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Introducing the Central Backup Cellular Manufacturing System (CBCMS)

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***Abstract*— In this paper, we present a new layout arrangement that we call the central backup cellular manufacturing systems (CBCMS). The CBCMS organization is inspired by the concept of the remainder cell in Group technology (GT) systems where the idea is to allocate products that are not easily partitioned in the parts-machine incidence matrix to the remainder cell through a cell that contains all process capabilities. The fractal cell layout can be thought of as replications of the remainder cell in the GT concept. The GT layout represents an efficient approach under certain static conditions, while the fractal layout represents a flexible approach that better deals with uncertainties. The objective of this paper is to explore how a designer can manage variability arising from internal and external disturbances in manufacturing systems while designing a layout and in doing so, to show that the CBCMS provides a framework to unify GT and fractal layouts.**

***Keywords*— Cell Formation; Cellular Manufacture; Fractal Manufacturing Systems; Group Technology**

I. INTRODUCTION

In the process of designing a facility, the material flow pattern must be determined first, after which the facilities designers can determine the type of layout to be implemented. The four general types of layouts are: process layout, product layout, fixed position layout, and group technology (GT) layout. These layout types are mainly used in manufacturing systems. There are also other new generations layouts mentioned in the literature, such as fractal, holonic, and distributed layouts [1][2][3][4]. Fractal layout forms part of the focus of interest in this paper, as it has been developed as an alternative for manufacturing job shops (process layout). Holonic and other distributed layouts are not within the scope of this paper because they do not have clear cellular divisions.

The new layout arrangement introduced in this paper, the Central Backup Manufacturing Systems (CBCMS) is based on the concept of the remainder cell in Group Technology (GT) system. The remainder cell in GT is a catch-all cell to provide flexibility [5]. The idea is to allocate products that are not easily partitioned in the parts-machine incidence matrix to the remainder cell. However, in the CBCMS system, the central backup cell (which is, in many ways, similar to the remainder cell) is explicitly designed in tandem with the other cells in the system. We then show how this construct is helpful in showing how the GT and fractal layout systems are just part of a continuum for a designer interested in developing alternative manufacturing systems layouts.

In other words, the CBCMS could be thought of as a special case of both the GT and fractal cellular systems. It is designed to accommodate variability arising from internal and external disturbances in a dynamic production environment. A facility designer is interested in developing an efficient and flexible layout that can adapt to uncertainty in cellular manufacturing. As an intermediate layout, the CBCMS provides the advantages of combining two layouts – namely, GT and fractal layouts. We note that the GT layout represents an efficient approach when the part-machine incidence matrix can be perfectly clustered. However, it has the disadvantage of being rigid. On the other hand, a fractal layout represents a flexible and adaptable approach to designing cells.

In this paper, we begin with an illustration of how a CBCMS is constituted and how it can be viewed from both the GT and fractal cell layout perspectives. We then examine cell design and configuration issues in dynamic and uncertain production environments, with an emphasis on variability or uncertainty due to external and internal disturbances. This is followed by an elaboration of the opportunities for designing efficient and flexible cellular manufacturing systems under uncertainty that a layout designer has by making trade-offs between efficiency and flexibility within the GT, CBCMS, and fractal layout spectrum. Finally, some thoughts are presented to highlight the robustness of the CBCMS layout.

The conceptual contribution of this paper is to show how the GT and fractal systems, traditionally considered in the literature as two totally different layout philosophies, are related to each other.

II. Framework for Central Backup Cellular Manufacturing Systems

The general layout arrangement of CBCMS, which is in the spectrum between GT and fractal layouts, is illustrated in Figure 1. Here, all cells in the layout arrangement are conventional GT cells, except for the cell in the center (which may be seen as a fractal cell). For example, cells 1 to 4 and 6 to 9 are regular GT cells to manufacture different types of products based on similar manufacturing operations or design attributes. Cell number 5, located in the center of the layout, is a central backup cell that includes all process and is designed to accommodate all part families manufactured in the CBCMS facility.

It is believed that a central backup cell will be sufficiently responsive and flexible to deal with abnormalities during production, while GT cells will be able to deal with scheduled production tasks. The manufacturing cells in a CBCMS layout can be made focused by using special purpose machines such as conventional lathe and milling machines, and the production support for these cells may be equipped with conventional material-handling systems. However, the manufacturing cells could be made flexible by using multi-purpose machines such as CNC lathe and milling machines, and the production support for these cells could be equipped with mechanized systems for material handling and industrial robots.

A flexible machine is designed for a very rapid changeover, whereas a focused machine is designed to produce similar parts or products frequently. A flexible machine has higher costs compared to a focused machine, but a focused machine has higher efficiency compared to a flexible machine.

Layout design is a challenging task for facilities planners because there are many trade-offs that need to be considered. For example, by purchasing CNC machines (flexible machines), we may reduce the flow and cost of material handling, but operation and investment costs will increase because CNC machines are more expensive to purchase and operate. On the other hand, by purchasing conventional machines such as lathe or milling (focused machines), we may reduce investment and operation costs, but the flow and the cost of material handling will increase because more parts routing is needed. These kinds of trade-offs are implicit in the multi-period cell formation problem (MPCFP) model presented in [6].

In real-world business, industrial companies have different strategies to achieve their objectives. These strategies, along with other factors, usually form the companies' business models. The factors include but are not limited to 1) the level of competition in the market, 2) the available resources within the company, 3) product mix variability, and 4) changing demand. Based on these factors, manufacturers may need to choose between focused and flexible cells in their facility to attain their objectives. It should also be noted that in the CBCM system, the number of fractal cells is a design decision. Although the illustration in Figure 1 shows only one fractal cell, many more are possible.

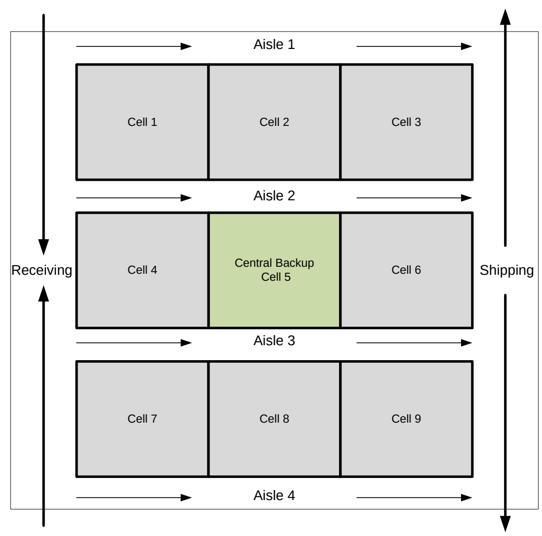

Figure 1: General schematic layout of central backup cellular manufacturing systems

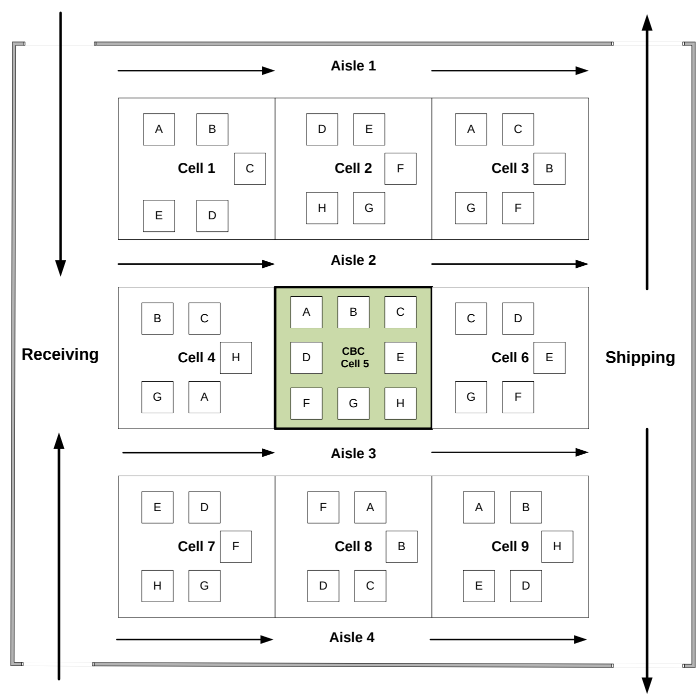

Figure 2: The location of the central backup cell within the proposed CBCMS layout

In the CBCMS layout, the machines are arranged in the cells based on the concept of GT and fractal cells to provide an efficient and flexible system for manufacturing in a changing production environment. For example, cell 1 contains a group of special-purpose machines (A, B, C, D and E), as illustrated in Figure 2, which are assigned to manufacture Part Family 1. Hence, cell 1 is dedicated to Part Family 1, cell 2 is dedicated to Part Family 2, and so on. Meanwhile the central backup cell (cell 5) is designed to be a flexible cell that may contain a group of special-purpose machines that can manufacture all products. For instance, the central backup cell consists of a group of special-purpose machines (A, B, C, D, E, F, G and H) that represent all types of machines in the facility.

We believe that the CBCMS arrangement is both efficient and responsive when performing a wide range of operations for the reasons that follow.

A. Variability Within the Context of CBCMS

Variability exists in all production systems and can have a significant impact on performance. Therefore, the ability to measure, understand and manage variability is crucial to effective manufacturing management [7]. In this paper, variability is classified into two types: 1) variability as a result of internal interruptions or, as a consequence of events related to our activities and decisions; and 2) variability as a result of external forces that are beyond our immediate control. In this paper, the term "uncertainty situation" is used interchangeably with the word "variability".

We are interested in investigating how variability can be managed in the context of central backup cellular manufacturing systems. CBCMS can be used effectively during variability resulting from internal and external interruptions. Examples of variability resulting from internal interruptions include equipment breakdowns, queuing delays, reject and rework, and variable process time. In contrast, variability resulting from external interruptions includes product mix variability, limited delivery time, and fluctuating demand. The focus at this stage is on how a CBCMS layout behaves in the face of variability.

1) Managing Variability Resulting from Internal Interruptions

To comprehend the various challenges mentioned above, it is important to elaborate on variability that results from internal interruptions. There are four main instances of this type of variability. First, equipment breakdowns (scheduled and unscheduled downtime) can greatly affect the production system. Scheduled downtime can be managed relatively easily because all affected activities are known beforehand. However, unscheduled downtime may occur suddenly (i.e., during a machine's performance of a job) and thus can greatly affect the flow of product within the facility. It is also important to note that frequent breakdowns are expected when the facility is used over a period of time due to the deterioration of machines. A second internal disruption is queuing delays, congestion caused by Work in process (WIP) near a machine or workstation that can result in delayed tasks. A third instance of internal disruption may occur in the case of reject and reworks, when quality problems may cause some tasks to be repeated and some products to be scrapped. If a task is done incorrectly during production, rework may be conducted on the same part to correct the problem. On the other hand, if a part is completely scrapped, repeating the task from the beginning is necessary. A fourth example of internal disruption arises in the case of variable process time, where the process time differs from product to product. The processing time for a product may also vary due to differences in operator skills and machine capabilities.

The central backup cell in CBCMS layout, as illustrated in Figure 3, can deal with any of the uncertainty situations resulting from internal interruptions. The jobs that cannot be performed in the designated cells could be transferred and processed in the central backup cell. Since all of these interruptions might not happen at the same time, manufacturers will be assured that there is an opportunity to finish the jobs more or less on time. While this is happening, manufacturers can follow the required procedures to repair the broken equipment in the GT cells. Also, manufacturers will be able to investigate and cover the proper solutions to issues related to in-process inventory and quality issues.

2) Managing Variability Resulting from External Interruptions

It is important to elaborate on the variability resulting from external forces:

Product mix variability: in today's business environment, product life cycles are short, resulting in the regular introduction of new products or modifications of existing products. As a result, a broader or different product mix may be handled and manufactured in the facility.

Limited delivery time: customers prefer to customize their products and at the same time demand shorter delivery times.

Varying demands: demand for certain products may vary in response to the business environment.

The central backup cell can deal with situations of uncertainty resulting from external forces, as illustrated in Figure 4. For example, when there is a need for more product variety in smaller quantities, all extra jobs that cannot be done in the designated GT cells can be transferred and completed in the central backup cell. In the case of a product that has a limited delivery time, the central backup cell can be used when GT cells are busy or cannot perform the tasks on time. The ability to cope with varying demand can also be incorporated into the CBCMS design. This will be discussed in greater detail later in this paper. From the business environment perspective, the product price and/or lead time is subject to change for any number of reasons at any given time.

It is known that changes in the product price and/or lead time may result in increased competition among competitors. Research in the multi-period cell formulation literature has largely ignored these considerations because they lead to more complexity and make it more difficult to come up with tractable solutions. Although the proposed models in this paper focus on minimizing the cost of manufacturing products, adding product price to such a model may require different business and management models to solve the problem.

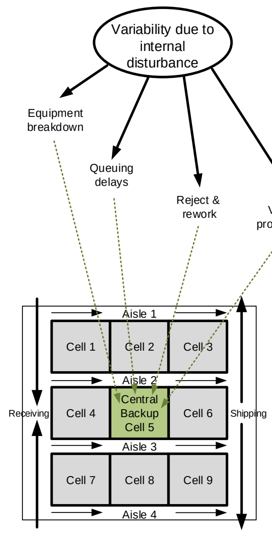

Figure 3: The CBCMS layout accommodates variability resulting from internal interruptions

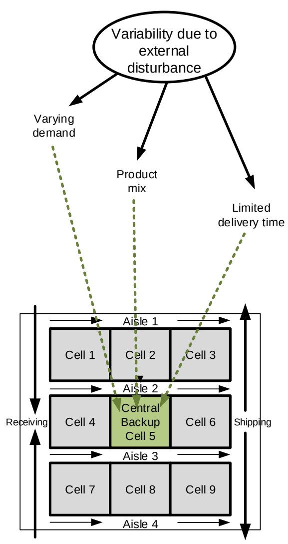

Figure 4: CBCMS layout accommodates variability resulting from external interruptions

Therefore, the product price and lead time issues will not be addressed in this paper. However, they should certainly be considered as issues for further research.

B. Other Aspects of CBCMS

Figure 5 describes other functional aspects of the CBCMS layout. The situations that we will discuss here are: providing training programs to machine operators, making prototypes, and using the central backup cell to expand the layout (i.e., initiating the first expansion cell).

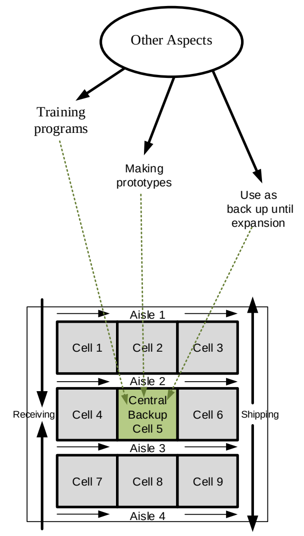

Figure 5: Using CBCMS layout for other situations

The central backup cell may handle some planned activities within the facility. For example, if training programs are required for operators in the facility, training may be performed in the central backup cell. As described earlier, the central backup cell contains different types of focused machines like machines that are available in the GT cells within the facility. In such cases, the trainees may use the available machines in the central backup cell during training sessions instead of using machines in GT cells. GT cells are dedicated for scheduled production.

The central backup cell can also be used for making prototypes whereby machines are required to create a physical model of a component or product. Therefore, the available machines in the central backup cell 5 can be used to develop the required prototypes instead of using machines in GT cells.

At some point, a manufacturing facility's capacity may be saturated, at which time expanding the existing facility is an option to enhance production. If this is the case, the central backup cell can be used temporarily until the designer recommends a complete plan for facility expansion.

C. Managing Demand Variability in the CBCMS Layout

Before discussing how to manage demand variability in the CBCMS layout, it is important to understand what is meant by demand in this study. Demand variability is considered one of the factors that affect layout design decisions. These days, researchers and facilities designers are interested in the issue of changing demand when designing a new or modifying an existing layout facility. In this paper, we attempt to understand demand variability and look for ways to mitigate the effect of uncertain demand in the context of using CBCMS.

Demand is the quantity of manufactured goods consumers are willing and able to purchase at a given price over a particular period of time. In this paper, demand is classified into three main categories based on a fast-changing business environment: a) steady demand, b) seasonal demand, and c) varying demand. Steady demand is a relatively stable demand for products and usually has a range of definite quantities. Seasonal demand reflects a manufacturer's interest in manufacturing particular products only during a specific period during the calendar year. On the other hand, varying demand occurs when demand rises or falls suddenly in response to product technology, changing economic conditions, or customer spending patterns.

Another key aspect of demand variability is whether it is short-term or long-term. Also, there may be clear trends in demand as new products are designed and introduced to a manufacturing facility while others become obsolete.

As shown in Figure 6, GT cells are responsible for handling relatively stable demand, while the central backup cell is responsible for handling fluctuating and seasonal demand. For example, GT cells in the CBCMS layout may accommodate the entire steady demand of all parts. In contrast, the central backup cell may accommodate the excess in demand and a portion of the seasonal demand when GT cells are working at full capacity. We may also note that both GT cells and the central backup cell can be used for seasonal demand. This depends on the volume of the seasonal demand during each calendar year. In a fast-changing business environment, demand may go up or down sharply, as mentioned earlier. Therefore, the central backup cell will be used to manage the excess demand. While we cannot escape variation in demand, we can consider the central backup cell as an effective means to cope with both short- and long-term demand variability.

Finally, exploring how to manage demand variability in the CBCMS layout is an interesting task that necessarily includes understanding demand variability and the influence of changing demand on manufacturing companies. We believe that more research is required to comprehend the related issues in demand variability with respect to cellular manufacturing system and CBCMS.

D. An Approach for Implementing CBCMS Layout in a Changing Environment

The workflow diagram below provides a general overview of the flow of tasks within the CBCMS layout in a dynamic manufacturing environment. The flow chart shows the process of manufacturing a product using the CBCMS layout, starting from the work order.

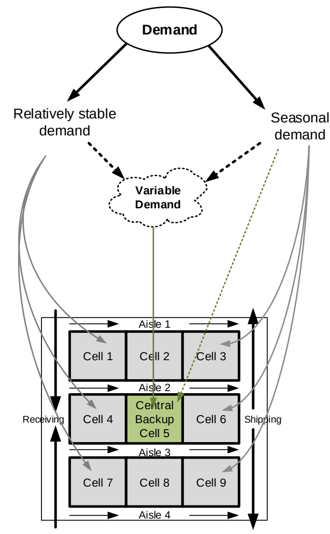

Figure 6: Handling demand variability in CBCMS layout

Figure 7 presents a simplified flowchart for implementing the central backup cellular manufacturing system layout in a changing environment. The work order includes tasks for manufacturing a product family. The work order may also include other tasks, such as providing training programs to machine operators, creating product prototypes, and initiating the first cell expansion as indicated earlier. The GT cells in the CBCMS layout may be used to carry out the tasks indicated in the work order. Therefore, the job may be assigned to a specific GT cell that is dedicated to manufacturing the product family. If the GT cells cannot handle the task, then work has to be taken to the central backup cell.

Effective implementation of the central backup cell requires consideration not only of processes and technologies, but also of organizational and human issues. Using the central backup cell in manufacturing improves the facility to respond to abnormalities more quickly and to ensure top operational practice to maintain a competitive position in the global market.

E. Understanding CBCMS Capabilities

In the literature, the traditional manufacturing systems are classified into job shop, batch and mass manufacturing systems. Job shop productions are appropriate for high part variety and low volume, whereas mass productions are suitable for high volume and low part variety. Batch productions are appropriate for medium volume and variety.

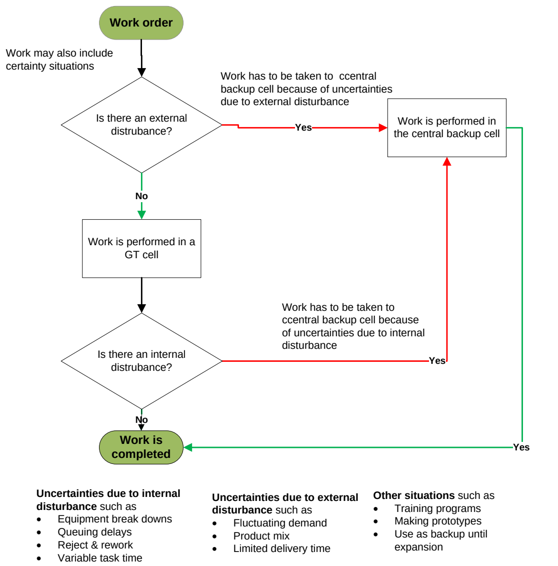

Figure 7: An approach for assigning work in a CBCMS environment

Similarly, GT and fractal layouts represent cellular manufacturing systems, the arrangement of machines, cells, and workstations make the facilities more integrated, efficient, and flexible. However, these layouts are respectively considered either efficient or responsive. The proposed CBCMS layout will have characteristics of both GT and fractal layouts (efficiency and responsiveness).

First, we provide some definitions. GT is a manufacturing concept that seeks to take advantage of design and processing similarities among parts, such as grouping parts according to their geometric similarities or grouping parts according to their manufacturing similarities [8]. In the fractal layout, the fractals are similar units of production that are able to produce all products in all cells. Fractals are designed to minimize the WIP flow. Each fractal acts as an independent unit, generating a highly decentralized system. The fractal cells have more flexibility to handle high product variety compared with GT. However, investment and maintenance of the fractal layout can be very expensive when compared with other layouts for the same production [9]. The CBCMS is a combination of GT and at least one central backup cell. The central backup cell serves as a flexible cell that dynamically accommodates different types of product families. Parts not manufactured in GT cells can be re-located and processed in the central backup cell.

Figure 8 adapted from [10] illustrates the relative position occupied by the CBCMS layout in comparison to function, product, GT, and fractal layouts. In the three-dimensional coordinate system, we represent the relative position occupied by the CBCMS layout in

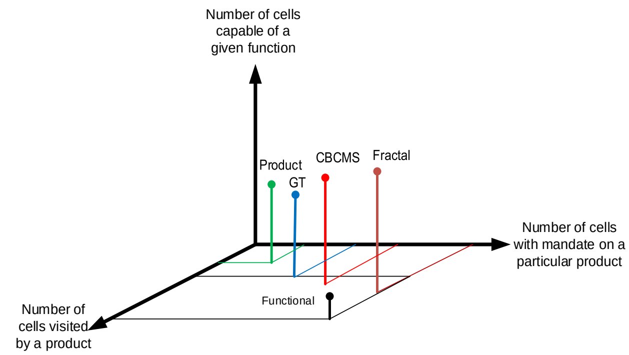

Figure 8: Relative position of CBCMS compared to other layouts

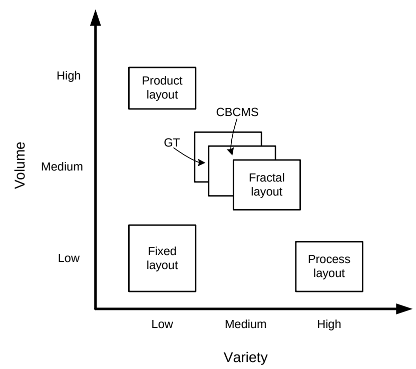

Figure 9: Volume-variety layout classification

comparison to other layouts such as GT and fractal layouts. Each axis in the three-dimensional coordinate system is labeled to represent the number of cells, respectively, with the mandate of meeting at least a fraction of a product demand, the number of cells visited by a product, and the number of cells capable of a given function.

From the point of view of number of cells capable of a given function and the number of cells with the mandate of producing a particular product, the following generalization is valid: (a) the GT layout has a lower cell capability index for a given function and a smaller number of cells with a mandate to produce a particular product; (b) the fractal layout has a higher cell capability index for a given function and a larger number of cells with the mandate to produce a particular product; and (c) the CBCMS is in between the GT and fractal layouts.

Traditionally, layouts can also be classified as product, fixed location, process, or product family (GT) [10]. Figure 9, adapted from [10], shows the central backup cellular manufacturing system in comparison to product layout, fixed layout, and process layout.

The adapted figure illustrates the relative position of CBCMS and the fractal layout in comparison to GT. In cases of medium demand for a medium number of similar components, these components, according to the above classification, may be assigned to a GT manufacturing facility. However, in today's business environment, the demand may vary, and the product type may change at any time. In this circumstance, GT is less responsive to these changes and therefore is not the best option. The CBCMS layout will be able to deal with product volume-variety changes and abnormalities due to uncertainty situations. A fractal layout offers even more flexibility but may not be as efficient.

Facilities have different characteristics that influence their responsiveness and efficiency. Layout responsiveness includes a facility's capability to respond to changes in demand, meet short delivery times, handle a large variety of products, and deal with uncertainties due to internal and external disturbances. The more of these capabilities a facility has, the more responsive it is. Responsiveness, however, comes at a cost. For example, a fractal layout may have higher investment and operational costs compared to GT and CBCMS because of the higher number of similar machines distributed in all cells and the need to provide tooling and setup at multiple locations. However, fractal layouts are more responsive and flexible, and are thus able to handle a large variety of products. The cost-responsiveness relation in Figure 10 shows the relative position of CBCMS in comparison to GT and fractal layouts. A GT layout has a lower responsiveness and relatively lower investment and operational costs, while a fractal layout has a higher responsiveness at relatively high costs. The CBCMS layout is, by definition, in between the two.

F. *The Concept of the Efficiency and Flexibility Spectrum in CBCMS*

To adopt the CBCMS layout, we must analyze the efficiency and the flexibility of the CBCMS layout in comparison to GT and fractal layouts. Traditionally, layouts range from those that focus on being efficient to those that focus on being flexible. The former is the design choice when design parameters are certain and the latter when the parameters are uncertain. We believe that, compared to GT, CBCMS is designed to be relatively more adaptive and robust, in that it responds well to changes and functions reasonably well under all scenarios. For example, the CBCMS has the capability to adjust to different kinds of variability, such as product mix variability, demand uncertainty, and delivery time.

At the same time, it is probably CBCMS has less flexibility in comparison to the fractal layout. However, flexibility comes at a cost. For example, to respond to product mix variability, layout flexibility must be increased (i.e., move toward fractal layout), which increases cost (e.g., investment, setup, tooling, etc.). Therefore, a GT layout may be more efficient than a

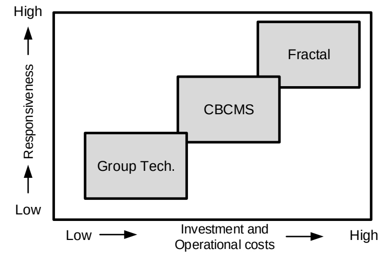

Figure 10: Cost and responsiveness relationship in GT, CBCMS, and fractal layouts.

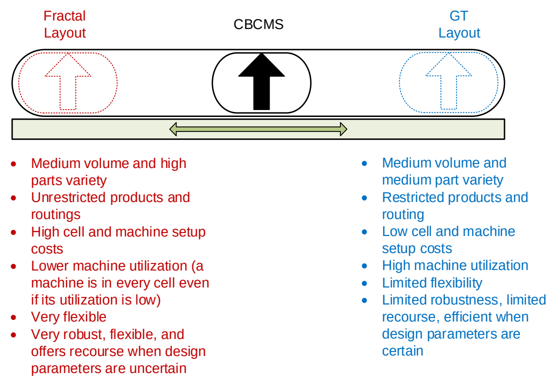

Figure 11: The concept of the efficiency and flexibility spectrum in CBCMS.

fractal layout, but GT has limited flexibility to handle product mix and demand uncertainty. Here, once again, CBCMS is situated in between GT and fractal layouts.

Figure 11 illustrates the concept of the efficiency and flexibility spectrum in CBCMS, showing where some layouts fall on this spectrum. The spectrum highlights the trade-offs involved in various strategies available for restructuring the CBCM system. As mentioned previously, the number of fractal cells in CBCMS is itself a design decision. This means that we may implement only one fractal cell in the CBCMS setting or more fractal cells, based on the layout design parameters.

The relative positions of GT and fractal layouts are exhibited on the efficiency and flexibility spectrum with the CBCMS somewhere along that spectrum. The GT layout that represents an inflexible layout may improve its flexibility by moving toward a fractal layout position by having more backup cells. On the other hand, it improves its efficiency by moving towards a GT layout by eliminating all backup cells. In fact, it is a trade-off between a more flexible but less efficient layout (i.e., more fractal cells) and an efficient but less flexible layout (i.e., only GT cells). The CBCMS layout may be adjusted to suit the desired level of flexibility and efficiency, allowing manufacturers to have the right balance of efficiency, adaptability, and robustness.

III. Conclusions and Recommendations for Future Study

We introduced the central backup cellular manufacturing system (CBCMS). This layout philosophy has not only practical design implications but also a theoretical one. The continuum between GT and fractal design alternatives was well understood in the literature and this paper resolves the question whether the two layout systems are interrelated at all. By introducing the CBCMS, we show that because the remainder cell is indeed like a fractal cell, the question in cellular design then becomes whether to make all other cells specialized as is done in GT, or generic, as is the case in fractal layouts.

For details on how the CBCMS is a unifying framework for fractal and GT design and how a designer can develop different cellular configurations using an optimization approach, the reader is referred to [12].

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