$, ** $\alpha \leq 0.01$, *** $\alpha \leq 0.001$

The results show that CM implementation improved coordination within a work group (Group Coordination) in the plant since the average score for this variable was 4.0 ($\alpha \leq 0.001$). More than seventy-six percent of the firms observed an increase in group coordination as a result of CM implementation.

The respondent firms also improved the utilization of their operators and pooling of their resources within their plants. The average score for these variables was 3.94 and

3.88 respectively ($\alpha \leq 0.001$). Over eighty-one percent of firms observed an increase in operator utilization time. Over seventy-six percent of the firms observed an increase in their resource pooling due to their implementation of CM.

The companies also observed a reduction in their new product launch times as a result of CM implementation. The average score for this variable was 3.81 ($\alpha \leq 0.01$). Since reduction in new product launch time indicates an increase in the mobility element of changeover flexibility, this result supports the findings in Section 5.4. that there is an improvement in the mobility element of changeover flexibility as a result of CM implementation.

The respondent companies also observed an improvement in their production control and scheduling after implementing CM. The mean score for the variable of production control was 3.65 and the mean score for the variable scheduling improvement was 3.59. Over sixty-four percent of the firms observed an improvement in their production control and scheduling.

5.7 Extent of Implementation of Human Factors in Cells

This section discusses the extent of implementation of human factors in the cells -namely, the extent of training, team work and job enrichment in cells. Different indicators to measure extent of implementation of each of these factors were identified through the literature search. The respondents were asked to indicate the extent of implementation of these indicators on a five-point scale (Section I, Q 6 to 11).

Descriptive statistics such as mean, standard deviations and relative/ absolute frequencies by category were used. A Student t-test was performed in order to determine whether the mean was significantly greater than the mid-point of the scale.

5.7.1. Training

The results suggest that most of the firms (82.4%) trained their workforce at the time of CM implementation. Since the type of training in new skills and knowledge required by the supervisors, operators and support staff could vary depending upon the skill requirements of the job, the extent and type of training which was given to the supervisors, operators and the support staff is as follows:

Supervisor Training

The companies provided training to most of the supervisors (average=86%) at the time of CM implementation. The extent of training given to the supervisors varied from none to 250 hours per person, with an average of 56.5 hours per person. Seventy-one percent of these companies provided training to all their supervisors

Table 21 - Training of Supervisors (N=14)

Supervisors' Training	% of companies
Skills/ knowledge imparted in training	
Development of soft skills such as leadership & team coordination skills	86.7%
Skill/knowledge to do more than one job	29.4%
Training to develop functional capabilities	26.7%
Training in preventive maintenance	13.3%
Training on state of the art machine tools	13.3%
Cross training on different machines	6.7%

The major focus of training was on the development of soft skills, such as team work and leadership skills, more than eighty-six percent of the respondents provided training in these skills. Some training was also provided for multiskilling of supervisors (29.4%) and to enhance such job-related functional capabilities (26.7%) as capacity analysis, production planning and control and statistical quality control.

Operator Training

Table 22 presents a summary of the extent and type of training which was provided to the operators by the respondent companies at the time of implementation of cells.

Table 22 - Training of Operators (N=14)

Operators' Training	% of companies
Skills/ knowledge imparted in training	
Cross training on different machines	93.3%
Skill/knowledge to do more than one job	93.3%
Training to develop functional capabilities	73.3%
Development of soft skills such as leadership and team coordination skills	66.7%
Training in preventive maintenance	60%
Training on state of the art machine tools	40%

The companies provided training to most of their operators (83%) at the time of CM implementation. The average amount of training which was given to an operator was 50 hours, while the duration of the training provided to operators varied from 8 hours to 120 hours per person.

Regarding the type of training given to the operators, the companies placed a great emphasis on the multiskilling (providing skills and knowledge to perform more than one job) of operators. It was found that over ninety-three percent of the respondents provided training to operators for multiskilling and cross-training on different machines. Many of the firms (73.3%) also placed emphasis on developing the functional capabilities of operators such as assembly skills and testing skills. Also, over sixty-six percent of the firms provided training to develop soft skills in their operators.

Support Staff Training

Table 23 presents a summary of the extent and type of training which was provided to the support staff by the companies when CM was introduced. The support staff consisted of employees who were responsible for production support functions -such as plant maintenance and programming.

Table 23 - Training of Support Staff (N=14)

Support staff Training	% of companies
Skills/ knowledge imparted in training	
Training in preventive maintenance	73.3%
Development of soft skills such as leadership and team coordination	73.3%
Training on state of the art machine tools	66.7%
Training to develop functional capabilities	53.3%
Skill/knowledge to do more than one job	46.7%
Cross training on different machines	40%

The results show that the companies provided training to most of their support staff (average=84%) and seventy-one percent of these companies provided training to all of their support personnel. The average amount of training given to the support staff was seventy-nine hours per person. A major focus of the training which was given to the support staff was to provide skills and knowledge on preventive maintenance and the development of soft skills. Seventy-three percent of respondents provided training in these areas. Also, companies placed a considerable emphasis on the training of their support staff on state-of-the-art machine tools, controls and programming.

5.7.2. Team Work

The extent of team work in the cells was measured by two indicators -namely, the extent of allocation of activities to team and the extent of cooperation among workers in performing a job. The score for the variable measuring the extent of the activities which were allocated to a team was calculated by adding the total number of listed activities performed by a team and reducing it to a five-point scale (5= when a team performs all the seven listed tasks). The mean score for this variable was 3.11, indicating that most of the teams in the cells did not perform all the identified activities. Table 24 presents a summary of results for the team work related indicators.

Table 24 - **Team work** Related Indicators (N=17)

Indicators	Mean	Std. Dev.	% responses
Team work content	3.11	1.53	47.1%
Cooperation in a job among operators	4.06***	0.75	76.5%

Five-point scale used 5=Very Much, 1=Very Little. * $\alpha \leq 0.05$ ** $\alpha \leq 0.01$ *** $\alpha \leq 0.001$

Over seventy-six percent of the companies observed considerable cooperation among operators in performing their jobs within the cell. The mean score of this variable was 4.06 ($\alpha \leq 0.001$).

The extent of activity allocation in teams varied from company to company in terms of activities for which the team was responsible. Over eighty-eight percent of the

teams were responsible for solving production problems. In addition, most of the teams (76.5%) were responsible for the training of new group members and the scheduling of tasks within the team (70.6%). Many of the teams (64.7%) also performed coordination with other teams. Interestingly, it was found that there was little involvement of the team in the scheduling of tasks and days off for team members within the cell (29.4%). Table 25 presents the percentage of companies that had allocated specific activities to the team rather than to individuals.

Table 25- Activity Allocation to the Teams (N=17)

Activities performed by the teams	% of companies
Solving production problems	88.2%
Training new group members	76.5%
Task scheduling within the cell	70.6%
Coordinating with other groups	64.7%
Monitoring performance in the cell	58.8%
Allocating jobs within the group	47.1%
Scheduling tasks and days off for group members	29.4%

5.7.3. Job enrichment

The extent of job enrichment in cells was measured by three indicators -namely, extent of autonomy of the operators in the planning and execution of their work, the extent of variety in the operators' jobs, and the extent to which the operators could identify themselves with their jobs (Section I, Q. 7, 8 and 9). The respondents were asked

to indicate the extent of the implementation of these indicators on a five-point scale from 1 to 5, with 1 indicating very little implementation and 5 indicating considerable implementation. Student t-statistics were used to determine the statistical significance of mean observations, indicating the extent implementation of indicators for job enrichment in cells. A Student t-test was performed with 3 as the reference point, in order to determine whether the mean was significantly greater than the mid-point of the scale. Table 26 presents results for the indicators of job enrichment among the operators:

Table 26- **Job enrichment** Related Indicators (N=17)

Indicators	Mean	Std. Dev.	% of responses for 4 & 5
Autonomy in execution of work	3.41	1.23	47.1%
Autonomy in planning of work	3.12	1.36	41.2%
Variety in the job	3.47	1.01	47.1%
Identification with the job	3.41	1.37	58.8%

Five-point scale used: 5=Very Much, 1=Very Little. * $\alpha \leq .05$, ** $\alpha \leq .01$, *** $\alpha \leq .001$

The results show that, in most of the companies, although the operators are involved in decisions related to the planning and execution of their work, they were not given complete autonomy in this area. Autonomy in the job was measured by the operators' autonomy in the execution and planning of their jobs. The mean score for the autonomy of operators in the execution of their work in the cell was 3.41. This implies that the operators had the flexibility to decide on the procedure for carrying out the work, but this autonomy was not complete. The mean score for the autonomy of operators in planning their work was 3.12. Forty-seven percent of the respondent companies gave

considerable autonomy (rating 4 or 5 on a five-point scale) to their operators in the planning and execution of their work. The mean scores for these two indicators of job autonomy were not found statistically significant when compared to the mid point of the scale.

It is also evident that there is some variety in the jobs of operators and that the operators perform many different activities, using a variety of skills and talents. The mean score of the indicator for the extent of job variety for the operators was 3.47. However, this score was not statistically significant. Some of the firms (47.1%) claimed considerable job variety for the operators in the cells. The mean score for the variable indicating the extent of identification of a job with the operator was 3.82. This indicator was also not found statistically significant. Over fifty-eight percent of the companies rated considerable identification (rating 4 and 5) of jobs with their operator.

From the scores of indicators for job enrichment in cells, it can be said that the job enrichment of the operators in the cells was moderate and that there is still scope for further enrichment in the jobs of these operators. None of the indicators of job enrichment were statistically significant when compared to the mid point of the scale.

5.8. Summary

Analysis of the data reveals some interesting observations regarding changes in the different flexibility types as a result of conversion to a cellular layout from a job shop layout. It was found that CM contributes most to the delivery flexibility of the

manufacturing system. This flexibility also happens to be the top priority of senior management as well as for the manufacturing facility itself.

The results also reveal that improvement in the mobility element of different flexibility types was greater than the increase in the range element of each type of flexibility. Improvements in the mobility element of mix flexibility, changeover flexibility, modification flexibility, volume flexibility and delivery flexibility were found to be statistically significant ($\alpha \leq 0.01$). This finding is consistent with the expectations which were developed in Section 2.3. The results also indicate a significant improvement ($\alpha \leq 0.05$) in the range elements of mix flexibility, changeover flexibility, volume flexibility and delivery flexibility. The improvement in the range element of delivery flexibility was consistent with expectations in Section 2.3. However, increase in the range elements of mix flexibility, changeover flexibility and volume flexibility is contrary to the expectation that the range element of these flexibility types would decrease. These results were based on the propositions which were developed in order to investigate the impact of CM implementation on different flexibility types.

Apart from the contribution of CM to flexibility, this study investigated the contribution of three other plant practices to different flexibility types -namely, design for manufacturability, kan-ban production control and implementation of group technology (a formal coding system for parts). It is evident that the contribution of CM to these flexibility types is relatively greater than the contribution of other plant practices. The results show that CM had an above average contribution to the improvement in different

flexibility types. The increase in delivery flexibility, volume flexibility and mix flexibility were statistically significant. This result supports the earlier finding that CM contributed to increases in delivery flexibility, volume flexibility and mix flexibility. This thesis, however, has not explored whether the contribution of CM to changes in flexibility is greater or less than the contribution of the other plant practices taken together.

Apart from its research objective this study also investigated the extent of the implementation of human factors in cells -namely, training, team work and job enrichment. Regarding training at the time of CM implementation, it is evident that most of the organizations (83%) provided training to the workforce. Since the type of training that is given to the employees depends on the existing skills, qualifications and the tasks performed by the employees, it was found that the focus of training for supervisors, operators and support staff was different for each category: there was more emphasis placed on supervisors' training in soft skills, such as leadership and team coordination; the training of operators was focused more on the development of a multiplicity of skills to perform a variety of jobs; the support staff was mostly trained to develop skills in preventive maintenance and to develop knowledge of state-of-the-art machines, controls and programming.

The results show that there was considerable cooperation among the operators in performing a job. Also the extent and type of activities performed by a team varied from company to company. A majority of the teams were responsible for solving production problems, training new group members, scheduling tasks within the team and coordinating

with other teams. The results suggest that very few teams were responsible for the scheduling of tasks and days off for team members within the cell.

The results also suggest that the job enrichment of operators in the cell was moderate and that there was a scope for further enrichment in the jobs of these operators. None of the indicators of job enrichment were statistically significant when compared to the mid point of the scale.

CHAPTER 6

DISCUSSION

The first section of this chapter presents the findings of the study; the second section considers some of the benefits. The limitations of this study are discussed in the third section. Finally, the fourth section projects the vistas for future research that have been opened up by the findings of this study.

6.1. Discussion of Results

The objective of this research was to understand the changes which were observed in different flexibility types of a job shop manufacturing system due to the implementation of CM. The research question posed in this study is as follows:

What is the effect of the implementation of CM on the following flexibility types of a manufacturing system which had previously been organized as a job shop: a) Mix Flexibility, b) Modification Flexibility, c) Changeover Flexibility, d) Volume Flexibility, e) Delivery Flexibility, and f) Flexibility Responsiveness.

The results of the study show that there was an improvement in the indicators of different flexibility types after the plants' conversion to a cellular layout from a job shop layout. The plants observed an improvement in the mobility element of mix flexibility, changeover flexibility, modification flexibility, volume flexibility and delivery flexibility.

The literature also suggests that there should be an improvement in the mobility element of mix flexibility, changeover flexibility and delivery flexibility as a result of the introduction of CM (Cross, 1984; Welke and Overbeeke, 1988). Cross (1984), in a conceptual paper while emphasizing the benefits of CM, has also suggested that CM offers greater responsiveness to schedule changes and product changes, implying improvement in the mobility element of mix, changeover and delivery flexibility. Similarly Welke and Overbeeke (1988), in a conceptual paper while emphasizing the benefits of CM, suggest that CM offers opportunity for achieving flexibility in product scheduling, implying an improvement in the mobility element of delivery flexibility. Past studies, however, do not mention the effect of CM on modification flexibility. The increase in the mobility element of different flexibility types was consistent with the expectations which were developed in Section 2.3, that there should be an improvement in the mobility element of mix flexibility, changeover flexibility, modification flexibility, volume flexibility and delivery flexibility as a result of the plants' conversion to a cellular layout.

The plants also observed an improvement in the range elements of mix flexibility, changeover flexibility, volume flexibility, and delivery flexibility. However, the results do not show a statistically significant change in the range element of modification flexibility. The increase in the range element of mix flexibility is inconsistent with the literature -which suggests that the range element of mix flexibility should decrease as a result of a plant's conversion to a cellular layout from a job shop layout (Hayes and Wheelwright, 1984; Vakharia and Kaku, 1993). Hayes and Wheelwright (1984) have

pointed out in their product-process matrix that the variety of products that can be produced in the cellular manufacturing layout is less than the variety of products produced in a job shop layout. However, this observation by them is only conceptual. Vakharia and Kaku (1993), based on a study using computer simulation, suggest that CM offers reduced range element of mix flexibility when compared to a job shop. Here they considered large variation in design of products in a given mix of products. The results of the study, on the contrary, show that the firms produced larger number of products with similar design as a result of introduction of CM. This implies that once CM is introduced, the firms increased the variety of products by producing a mix of products with a high similarity in design. Wemmerlov and Hyer (1989) and Knudsen et al. (1994), in their surveys of plants that implemented CM, suggest that plants observed an improvement in range element of changeover flexibility as the plants introduced new products after implementing CM. The increase in the range element of changeover flexibility in this study is consistent with these observations.

However, the effect of the implementation of CM on the range element of volume flexibility, modification flexibility and delivery flexibility could not be found in the literature. The increase in range element of delivery flexibility, however, is consistent with the expectation outlined in Section 2.3 that cellular layout improves the range element of delivery flexibility as a result of improved ability to respond to schedule changes. The increase in the range elements of mix flexibility, changeover flexibility and volume flexibility is contrary to the expectations in Section 2.3. There is a difference between the

expectations and findings for the range element, as the expectations were based on large variation in design among products within the range, whereas it was found that the firms produced larger number of products, and introduced new products with a high similarity in design.

The increase in the mobility element of each of the flexibility types was more pronounced than the increase in the range element for the respective flexibility types. In other words, CM contributed more towards the responsiveness of the facility to deliver products on time, introduce new products, introduce design changes in existing products and respond to fluctuations in product demand. The probable reason for this is that the range element is dependent on the capability of the production equipment to a greater degree than the mobility element. Although the mobility element of flexibility is also dependent upon the production equipment, but considering the domain of existing equipment in the facility, implementation of CM improved the mobility element of different flexibility types.

The results show that the contribution of CM to flexibility was relatively greater than three other plant practices -namely, design for manufacturability, kan-ban production control and the implementation of group technology. This thesis, however, has not explored whether the contribution of CM to changes in flexibility is greater or less than the contribution of the other plant practices combined together.

Another important finding of this study was that delivery flexibility and changeover flexibility were most emphasized by the firms, and the market environment

also demanded an increase in these flexibility types.

Apart from its research objective this study also investigated the extent of the implementation of human factors in cells -namely, training, team work and job enrichment. It was found that most of the firms provided training to the workforce. The focus of training for supervisors, operators and support staff was different for each category - for example- firms placed more emphasis on supervisors' training in soft skills, such as leadership and team coordination, whereas the emphasis of training of operators was more on the development of a multiplicity of skills to perform a variety of jobs: the firms provided training to support staff to develop skills in preventive maintenance and to develop knowledge of state-of-the-art machines, controls and programming

The findings suggest that there is a scope for allocating more activities to the teams, as the extent of team work in the cells was moderate. The extent and type of activities performed by a team varied from company to company. A majority of the teams were responsible for solving production problems, training new group members, scheduling tasks within the team and coordinating with other teams. The results suggest that very few teams were responsible for the scheduling of tasks and days off for team members within the cell. Also there is scope for further enrichment in the jobs of these operators as the job enrichment of operators in the cell was moderate.

From the results, it can be seen that the plants observed an improvement in different flexibility types as a result of implementation of CM and without having to invest in automated equipment. This conforms to Gerwin's (1993) view that managers

should try to tap existing capabilities through improvements in plant procedures and practices in order to improve flexibility in the manufacturing systems as an alternative to investment in capital-intensive equipment and automated manufacturing technologies. This suggests that the companies should consider purchasing new equipment for improving flexibility only when the marginal gains from improvements in plant practices and procedures could be considerably enhanced by the adoption of new technology or equipment.

The results reveal that though market environment required greater volume flexibility as compared to modification flexibility, the plants placed more emphasis on modification flexibility. This suggests that there may be a gap between requirement of flexibility based on market need and the emphasis given to different flexibility types. The managers should measure this gap and accordingly plan to narrow the gap. The instrument developed in this study can be used as a tool to measure different flexibility types in a manufacturing system. This study has just begun to throw light on the topic of evaluating, planning and managing flexibility, which is getting increasingly important for the managers.

6.2. Benefits of the Study

This research facilitates a better understanding of the importance of cellular manufacturing and its contribution towards improvements in different flexibility types in manufacturing systems. This study provides managers with a guideline to implement CM

to realize flexibility in their manufacturing systems. Another valuable contribution of this study is the development of indicators for measuring change in different flexibility types.

The instrument developed for evaluating change in the different flexibility types will also be of interest to academicians. This may be a practical tool for managers in the industry if they wish to evaluate changes in the flexibility of their manufacturing systems. This evaluation of flexibility will help manufacturing managers to plan and manage the flexibility of their manufacturing systems. The measures can be used for the analysis of gaps between actual flexibility and potential flexibility to evaluate requirement for different flexibility types in the future and plan accordingly.

6.3. Limitations of the Study

There are several limitations to this study:

First, there may be the problem of selective recall due to the fallibility of respondent's memory of the environment prior to their implementation of CM.

Second, extraneous factors which affect the implementation of CM may inhibit or enhance manufacturing flexibility. As discussed in chapter 2, the extent of implementation of human factors -such as work structures, job design and training of staff- may also impact changes in flexibility. On the other hand, factors such as market demand and labour laws could inhibit the realization of flexibility. Other influencing factors -such as manufacturing strategy, production equipment, and scheduling procedures- may also inhibit or enhance the realization of manufacturing flexibility. Another research design,

based on comparison of change in flexibility of firms which implemented CM and firms which did not implement CM over a period of time, could facilitate in better isolating the effect of change in market demand on the changes in flexibility as a result of CM implementation. However, in such a research design, it would be difficult to isolate the effect of plant practices other than CM and other influencing factors from the change in flexibility as a result of CM implementation. Although, in this study, it is difficult to separate the impact of all factors, an attempt was made through the questionnaire to isolate these impacts from the impact of CM on flexibility. The survey instrument was designed in a way to make sure that respondents were answering the impact of CM on flexibility.

Another major limitation of this study is the fact that the use of managerial perception leaves the data open to bias, whereas measures based on objective data would eliminate the bias which results from subjective responses.

Finally, concerns about the generalizability of the findings of this study must be noted, given the fact that a small sample required a non-probability sampling design. The exploratory nature of the study and the nature of the data also limit the conclusions that can be inferred from the data analysis.

6.4. Implications for Future Research

There are numerous avenues for expanding this study in future research. This study has opened doors for future in-depth studies which will attempt to understand the

contribution of production management practices in managing the flexibility of manufacturing systems.

The results of this research should be considered exploratory, as changes in flexibility were measured based upon the perception of individual respondents and this may not be the best method of evaluating changes in flexibility. Future research can be conducted which could be based upon an objective measurement of indicators to evaluate changes in flexibility.

This study considered only seventeen companies in the electronics and telecommunication industry. A study of plants across a wider population, based on the same framework, would help to validate the results statistically. In addition, a similar study could be conducted for manufacturing plants in other industries which have implemented CM. Moreover, a detailed study could focus on understanding the impact of other plant practices -such as, design for manufacturability, kan-ban and group technology- on flexibility of manufacturing systems. In addition, future research could also focus on studying the impact of implementation of human factors -such as, training, team work and job enrichment- on the flexibility of a manufacturing system.

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APPENDIX 1

Partial List of the Types and Definitions of Flexibility Proposed in the Literature

Author

Type of Flexibility	Description
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Mandelbaum (1978)

Action	Leaving options open so that it is possible to respond to changes by taking appropriate action.
State	The ability of the system to process a wide variety of parts of assemblies without intervention from outside to change the system.

Buzacott (1982)

State	Same as Mandelbaum
Job	The ability of the system to cope with changes in the jobs to be processed.
Machine	The ability of the system to cope with changes and disturbances at the machines and work stations.

Zelanovic (1982)

Design Adequacy	The probability of the system to adapt itself to environmental conditions and to process requirements within the limits of given design parameters.
Adaptation	The value of time needed for system transformation / adaptation from one to another job task.

Browne et al.(1984)

Machine	Ease of making changes to a given set of parts.
Process	Ability to produce a given set of part types, each possibly using different materials, in several ways.
Product	Ability to change over to produce a new set of products very economically.
Routing	Ability to handle breakdowns and to continue producing a given set of parts.
Volume	Ability of operate profitably at different production volumes.
Expansion	Capacity of the system to expand as needed, easily and modularly.
Operation	Ability to interchange the ordering of several operations for each part type.
Production	Ability to produce a large universe of part types.

Jaikumar (1984)

Process	Ability to reroute a part when a machine is down.
Program	Ability to run the system unattended.
Product	The total incremental value of new products that can be fabricated within the system for a defined cost of new fixtures, tools, and parts programming.

Sethi & Sethi (1990)

Machine	Types of operations that machine can perform without requiring a prohibitive effort in switching from one operation to another.
Material Handling	Ability of the system to move different part types efficiently.
Operation	Ability of a part to be produced in a different way.
Process	Ability of the system to produce a set of part types without major setups.
Product	Ease with which new parts can be added or substituted for existing parts.
Routing	Ability to produce a part by alternate routes through the system.
Volume	Ability of the system to be operated profitably at different overall output levels.
Expansion	Ease with which capacity and capability of the system can be increased when needed.
Program	Ability of the system to run virtually untended for long periods.
Production	Universe of part types that the manufacturing system can produce without adding major capital equipment.
Market	Ease with which the manufacturing system can adapt to changing market environment.

Gerwin (1992)

Mix	Ability to produce a number of different products at the same point in time.
Changeover	Ability of a process to deal with additions to and subtractions from the product mix over time.
Modification	Ability to make functional changes in the product.
Rerouting	Degree to which the operating sequence through which the parts flow can be changed.
Volume	Ease with which changes in the aggregate amount of production can be achieved.
Material	Ability to handle uncontrollable variations in the composition and dimensions of the parts being processed.

APPENDIX 2
Survey Instrument

Carleton University
School of Business

Cellular Manufacturing Study
Effect on Manufacturing Responsiveness

Overview of Project

The aim of this project is to study the experiences of the manufacturing companies which have introduced cellular manufacturing (CM) without major investments in capital equipment. We are interested in knowing about the changes in manufacturing capabilities for a product line at the plant level that have contributed to the ability of the plant floor to respond to the changes in market demand.

In this study, we are considering those manufacturing plants

- (i) which have reorganised their shop layouts into cells to produce several models of a product line; or to produce parts with similar processing requirements,
- AND (ii) in which the new equipment accounts for not more than 20% of the total equipment.

Section I of this questionnaire asks about the nature of CM operations in the plant. Section II asks about the changes in certain performance indicators as a result of introduction of CM.

Your answers to these questions will be treated as strictly confidential. Data from your company will be combined with data from other companies in a final summary report to all participant companies in the study. Neither individual people nor companies will be identified in any of the analyses published from this study.

Thank you for assisting us in this research

NOTE : This questionnaire was developed to be answered by individuals in a number of different companies producing a wide variety of products. Also, since the extent of CM operations varies from company to company, some of the questions and some of the answer categories may not apply to your situation.

If the question does not seem to apply please note this in the margin and do not attempt to answer it.

If the answer categories are not applicable please suggest a better category for your situation.

We would also appreciate any comments and suggestions and additional information you may have in regard to this study. Again, thank you for your help in this project.

Background Information:

1. Company name _____
2. Name of respondent _____
- 3 Title / Designation of respondent _____
- Years in current position _____
- Years with company _____
- Years in manufacturing _____
4. Telephone number for contact _____
- 5 Final products produced _____
- 6 Number of employees in the plant _____
7. Annual sales revenue _____

Instructions on Questionnaire

Please think of your plant's operations when responding to this questionnaire. If you have more than one product line in your plant, please pick only those product lines in which extent of cellular manufacturing operations is maximal, and use them in your responses.

SECTION I**CM Implementation**

This section consists of questions concerning

- a) nature and extent of cellular manufacturing (CM) operations in your company. and
- b) the organization of work in the cells.

1) The following question elicits information on cells in your plant. These may be assembly cells specific to a product line or processing cells for same family of parts

- a) How many cells do you have in your facility? _____
- b) How many cells are ASSEMBLY CELLS _____
i.e. producing a product line _____
- c) How many cells are PROCESS FOCUSED _____
i.e. performing similar process on different parts _____
in the part family.

- d) Identify four cells which represent the majority of CM operations in your plant, representing most of the CM activities for a product line. Please complete the following table for these cells.

	(1) Please Identify the Cell and the product line to which it belongs. Cell Name and / or Product Line	(2) Cell Type 1 Assembly Cell 2 Process Cell (CIRCLE appropriate category)	(3) Years in Operation	(4) Number of models produced in the Cell or Number of parts in Cell family	(5) Batch Size for models or parts Min. Max.	(6) Production Volumes for a model or part in a week Min. Max.	(7) Manufacturing Activities carried out in Cell 1 Component Manufacturing 2 Mechanical Assembly 3 Product Assembly 4 Printed Circuit Board Assembly 5 Other _____ (Specify) CIRCLE appropriate Categories
1	_____	1 Assembly Cell 2 Process Cell	_____	_____	_____	_____	1 2 3 4 5 _____
2	_____	1 Assembly Cell 2 Process Cell	_____	_____	_____	_____	1 2 3 4 5 _____
3	_____	1 Assembly Cell 2 Process Cell	_____	_____	_____	_____	1 2 3 4 5 _____
4	_____	1 Assembly Cell 2 Process Cell	_____	_____	_____	_____	1 2 3 4 5 _____

2) It may not be possible to convert all the production operations in the plant into cells due to certain constraints such as high equipment cost or low capacity utilization in a cell. We wish to know extent of plant operations that have been converted into cells

a) In your opinion, what percentage of total production hours (machine processing hours) in the plant are spent in the cells?

(PLEASE CIRCLE number related to appropriate percentage)

0 -40%	40 -60%	60 -80%	80 -90%	90 -100%
1	2	3	4	5

b) What percentage of the plant's total production (in terms of number of parts) is produced in the cell?
(PLEASE CIRCLE number related to appropriate percentage)

0 -40%	40 -60%	60 -80%	80 -90%	90 -100%
1	2	3	4	5

3) It may not be possible to completely manufacture a product or completely process a part within a cell, without the need for the product or part to go outside the cell for processing

a) Please indicate the percentage of total processing time spent by a product or a part within a cell
(PLEASE CIRCLE correct code)

Cell / Product Line	Percentage of total processing time within cell				
	0 -40%	40 -60%	60 -80%	80 -90%	90 -100%
1 _____	1	2	3	4	5
2 _____	1	2	3	4	5
3 _____	1	2	3	4	5
4 _____	1	2	3	4	5

4) We wish to know about the equipment, staffing and material flow within the cells. Please provide this information for each of the selected cells, the table below.

Cell #	Cell Name/ Product Line	Number of Workstations	Number of Machines	Number of Operators	Work Flow within Cell 1 Continuous Flow 2 Batch Flow 3 Mixed Flow (CIRCLE appropriate category)	Average Move times for a job between the Workstation s (In Minutes)	Type of Equipments in Cell 1. Machine with DIRECT NUMERICAL CONTROL (DNC) Set of machines controlled by one computer 2. Machines with INDIVIDUAL PROGRAMMABLE CONTROL (e.g. CNC machines, programmable robots, automated tool changers) 3. Machines requiring MECHANICAL CONTROL 4. Machines requiring MANUAL CONTROL 5. _____ (Other), SPECIFY PLEASE SPECIFY NUMBER OF EACH TYPE OF EQUIPMENT IN CELL
1.					1 Continuous 2 Batch Flow 3 Mixed Flow	1. _____, 2. _____, 3. _____ 4. _____, 5. _____	
2.					1 Continuous 2 Batch Flow 3 Mixed Flow	1. _____, 2. _____, 3. _____ 4. _____, 5. _____	
3.					1 Continuous 2 Batch Flow 3 Mixed Flow	1. _____, 2. _____, 3. _____ 4. _____, 5. _____	
4.					1 Continuous 2 Batch Flow 3 Mixed Flow	1. _____, 2. _____, 3. _____ 4. _____, 5. _____	

5) What percentage of equipment in the cells was purchased specifically for setting up the cells? (PLEASE INDICATE in terms of PERCENTAGE of total cost of equipment in the cell)

SECTION II

This section seeks your opinion on the possible effects of reorganization of the plant floor into cells on your plant's ability to respond to changes in market demand.

This section is to be answered separately by

- i) the manufacturing manager, and
- ii) one other person in the production team responsible for overall production activities who is familiar with production data from the past

1) As a result of the introduction of CM, what has been the change in your plant's ability to (PLEASE CIRCLE appropriate category)

	Considerable Decrease		No Change	Considerable Increase	
a) Manage production of a variety of models	1	2	3	4	5
b) Manage production of new models	1	2	3	4	5
c) Manage introduction of minor design changes in existing products	1	2	3	4	5
d) Manage fluctuations in production levels due to changes in market demand (ability to operate at varying levels of production)	1	2	3	4	5
e) Manage timeliness in delivery of products	1	2	3	4	5
f) Manage adaption of facility to future changes in product designs and manufacturing processes	1	2	3	4	5

The following question pertains to changes in production performance indicators related to responsiveness of the plant which might have changed as a result of introduction of cellular manufacturing (CM). We wish to evaluate the change in the amount of flexibility designed into the system and amount of flexibility actually obtained in practice.

2) Listed below are a number of performance indicators that may have changed after the introduction of CM. We wish to know your opinion about the following two kinds of changes in the listed parameters.

a) Change that could be achieved:

(Extent of change, you think could be achieved in the listed parameters as a result of CM introduction. In other words how has the **potential capability** of the system changed)

AND

b) Change actually achieved

(In your opinion, what has been the actual change in these parameters as a result of CM introduction. In other words, extent of **Achieved change** in the listed parameters)

For example we want to know your estimate of change that could be achieved in the variety of models produced in the plant and what change has actually been achieved, when existing CM layout is compared to job shop layout as a baseline.

Please answer the following:

	<u>Change that Could be Achieved</u> (POTENTIAL)					<u>Change Actually Achieved</u> (ACTUAL)				
	Considerable Decrease	No Change	Considerable Increase			Decreased a lot	No Change	Increased a lot		
	1	2	3	4	5	1	2	3	4	5
a) Variety of models produced in the factory	1	2	3	4	5	1	2	3	4	5
b) Set up time to switch production to a different model	1	2	3	4	5	1	2	3	4	5
c) Variation in design among different models of the product line	1	2	3	4	5	1	2	3	4	5
d) Number of new models handled by the cell	1	2	3	4	5	1	2	3	4	5
e) Variation in design of new models from existing models in the product line	1	2	3	4	5	1	2	3	4	5
f) Start-up time for full scale production of a new model after its design has been finalized	1	2	3	4	5	1	2	3	4	5
g) Average time to implement a minor design change (E.C.O) in an existing model in the cell	1	2	3	4	5	1	2	3	4	5

	<u>Change that Could be Achieved</u> (POTENTIAL)					<u>Change Actually Achieved</u> (ACTUAL)				
	Considerable Decrease		No Change		Considerable Increase	Decreased a lot		No Change		Increased a lot
h) Number of minor design changes in existing models	1	2	3	4	5	1	2	3	4	5
i) Amount of fluctuation in production levels for different models as a result of variation in demand										
i) from one day to the next	1	2	3	4	5	1	2	3	4	5
ii) from one week to the next	1	2	3	4	5	1	2	3	4	5
iii) from one month to the next	1	2	3	4	5	1	2	3	4	5
j) Average time to change the production levels of models in a cell to adjust to change in demand	1	2	3	4	5	1	2	3	4	5
k) Percentage of orders delivered on schedule	1	2	3	4	5	1	2	3	4	5
l) Number of days by which late deliveries are delayed	1	2	3	4	5	1	2	3	4	5

3) Which of the following changes have occurred in your product markets since the introduction of cellular manufacturing? (PLEASE CIRCLE)

- a) Increased need to **quickly introduce** new models (shorter product life cycle of products)
- b) Increased **frequency of fluctuations** in demand (volatility in market demand)
- c) Increased need to have a **wide variety** of models (broader Product Line)
- d) Increased need to make **frequent changes in product design**
- e) Increased need to **deliver products on time** (emphasis on reliability in supply dates)

4) Some plant practices may have changed at the same time as or after the introduction of CM.

a) Which of the following plant practices have you introduced at the same time or after the introduction of CM? (PLEASE CIRCLE)

1. DESIGN FOR MANUFACTURING (D.F.M.) - Design of products with greater component and process commonality

2. KAN-BAN - Pull type Just in Time (JIT) production control system based on final assembly schedule

3. GROUP TECHNOLOGY - Formal classification system for part assignment in cells

4. Other _____ (Please Specify)

b) In your opinion how did each of the introduced plant practices affect the following capabilities of the production floor?(mentioned in the table below)

(Using the scale below, ENTER the appropriate CODE into the corresponding box in the table)

No Contribution	Some Contribution	Average Contribution	Above Average Contribution	Large Contribution
1	2	3	4	5

PRACTICES	Design for Mfg.) (D.F.M.)	Kan -Ban	Group Technolog y (G.T)	Cellular Mfg (C.M.)	_____ (specify)
CAPABILITY					
a. Ability to produce a wide variety of models (parts)					
b. Ability to frequently introduce new models (parts)					
c. Ability to incorporate design changes in existing products					
d. Ability to frequently vary production levels due to changes in market demand					
e. Ability to deliver orders on time					

5) What has been the affect of CM Introduction on overall factory performance measures such as
(PLEASE CIRCLE appropriate response category)

	Decreased		No	Increased	
	a lot	a little	change	a little	a lot
a) Average lot size	1	2	3	4	5
b) Job waiting time	1	2	3	4	5
c) Job flow times	1	2	3	4	5
d) Work in progress turns	1	2	3	4	5
e) Stock inventory turnover	1	2	3	4	5
f) Machine idle times	1	2	3	4	5
g) Operator idle times	1	2	3	4	5
h) Stability in production costs at varying production volumes	1	2	3	4	5
i) New product launch times	1	2	3	4	5
j) Improvement in downtime performance	1	2	3	4	5
k) Reduction in tooling set up cost	1	2	3	4	5
l) Improved scheduling	1	2	3	4	5
m) Ease of production control	1	2	3	4	5
n) Group coordination	1	2	3	4	5
o) Pooling of resources in the cell	1	2	3	4	5
p) Material handling	1	2	3	4	5

6) How important is it for your facility to:
(PLEASE CIRCLE appropriate category)

	<u>Not Important</u>		<u>Somewhat Important</u>		<u>Extremely Important</u>
a) Produce a wide variety of models	1	2	3	4	5
b) Frequently handle introduction of new models	1	2	3	4	5
c) Incorporate minor design changes in existing products	1	2	3	4	5
d) Make changes in production levels due to change in market demand on a					
i) Daily basis	1	2	3	4	5
ii) Weekly basis	1	2	3	4	5
iii) Monthly basis	1	2	3	4	5
e) Deliver products on scheduled dates (Timeliness in delivery)	1	2	3	4	5
f) Have the ability to reconfigure the production layout	1	2	3	4	5

7) How important is each of the following issues to your company's senior management?
(PLEASE RANK them in the order of priority)

	Priority					
	<u>High</u>			<u>Low</u>		
a) Producing a wide variety of models	1	2	3	4	5	6
b) Frequently introducing new products	1	2	3	4	5	6
c) Frequently introducing enhancements in existing products	1	2	3	4	5	6
d) Adjusting production level due to changes in market demand	1	2	3	4	5	6
e) Delivering products on schedule	1	2	3	4	5	6
f) Changing above priorities to meet new competitive priorities	1	2	3	4	5	6

Thank you for your assistance in this project.

PLEASE FAX THE COMPLETED SURVEY TO:

Virender Ambwani, at FAX # (613) 788 2532, (613) 788 4427

Appendix 3

Introductory Information

Cellular Manufacturing Study

Effect on Manufacturing Responsiveness

Introduction

Management of flexibility in the production plants is one of the key issues with respect to a firm's competitiveness.

Flexibility is synonymous with quick responsiveness of the production floor to changes in market demand in terms of broader product variety, design changes in products and aggregate production volumes, as well as responsiveness to internal process variability such as machine breakdowns or raw material problems.

Cellular Manufacturing (CM) is one of the production management methods, based on product focussed modularization of the shopfloor, which is being adopted by firms to improve their operational performance.

This study is aimed at investigating the changes in the capabilities of the production floor specifically related to changes in responsiveness of the shopfloor to variability in product demand and production process

Objectives

The aim of this project is to study the experiences of the manufacturing companies which have introduced cellular manufacturing (CM) without major investments in capital equipment. We are interested in knowing about the changes in manufacturing capabilities for a product line at the plant level that have contributed to the flexibility of the plant floor in the face of changes in market demand.

We are seeking involvement of the companies

In this study we are seeking involvement of those manufacturing plants in the Electronics and Telecommunications industry,

- * Which have reorganized their job shop layouts into cells (product focussed modules) to produce several models of a product line; or to produce a family of parts with similar processing requirements, **and**
- * Where the capital investment on new machines is not significant (less than 20% of the total equipment in cells)

Extent of Involvement

Plants participating in the study need to answer a specific set of questions related to CM operations. It takes about forty-five minutes to answer these questions. The questions need to be answered by manufacturing operations manager or production manager. The questionnaire shall be faxed to the participating plants. The questions relate to the CM

practices adopted in the plant and consequent changes in the performance indicators related to the responsiveness of the plant.

Confidentiality

To respect confidentiality you will be able to review drafts of the papers before they are published. Also the study will not mention individuals or companies by name.

Benefits

The findings of the study will be presented to the participant firms with a specific focus on improvement in their CM operations and practices. This research, based on responses from a number of companies, will help to develop a benchmark for CM practices in plants for developing flexibility in the face of changes in market demand.

Answering the questionnaire itself will be revealing to the participating plants in terms of measuring their plant's performance towards responsiveness to change.

Current Status of Project

Currently this research is in the process of data collection through interviews with manufacturing executives of firms in the Electronics and Telecommunications Industry.

To Get Involved ...

Please contact **Virender Ambwani** at Phone # (613) 231-7786 or
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OR

Dr. **Donald Gerwin** at (613) 744 -8747 and (613) 788-2386 or E-mail dgerwin@carleton.ca.

OR

Dr. **Vinod Kumar** at (613) 788 -2379 or E -mail vkumar@carleton.ca.

(This study is sponsored by Research Program in Managing Technological Change in Manufacturing and is being undertaken as a part of Master's Thesis Requirement of School of Business, Carleton University, Ottawa by Virender Ambwani under guidance of Dr. Donald Gerwin & Dr. Vinod Kumar.)

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