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Chapter 1

CELLULAR MANUFACTURING SYSTEM EVOLUTION FROM GROUP TECHNOLOGY TO A RECONFIGURABLE MANUFACTURING SYSTEM: A CASE STUDY OF A DYNAMIC CELLULAR MANUFACTURING SYSTEM (DCMS) IN AN ELECTROMECHANICAL ASSEMBLY INDUSTRY

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ABSTRACT

This chapter defines some characteristics of the Cellular Manufacturing System (CMS), and explores the most important features from the literature and the practices that can be used to develop a Dynamic Cellular Manufacturing System (DCMS). The possibility of system reconfiguration makes those new systems the most efficient in the presence of a dynamic environment. The main objective of this study is to assist decision makers and/or designers in choosing one of the most appropriate layouts using the DCMS. This task becomes more difficult because it is usually associated with many other decisions like production planning and resource allocation. By the end of this chapter, a case study related to the implementation of a DCMS in the electromechanical assembly industry will be presented.

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INTRODUCTION

International competition and technological evolution create turbulence throughout the environment of many Manufacturing Companies (MCs). These changes urged researchers and practitioners to propose new layout models and find suitable solution techniques.

This dynamic environment directly affects all the departments of manufacturing companies, thus making it more difficult for the facilities to plan projects. This chapter will mainly focus on the *production facilities*. In addition, it will make the reader aware of some techniques aiming at handling the difficulties resulting from the integration of *transportation facilities*, because they are both connected to one another, as stated by (Tompkins et al., 2003). People interested in other issues related to this kind of project, for instance the choice of an appropriate transportation installation, the layout of other facilities forming the manufacturing companies, etc. are invited to consult to (Tompkins et al., 2003).

This chapter will focus on one type of conventional manufacturing system called the Cellular Manufacturing System (CMS), as well as one important kind of Reconfigurable Manufacturing System (RMS), namely the Dynamic Cellular Manufacturing System (DCMS). This does not mean that other manufacturing systems like Job Shops (JS) are obsolete; they still remain efficient in certain circumstances.

The first motivation to transition to the RMS is to handle the increasing amount of turbulence that can cause serious issues, especially when enterprises cannot respond quickly. Many internal and external factors can lead to this type of environment. In addition, it is important to mention that a RMS can be implemented to manage either the supply chain or the production facilities.

This chapter will focus on giving a detailed definition of a DCMS, which was suggested for the first time by (Rheault, Drolet, & Abdulnour, 1996).

The rest of this chapter will be organized as follows: the second section will introduce the fundamental concepts of the CMS and present an overview of the Cell Formation (CF) techniques, the third section will attempt to define what a dynamic environment is, the fourth section will introduce the DCMS in detail, and, finally, the fifth section will lay down certain perspectives on that matter.

CELLULAR MANUFACTURING SYSTEM (CMS)

In this chapter, the reader can discover the evolution of many layout systems, from their beginnings until the Reconfigurable Manufacturing System (RMS). The first epoch of Manufacturing Companies (MCs) was considered stable. In 1880, *Taylorism* suggested that there is one and only one better way to produce. Then, by 1908, *Fordism* followed this same strategy, while adding other principles such as standardization and assembly-line work. Both systems were suitable to address the market needs of their time, which required higher productivity of a few sets of products. However, the increase in the number of product types in the order book forced some MCs to adopt the Job Shop (JS) system, which offered them more flexibility. Unfortunately, those systems did not allow for a high productivity.

The Origin of CMS and a Definition

Figure 1 shows the most probable layout for each combination of *product variety* and *product volume per variant*. It is possible to notice that the Line Layout is suitable for a high volume of a few products. It is characterized by a high productivity, but also by a low flexibility, especially when trying to introduce new products. On the opposite side, the Functional Layout (FL) is the most flexible, but does not generate productivity. As for the intermediate levels, Figure 1 shows that the Group Layout (GL) can offer more productivity while keeping an acceptable level of flexibility.

When analyzing Figure 1, it can be noted that it consists in a very general manner of establishing a conclusion regarding the layout type. For example, in practice, in addition to producing a high volume, enterprises are also seeking to optimize many other Key Performance Indicators (KPIs) like lead time, lateness, Work in Process (WIP) level, Material Handling Cost (MHC), etc. Furthermore, both FL area and GL area can overlap depending on the MC context. Finally, many other additional parameters are necessary when planning a facility, so it is important to explore other ways to make the right choice with respect to the layout system.

According to (Tompkins et al., 2003), the percentage of operating costs resulting from the MHC varies from 20 to 50%. They agree that an effective facility planning can reduce MHC by 10 to 30%. For example, MCs can achieve this goal by moving from the FL to the GL. This decision can also contribute to simplifying the material flows, as displayed in Figure 2.

To proceed to this transition, the facility planner can apply many techniques of the Group Technology (GT). An approach proposed by (Kusiak & Heragu, 1987) offers many advantages by taking into account part similarities, like the simplification of the *product engineering phase*, and then facilitating the introduction of new ones. The main objective of the GT is the Cell Formation (CF). It is equivalent to establishing a Cellular Manufacturing System (CMS) that assigns each *product family* to one *group of machine*s.

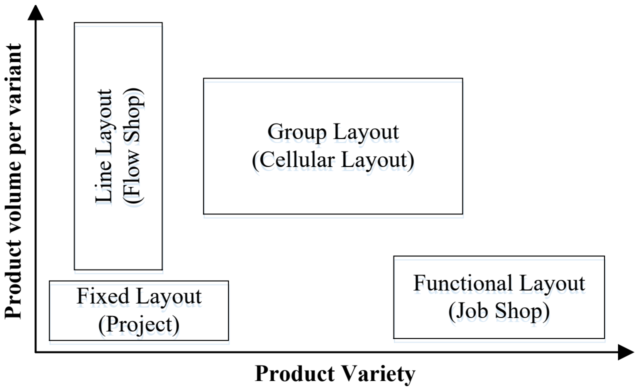


Figure 1. The relation between the layouts, product variety, and production volume per variant.

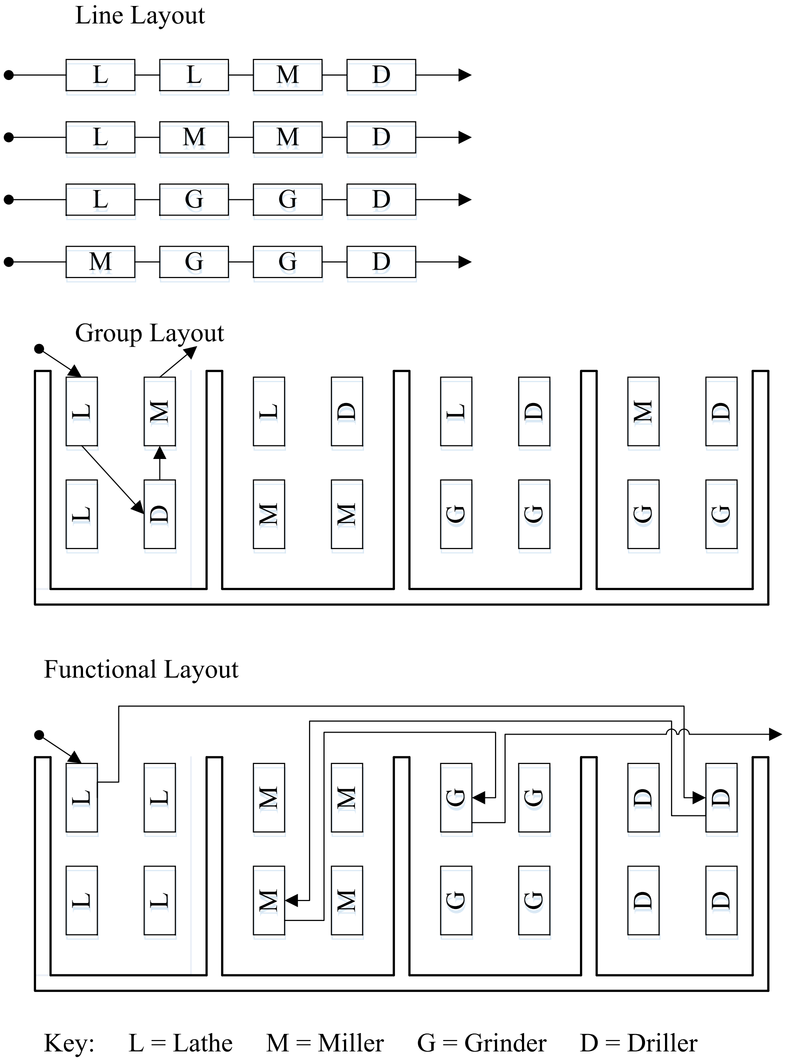


Figure 2. Types of Layout, (Burbidge, 1971).

CMS's Techniques

Several methods may be used by the GT in order to establish those Classical Cells (CCs). For example, (Masmoudi & Hachicha, 2013) group them as such: *classification and coding system*, *machine-component group analysis*, *mathematical and heuristic approaches*, *similarity coefficient based on clustering methods*, *graph-theoretical methods*, *knowledge based and pattern recognition methods*, *fuzzy clustering methods*, *evolutionary approaches,* and *neural network approaches*.

Since this chapter is not only dedicated to CCs and the GT, and since all the techniques of each group are leading to the same *main objective,* there will be a focus on the quality of the results. Instead of explaining all of them in detail, the *classification and coding approach* and the *similarity coefficient based on clustering methods* have been selected for the purpose of this study.

Classification and Coding Approach

(Kusiak & Heragu, 1987) give an overview of the first group that can be named *classification approach* or *classification and coding approach*. It allows to code parts using numbers or letters, or a combination of both. They propose the following four characteristics to implement GT:

1. Required operations
2. Shapes and dimensions
3. Material
4. Tolerance requirement

According to (Kusiak & Heragu, 1987), this approach simplifies the retrieval design, process planning, and scheduling. They listed seven classifications and coding systems among more than fifty systems. C*lassification* systems are very useful. For example, they help employees and all other supply chain partners to be more familiar with the products and facilitate communications. However, they do not consist of a systematic approach and might require many tests before the appropriate system can finally be chosen. Finally, if the facility planner opts for another approach like clustering, it remains useful for all the services involved.

Similarity Coefficient Based on the Clustering Methods

PFA: Product Flow Analysis

(Burbidge, 1971) proposed the Product Flow Analysis (PFA), which is an approach used to introduce the Group Technology (GT) to Manufacturing Companies (MCs). The author defines the PFA as "*an analytical technique which finds the groups and families by a progressive analysis of the information contained in the component route cards. It is based solely on the methods used to make components and is not concerned with the details of their design*." In order to tackle this issue within a crane manufacturer in Great Britain, the author proceeded with three successive level analyses. The first level is called the factory flow analysis. The inputs at this level are routes card samples and plant Layout. Interdepartmental flows are simplified. It is assumed that the company could outsource some components, then this task became relatively easy. The group analysis is the second level of the PFA; it consists of Cell Formation for every department already defined. The method, is based on eight steps that specifically consist of sorting routes in batches in order to specify groups and families. The third and final level is the line analysis, in which the author found the sequence of the layout for the machines, which will give the nearest approximation of line flows. Then it will be easy to install the most appropriate material handling system. It is then possible to conclude that the PFA requires a lot of manual tasks and many interventions on the user side. However, when talking about the requirements of its epoch, it can be considered as an important approach. The next paragraph will introduce another technique based on algorithms.

DCA: Direct Clustering Algorithm

Next, the Direct Clustering Algorithm (DCA) (Chan & Milner, 1982) will be introduced, because it is one simple technique, and because it is cited in about 600 studies (see Figure 3).

(1) Count the number of positive cell entries "K" in each column and row in turn. Rearrange the machine component matrix with columns in decreasing order of "K" and rows in increasing order of "K".
(2) Starting with the first column of the matrix, transfer the rows which have positive cell entries in this column to the top of the matrix. Repeat the procedure with the second column, then the other columns, until all the rows are rearranged.
(3) Are the current matrix and the one immediately preceding it the same? If so, go to 6. If not, go to 4.
(4) Starting with the first row of the matrix, transfer the columns which have positive cell entries in this row to the leftmost position of the matrix. Repeat the procedure with the second row, then the other rows, until all the columns are rearranged.
(5) Are the current matrix and the one immediately preceding it the same? If so, go to 6. If not, go to 2.
(6) Stop.

Figure 3. Direct Clustering Algorithm (DCA) (Chan & Milner, 1982).

	M/C	NO													
COMP NO	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1		x								x	x	x				4
2			x		x			x					x		x	5
3	x					x			x					x		4
4	x			x					x					x		4
5			x		x			x					x		x	5
6	x			x		x			x					x		5
7		x					x			x	x	x				5
8			x		x			x					x		x	5
9				x		x			x					x		4
10		x					x			x	x	x				5
	3	3	3	3	3	3	2	3	4	3	3	3	3	4	3	

Figure 4. Example matrix.

	M/C	NO														
COMP	14	9	15	13	12	11	10	8	6	5	4	3	2	1	7	
9	x	x							x		x					4
4	x	x									x			x		4
3	x	x							x					x		4
1					x	x	x						x			4
10					x	x	x						x		x	5
8			x	x				x		x		x				5
7					x	x	x						x		x	5
6	x	x							x		x			x		5
5			x	x				x		x		x				5
2			x	x				x		x		x				5
	4	4	3	3	3	3	3	3	3	3	3	3	3	3	2	

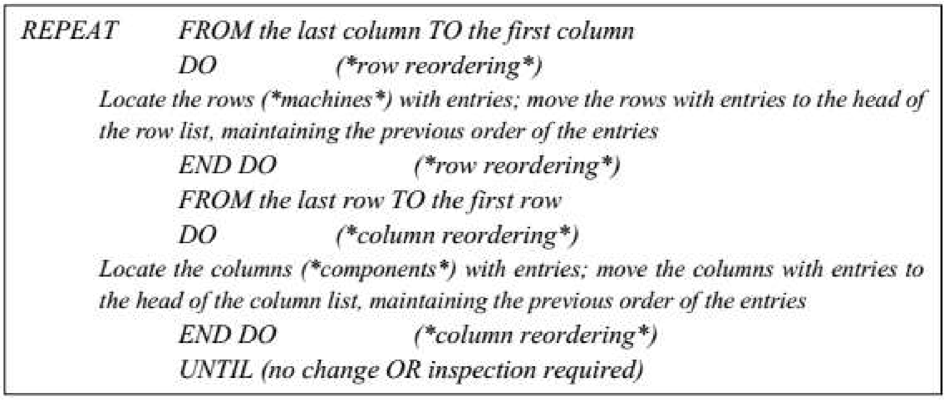
Figure 5. Matrix after initial arrangement.

	M/C	NO													
COMP	14	9	15	13	12	11	10	8	6	5	4	3	2	1	7	
9	x	x							x		x					4
4	x	x									x			x		4
3	x	x							x					x		4
6	x	x							x		x			x		5
8			x	x				x		x		x				5
5			x	x				x		x		x				5
2			x	x				x		x		x				5
1					x	x	x						x			4
10					x	x	x						x		x	5
7					x	x	x						x		x	5
	4	4	3	3	3	3	3	3	3	3	3	3	3	3	2	

Figure 6. Matrix after Row Rearrangements.

	M/C	NO														
COMP	14	9	6	4	1	15	13	8	5	3	12	11	10	2	7	
9	x	x	x	x												4
4	x	x		x	x											4
3	x	x	x		x											4
6	x	x	x	x	x											5
8						x	x	x	x	x						5
5						x	x	x	x	x						5
2						x	x	x	x	x						5
1											x	x	x	x		4
10											x	x	x	x	x	5
7											x	x	x	x	x	5
	4	4	3	3	3	3	3	3	3	3	3	3	3	3	2	

Figure 7. The Finalized Patterns.



```
REPEAT    FROM the last column TO the first column
          DO            (*row reordering*)
      Locate the rows (*machines*) with entries; move the rows with entries to the head of
      the row list, maintaining the previous order of the entries
          END DO                  (*row reordering*)
          FROM the last row TO the first row
          DO            (*column reordering*)
      Locate the columns (*components*) with entries; move the columns with entries to
      the head of the column list, maintaining the previous order of the entries
          END DO                  (*column reordering*)
          UNTIL (no change OR inspection required)
```

Figure 8. ROC2 algorithm, (John R King & Nakornchai, 1982).

The authors proposed the following incidence matrix shown in Figure 4. Figure 5 shows the matrix after the initial arrangement (step 1). Figure 6 displays the matrix after row rearrangements. Figure 7 determines the finalized pattern resulting in column rearrangements. It can be seen in Figure 7 that three independent cells were created. The term “independent” means that every component requires only one group of machines to be produced. In addition, with the proposed algorithm, further steps are suggested in the case of cells dependencies.

ROC and ROC2: Rank Order Clustering

Another algorithm which is similar to DCA is the Rank Order Clustering (ROC) proposed by (James R King, 1980). Instead of calculating the simple sum of the entries for each row and column, the authors suggest using the sum of the decimal equivalents to binary representation. After the calculation of this sum, they proceed first by sorting rows in decreasing order from top to bottom, and then by sorting columns also in decreasing order from left to right, and so on.

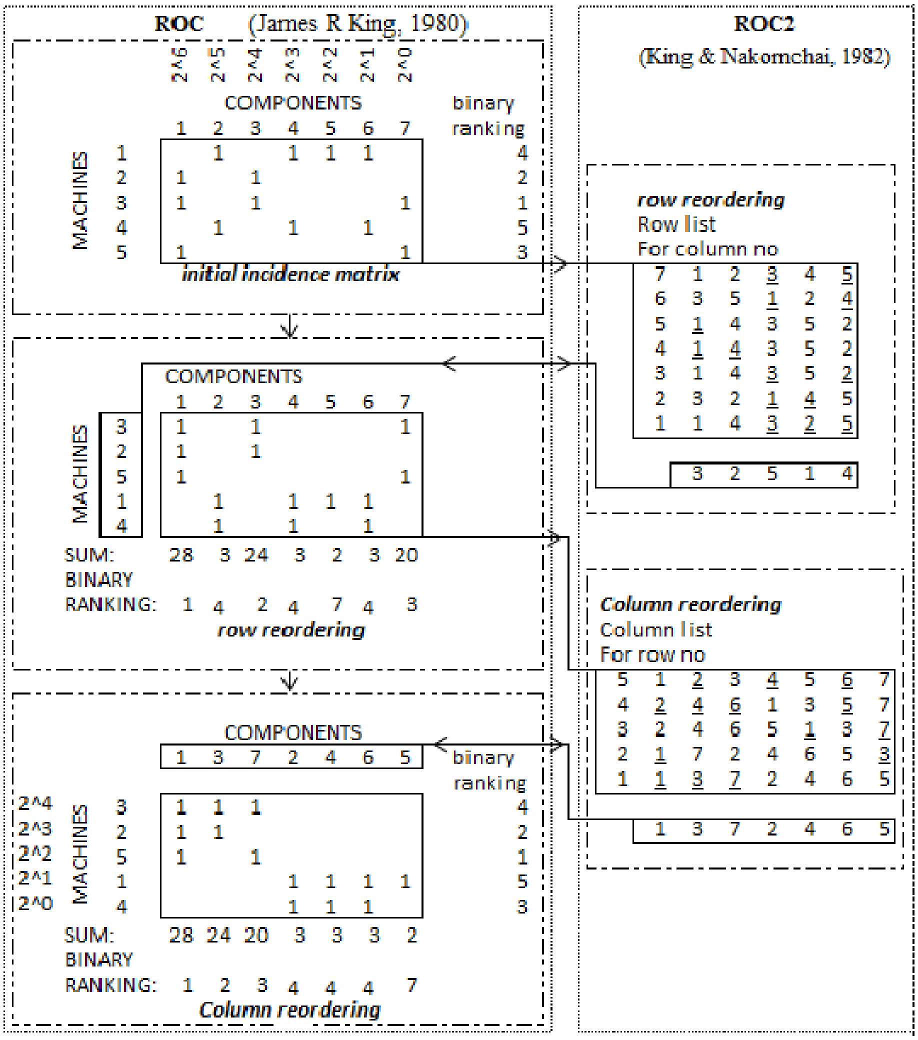


Figure 9. ROC and ROC2 algorithm results.

Techniques of Efficiency Measures

All results of the Direct Clustering Algorithm (DCA) and Rank Order Clustering (ROC) reported respectively in Figure 7, Figure 8 and Figure 9 lead to independent cells. However, this is not always achievable. In this case, some products are manufactured with machines belonging to two or more cells. In a block-diagonal matrix, the elements which are located outside the blocks are called Exceptional Elements (EEs). The presence of such elements can cause a lot of disadvantages, for example the rise of intercellular transportation and the management costs. Indeed, according to the CM context, intercellular transportation costs are very important, and employees do not necessarily have the same hierarchy and standards. In addition, when taking into account the production sequence, one EE can provoke two inter-cell movements. The reader can also imagine other issues resulting in the presence of EEs concerning production planning, scheduling, etc.

Another difficulty to be handled is the presence of *bottleneck machines*. They can be considered as machines required for a large number of components (James R King, 1980). However, it is also important to consider other factors such as the production volume, sequence, operation time, etc. To avoid problems provoked by this kind of machine, the practitioner can duplicate them, especially when a part allocated to two independent cells that shares one of those machines. Other alternatives can be considered, like changing the way of processing the product, augmenting the machine capacity using the extra time, etc.

EEs and *bottleneck machines* can help the practitioner interpret the results more easily. The literature addresses different methods to evaluate the performance of the several techniques of Cell Formation (CF). Among them are the thirteen efficiency measures defined by (Sarker & Mondal, 1999). They are (1) group efficiency; (2) modified group efficiency; (3) efficiency measure pertaining to the inner-cell load; (4) measure of underutilization of an individual machine; (5) group efficacy; (6) grouping index; (7) grouping measure; (8) quality index; (9) grouping capability index (GCI); (10) clustering measure; (11) global efficiency; (12) group technological efficiency; and (13) proportion of exceptional elements (PE).

Other Forms of Cellular Manufacturing Systems

Actually, many types of CMS exist and can be adapted to different environments. For instance, the CMS with the Remainder Cell (CMS-RC), which allows dividing the floor into two areas; the first one consists in one or several cells, and the second one represents a JS. It seems evident that this system enables the reduction of intercellular movements by assigning EEs to the JS area. However, it needs further requirements, like much more time to produce products, because when considering the learning curve, employees working in this area are not necessarily familiar with all products. The Fractal Manufacturing Cells (FCMS) are another form of CF. This consists of transforming the floor of the shop into two or more identical cells. It is then considered as a robust design since it can easily handle external and internal turbulence coming respectively from demand variation and machine breakdown. (Renna & Ambrico, 2011) make a comparison between CMS, CMS-RC, and FCMS through simulation, and they concluded that CMS-RC represents a very interesting solution.

Unfortunately, the systems mentioned above fail to adapt when it comes to some important issues like reliability. A good example would be one shop floor constituted by several independent cells, where each of them is organized following the line layout. Then, if one particular machine broke, it can stop the production of the entire cell, which is equivalent to stopping the production of all the products of one family. In order to give more flexibility to the production planner while creating cells, each cell can be assigned another one which can assist it in the emergence of breakdowns or overload. Those associated cells are called Virtual Cellular Manufacturing Systems (VCMS). (Rheault, Drolet, & Abdulnour, 1995) define a VCMS as "*a logical grouping of processers that are not necessarily transposed into physical proximity*." They allow the assignment of the product family even to one group of distant machines. This method was first proposed by the National Bureau of Standards (McLean, Bloom & Hopp, 1982). While citing this type of cell, it is important to mention that although this concept is very interesting, it requires a lot of preparation, like the development of computer programs, special training, etc.

USING SIMULATION TO EVALUATE THE CELLULAR MANUFACTURING SYSTEMS (CMS)

The thirteen efficiency measures of the block-diagonal matrix in Section (2.3) do not address the common measures in practice, like throughput, Work in Process (WIP) level, lead time, and many others. So, many authors proceed to simulation after the Cell Formation (CF). (Masmoudi & Hachicha, 2013) use simulation to focus more on exceptional elements by analyzing the mean transfer time, the mean flow time, etc. Then they are capable of measuring and improving the process of CF simultaneously. Many other authors use simulation to measure such performances, for example (Drolet, Marcoux, & Abdulnour, 2008), (Ramos & Ferreira, 2013), and (Renna & Ambrico, 2011).

DISADVANTAGES OF THE CELLULAR MANUFACTURING SYSTEMS (CMS)

First, it is important to mention that the CMS is suitable only for a relatively long Product Life Cycle (PLC). However, when the length of PLC varies, this system becomes less attractive. For example, (Abdi & Labib, 2003) underline some CMS disadvantages, for instance: their design, which is dedicated to a part family known in advance, the difficulty of introducing new products, their economic weakness due to the variation of the demand.

DYNAMIC CELLULAR MANUFACTURING SYSTEM (DCMS)

The *DCMS* is a type of *Reconfigurable Manufacturing System* (RMS) based on the *reconfigurations* of the facilities, which are required in order to adapt the floor of the shop to the *dynamic environment*. Those notions will be defined in the following sections of this chapter.

Dynamic Environment

As stated in the introduction, competition and technological evolution are among the main factors responsible for dynamic environment, which is characterized by its turbulence. The intent is not to define all the sources of turbulence or to explain the mechanism of each of them, but rather to directly list the several characteristics of this environment such as reported by (Rheault et al., 1995):

- Highly variable demand, size of production lots and setup times:

Demand variability represents the results of mix variability and/or quantity variability. In a dynamic environment, the production lot size may vary frequently. For example, the use of one new technology can considerably reduce the setup time and can then reduce the production lot size. On the other hand, and as demand increases, the manager also tends to increase the production lot size. In certain cases, and when a new industrial approach such as Just-In-Time is implemented, the production lot size should be modified, since adapting techniques such as Singular Minute Exchange of Die (SMED) or Kanban is then accepted.

- Highly variable processing times:

When employees make the same product every day, they end up becoming more productive due to the effect of the learning curve. Unfortunately, this is not the case in a dynamic environment because the demand variability of Manufacturing Companies (MCs) has an important employee turnover. Consequently, they are sometimes increasing productivity by retaining employees, but sometimes they are obliged to lose the effect of the learning curve and training. This is why many authors consider the possibility of hiring and firing employees in their models.

- Partial or total stochastic demands:

Deterministic demand is the most used form of DCMS. According to the literature, it is also crucial to treat other forms like stochastic and fuzzy ones, and to clarify that even in a deterministic model of DCMS, demand parameters are generated according to some known distributions. Here, the real issue relates to the demand forecasting system. In this chapter, it is assumed that it is already available. For example, in the automotive and aeronautic industries, enterprises have a powerful demand forecast system, and are hence able to communicate previsions to suppliers, and so on. Then, the suppliers know if they will get a new product or not, and should thus be informed about the future production volumes. In this case, the implementation of a DCMS becomes easier since the rearrangements do not necessarily take a year, but can be done in simply a week, a month or several months.

- Variable production sequences:

(Kia, Javadian, Paydar, & Saidi-Mehrabad, 2013) prove that alternative process routing reduces the production costs of the DCMS. Since machine-related technology is always changing, practitioners always try to find at least one suitable route.

Physically Reconfigurable Virtual Cells

(Rheault et al., 1995) affirm that the Virtual Cellular Manufacturing System (VCMS) can profit from processors (work stations) moving to let them reach their full power. In practice, a lot of Manufacturing Companies (MCs) belonging to one of several sectors of activities like aeronautic, automotive, makers of wooden furniture, etc. possess this kind of machinery. For example, in one of the aeronautic industry supplier of composite parts, all machines can be moved, during every shift (molding, deburring, finishing, inspection, and packaging) except autoclave, Computer Numeric Control (CNC) machines, and paint shop.

Definition of the Dynamic Cellular Manufacturing Systems (DCMS)

The last CMS form defined in the previous section leads us to the Dynamic Cellular Manufacturing Systems (DCMS) proposed first by (Rheault et al., 1996). They allow the moving of certain machines when it is economical to do so. Before giving additional details about it, it is essential to define the Reconfigurable Manufacturing System (RMS).

(Abdi & Labib, 2003) state different definitions for the RMSs, and even propose a new one during their design strategy for RMS using an analytical hierarchical process. First, (Koren et al., 1999) define the RMS as "*one system designed at the outset for rapid change in its structure, as well as its hardware and software components, in order to quickly adjust its production capacity and functionality, within a part family, in response to sudden market changes or intrinsic system changes.*" (Abdi & Labib, 2003) define a RMS as "*one system which is expected to be able to adjust rapidly to new circumstances by rearranging and/or changing its hardware and software components in order to accommodate not only the production of a variety of products, which are grouped into families, but also a new product introduction within each family.*"

It can be noticed that the first definition of the DCMS corresponds to the RMS requirements, especially in terms of rearranging and/or changing hardware. In this chapter, the term "hardware reconfiguration" will be used. To be more accurate, a slight modification to the definition of (Rheault et al., 1996) will be included. First, the term "moving" is replaced by "reconfigure" in order to include all reconfiguration possibilities. Finally, the term "economic" will be replaced by "advantageous," because manufacturing companies should focus simultaneously on "the costs," "the quality," and "the delay."

Exhaustive List of Possible Reconfigurations in the Case of DCMS

Replacing the term "moving" by "reconfigure" comes from many researches and observations of real manufacturing systems. The reconfigurations can be grouped depending on the concerned facilities:

Cell Reconfigurations

To the best of our knowledge, only (Kia, Shirazi, Javadian, & Tavakkoli-Moghaddam, 2015) use the cell formation costs in their model in addition to machine installation and uninstallation costs. Other authors only use cell rearrangement, for instance (McKendall Jr & Shang, 2006) and (Tian, Li, & Zhao, 2010).

In this sense, (Kia et al., 2015) mention the fact that if the number of cells to be formed is established in advance, this can lead to the formation of more cells, causing more reconfiguration costs.

Machine Reconfigurations

The list of remaining reconfigurations that directly affect machines will be reported below.

Machine Acquisition

This reconfiguration should be taken into account since its associated costs are very important and it is used to respond to demand variation. Unfortunately, the machine acquisition is not always possible due to budget constraints. This is equivalent to the use of a budget's upper limit bound for duplicated machines for each type, (Kia et al., 2015), (Aghajani, Didehbani, Zadahmad, Seyedrezaei, & Mohsenian, 2014), (Kia et al., 2013), (Javadian, Aghajani, Rezaeian, & Ghaneian Sebdani, 2011), and (Saxena & Jain, 2011).

Machine Installation and Uninstallation

Many research admits that the costs of these two types of reconfigurations are equal. This assumption should be redefined because, in practice, in most cases, they require different costs as supposed by (Bayram & Şahin, 2016), (Aghajani-Delavar, Mehdizadeh, Torabi, & Tavakkoli-Moghaddam, 2015), (Azadeh, Moghaddam, Nazari-Doust, & Jalalvand, 2015), (Defersha & Chen, 2009), and (Chen, 1998).

Moving Machine

In some cases, the costs of this reconfiguration are important and even exceed the installation or uninstallation costs. For example, installing a sewing machine can be done quickly, but moving it to another department can take more time. To the best of our knowledge, it is only used by (Javadi, Jolai, Slomp, Rabbani, & Tavakkoli-Moghaddam, 2014).

Inter- and Intra-Cellular Machine Rearrangement

It is a sequence of the three reconfigurations mentioned above; uninstallation, moving and installation. It is logical to consider that the intercellular one is more expensive.

Machine Rearrangement between Shop Floor and the Machine Depot

Instead of selling idle machines, some authors choose to keep them in a machine depot (Azadeh et al., 2015), (Kia et al., 2015), (Kia et al., 2013), (Javadian et al., 2011), and (Asgharpour & Javadian, 2004).

Machine Storage

After moving the machines to the machine depot, additional costs must be added. To the best of our knowledge, only (Javadian et al., 2011) used this reconfiguration.

Machine Selling

Instead of moving the machines to the depot, companies can sell those machines. This is used by (Azadeh et al., 2015), and (Rafiee, Rabbani, Rafiei, & Rahimi-Vahed, 2011).

Machine Modification

Another reconfiguration able to replace one or many reconfigurations is machine modification. It can replace, for example, the purchasing or the selling of new machines. Finally, it can replace a lot of rearrangements, as published in (Babazadeh, Rafiei, & Rabbani, 2013).

DCMS Models

The DCMS model was first proposed by (Rheault et al., 1996), and it includes 4 modules which are 1) loading and routing module, 2) dynamic cell configurator, 3) scheduling module, and 4) system monitoring. It minimizes the sum of the following costs: cell reconfiguration costs and inter-cell material handling costs.

DCMS, can be grouped into two important groups depending on their objective(s); costs or multi-objectives.

Cost Minimization Models

The focus will only be brought on certain costs mentioned in the literature or judged to be important. In addition, when integrating more costs, the model becomes more complex. Hence, the practitioner should make certain pre-analyses before starting to create his model depending on the enterprise's context. For example, if employee costs such as hiring, salaries, firing, etc., are important and the enterprise has an important turnover, then it has to be included in the DCMS model. The following section will mention some cost-related elements:

Inter-Cellular Material Handling Cost (IE-MHC)

They are the costs that are most used in practice. They can be calculated using two methods: distance based costs or fixed costs. It is evident that the second method is more attractive.

Intra-Cellular Material Handling Cost (IA-MHC)

Usually, this type of cost is neglected. In addition, it is unfortunately not possible to assess if it represents a good solution or not. ICA-MHC depends on the enterprise's activities. For example, in the case of distant work stations inside one cell, these costs should be considered. Some studies consider it in more detail by dividing it into two types of costs:

Forward Intra-Cellular Material Handling Cost (FIA-MHC) and Backward Intra-Cellular Material Handling Cost (BIA-MHC).

Reconfiguration Cost

Depending on the reconfiguration activities mentioned in section 3.4, it is possible to use those relative costs; Machines Acquisition Cost (MAC), Machines Rearrangement Cost (MRC), Cells Rearrangement Cost (CRC), and Cell Formation Cost (CFC).

Maintenance Cost

Certain authors work with Machine Failure Cost (MFC), like (Sakhaii, Tavakkoli-Moghaddam, Bagheri, & Vatani, 2016) and (Saxena & Jain, 2011), and others use Machine Maintenance Cost (MMC).

Employee Cost

Certain costs found in the literature can also be pointed out, for example, Employee Hiring Cost (EHC), Employee Training Cost (ETC) (Sakhaii et al., 2016), and salaries.

Production Cost

The production costs related to machines can be divided into two important groups. The first one is the Machine Fixed Cost (MFC), which is also called “overhead cost”; the limit between MHC and the maintenance cost should be defined, since some authors include maintenance costs in MHC. The second one is the Machine Variable Cost (MVC). It can be divided into two subgroups, namely MVC on Regular Time (MVC-RT) and MVC on Extra Time (MVC-ET) (Ghotboddini, Rabbani, & Rahimian, 2011) and (Rafiei & Ghodsi, 2013). The second sub-group is very important because it allows for the handling of some demand variation, and especially of an increased demand.

Product Sub-Contracting Cost (PSCC)

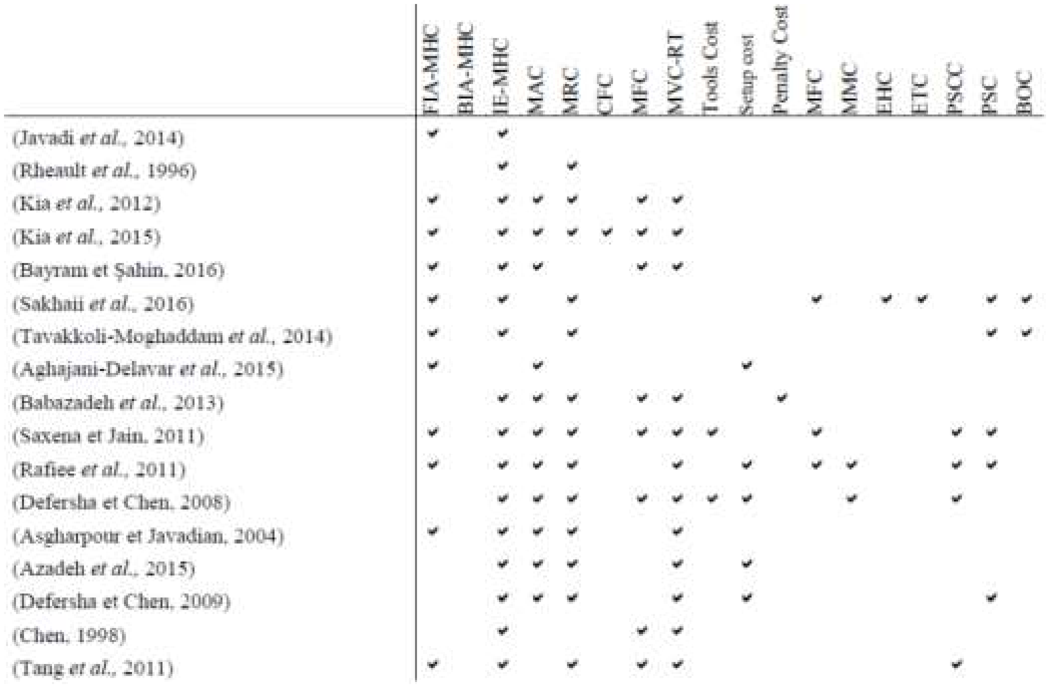
Another way of dealing with demand variation is by subcontracting. (Aghajani-Delavar et al., 2015), (Azadeh et al., 2015), and (Rafiei & Ghodsi, 2013) are randomly selected as a group of authors using this alternative. This can affect the whole production or certain production operations.

Product Storage Cost (PSC)

This alternative should be chosen to respond to demand variation, but with great caution. In certain cases, product storage in the presence of a dynamic environment can represent a serious risk, especially at the end of its life cycle.

Back Order Cost (BOC)

In our context, the loss of orders is very probable. In addition, some companies are charged an extra fee when shipping orders with lateness, (Javadian et al., 2011), (Sakhaii et al., 2016), and (Tang, Nouri, & Motlagh, 2011).



	FIA-MHC	BIA-MHC	IE-MHC	MAC	MRC	CFC	MFC	MVC-RT	Tools Cost	Setup cost	Penalty Cost	MFC	MMC	EHC	ETC	PSCC	PSC	BOC
(Javadi *et al.*, 2014)	✓		✓															
(Rheault *et al.*, 1996)			✓		✓													
(Kia *et al.*, 2012)	✓		✓	✓	✓		✓	✓										
(Kia *et al.*, 2015)	✓		✓	✓	✓	✓	✓	✓										
(Bayram et Şahin, 2016)	✓		✓	✓			✓	✓										
(Sakhaii *et al.*, 2016)	✓		✓		✓							✓		✓	✓		✓	✓
(Tavakkoli-Moghaddam *et al.*, 2014)	✓		✓		✓												✓	✓
(Aghajani-Delavar *et al.*, 2015)	✓			✓						✓								
(Babazadeh *et al.*, 2013)			✓	✓	✓		✓	✓			✓							
(Saxena et Jain, 2011)	✓		✓	✓	✓		✓	✓	✓			✓				✓	✓	
(Rafiee *et al.*, 2011)	✓		✓	✓	✓			✓		✓		✓	✓			✓	✓	
(Defersha et Chen, 2008)			✓	✓	✓		✓	✓	✓	✓			✓			✓		
(Asgharpour et Javadian, 2004)	✓		✓	✓	✓			✓										
(Azadeh *et al.*, 2015)			✓	✓	✓			✓		✓								
(Defersha et Chen, 2009)			✓	✓	✓			✓		✓							✓	
(Chen, 1998)			✓				✓	✓										
(Tang *et al.*, 2011)	✓		✓		✓		✓	✓								✓		

Figure 10. The cost elements that are most used by DCMS (Nouri & Abdul-Nour, 2016).

Multi-Objective Models

For further cost minimization, facility planners can take into account many other objectives, see Figure 11:

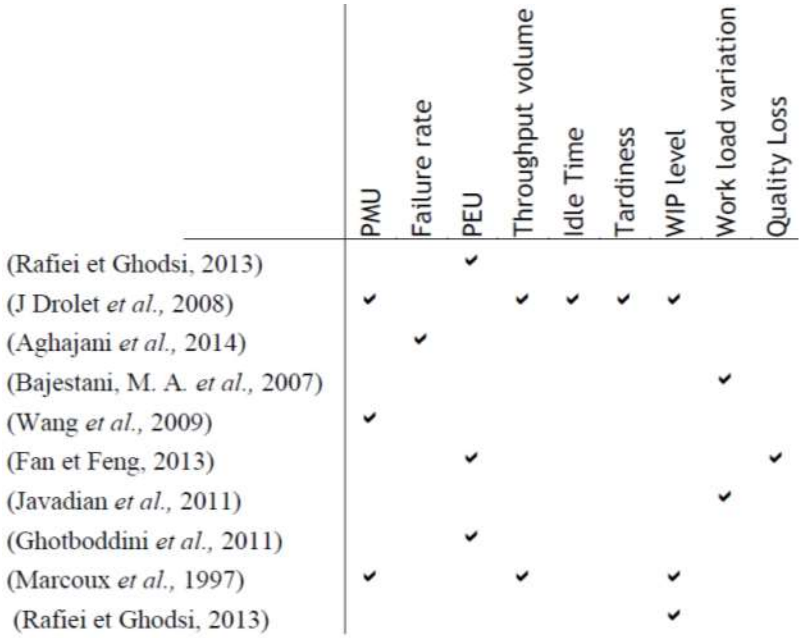
- The maximization of the percentage of machines and employees' utilization, which are respectively called (PMU) and (PEU)
- The minimization of the throughput time
- The minimization of the Work in Process (WIP) level
- The maximization of the machine's reliability.
- Optimization of failure rate, throughput volume, idle time, lateness, work load variation, quality loss, etc.

According to the figure above, (Drolet et al., 2008)'s model can integrate 5 objectives among 9. The particularity of this study is the use of the simulation and the Design of Experiments (DOE) together. This approach can make several comparisons between two or more layout alternatives.

Functions of the DCMS

In addition to forming Dynamic Cells, many DCMSs can perform multiple other functions, for example Group Layout (GL), production planning (PP), Resource Allocations

(RA), Group Scheduling (GS), and reliability improvement. Then, the complexity of the DCMS can increase proportionally with the number of integrated functions.



	PMU	Failure rate	PEU	Throughput volume	Idle Time	Tardiness	WIP level	Work load variation	Quality Loss
(Rafiei et Ghodsi, 2013)			✓						
(J Drolet *et al.*, 2008)	✓			✓	✓	✓	✓		
(Aghajani *et al.*, 2014)		✓							
(Bajestani, M. A. *et al.*, 2007)								✓	
(Wang *et al.*, 2009)	✓								
(Fan et Feng, 2013)			✓						✓
(Javadian *et al.*, 2011)								✓	
(Ghotboddini *et al.*, 2011)			✓						
(Marcoux *et al.*, 1997)	✓			✓			✓		
(Rafiei et Ghodsi, 2013)							✓		

Figure 11. Some Multi-Objective DCMS reported by (Nouri & Abdul-Nour, 2016).

CASE STUDY: THE DCMS IN AN ELECTROMECHANICAL ASSEMBLY INDUSTRY

Introduction

It is known that growth is one of the most difficult issues faced by organizations. An enterprise starts, finds and retains customers and gets a growing space on the market. If in the beginning the sales are the true bottleneck, it is only a matter of time before the production lags behind. Inefficiency and the hidden wastes in production get bigger as an enterprise grows. When growth slows down, it is time to take over control.

The enterprise studied here grew significantly over the last 10 years. The initial space and optimization techniques used could no longer respond to the incessant and growing demand. The efficiency of the operations, the inventory management, the information and material flow, the communication channels and much more had become outdated. A whole new philosophy needed to be implemented within the enterprise: *lean management*. Being in a competitive market where efficiency and flexibility are vital, the organization had to drastically modify its way of doing and thinking. For instance, at the beginning of the project, all the tasks would be done in a sequential order. A first glimpse of *lean* suggests overlapping tasks. This is where DCMS starts to become interesting.

Due to an agreement between CNRC, Mitacs, Université du Québec à Trois-Rivières and an electromechanical assembly industry in Québec, it was possible to test the effects of a

DCMS on the field. The implementation lasted 24 months. During the first 6 months, data were collected in order to better understand the reality of the enterprise, the scope and the importance of their work as well as the side effects of such a change inside and outside the organization. The other 18 months have been spent on the implementation phase.

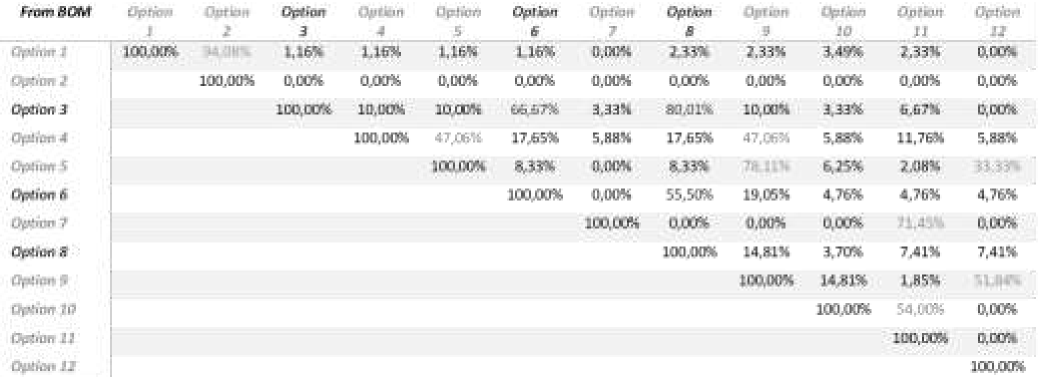
This case study will cover a quick overview of the value stream mapping of the project and logic behind the layout development. The implementation phase will also be explored, followed by the results of such a project. An analysis of the results will be discussed where, right after, the key success factors will be underlined. This study will end with a brief conclusion.

Value Stream Mapping

During the first month, a Value Stream Mapping (VSM) was conducted in order to better understand the enterprise as a whole. Several observations were noted during this study. It appeared that the floor layout, the scheduling system, the quality control procedures, the use of the ERP system, the inventory management, the material's availability, the work methods, the training and leadership in production, the cleanliness of the workplace and even the engineering were either lacking or needed to be revisited. The Overall Equipment Effectiveness (OEE) was also calculated to obtain a quantitative idea of the effectiveness of the plant.

Considering the type of products that the enterprise manufactured, the DCMS seemed to be a convenient solution. The final products were composed of quite standard options that could be integrated in different combinations on the main frame of a machine. The combinations, and also the length and the width of the machine – and the options – could change, depending on the customer. The dynamic cells would then manufacture the options that would be pulled by a mix line.

Table 1. Similarities between the different options



From BOM	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9	Option 10	Option 11	Option 12
Option 1	100,00%	34,88%	1,16%	1,16%	1,16%	1,16%	0,00%	2,33%	2,33%	3,49%	2,33%	0,00%
Option 2		100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Option 3			100,00%	10,00%	10,00%	66,67%	3,33%	80,01%	10,00%	3,33%	6,67%	0,00%
Option 4				100,00%	47,06%	17,65%	5,88%	17,65%	47,06%	5,88%	11,76%	5,88%
Option 5					100,00%	8,33%	0,00%	8,33%	78,11%	6,25%	2,08%	33,33%
Option 6						100,00%	0,00%	55,50%	19,05%	4,76%	4,76%	4,76%
Option 7							100,00%	0,00%	0,00%	0,00%	71,43%	0,00%
Option 8								100,00%	14,81%	3,70%	7,41%	7,41%
Option 9									100,00%	14,81%	1,85%	51,84%
Option 10										100,00%	54,00%	0,00%
Option 11											100,00%	0,00%
Option 12												100,00%

In this example, 4 groups were generated: Options 1 – 2; Options 3 – 6 – 8; Options 4 – 5 – 9 – 12; and Options 7 – 10 – 11. Each group would represent a manufacturing cell where every option composing the group could be assembled.

Standardization and Modular Structure

Following the VSM, a Pareto study was conducted to see all the different products/options that could be manufactured in the enterprise. They were then put in a flowchart, in a precedence diagram and in a similarity matrix, to see the resemblance in production and their potential grouping. Table 1 gives an example of a similarity matrix between the parts composing every option.

After recognizing the groups, the engineering department worked on the design to standardize the options even more as well as enhancing the similarities between the options of a same group. By standardizing and redesigning the product, a modular structure approach can be developed. Every option became a different module, standardized at best, and with few differences at worst. The more standardized the components and the sub-assemblies are, the better it is for the manufacturing system.

DCMS and Networks

At the very beginning of the project, the production plant worked with one manufacturing cell and many fix layout workstations. Each employee worked on his/her machine from the beginning to the end. They were the “specialist” of their machine and performed all the tasks sequentially. After finalizing the assembly, they moved the machine to another workstation where the fine tuning was done by another employee. After a few days of fine tuning, the machine was packed up and shipped.

The one manufacturing cell was the foundation of all the future layouts. This specific option did not change much between each order. It was then decided to assemble it in parallel in an autonomous workstation. When ready to plug in the final machine, the option was moved to the fixed line and assembled. The idea to work in parallel was reproduced with all the other options. Figure 12 shows the interest of working in parallel instead of sequentially. Globally, this method reduces the cycle times (CT) required per product. In other words, it reduces the overall lead time considerably. Each square in the Figure represents a manufacturing cell where the groups formed in the previous section are shown and where the tasks are balanced.

As the weeks went by, the enterprise continued standardizing and modularizing their products and options. Some modules and small sub-assemblies were even outsourced. This is where the networks were introduced. The expertise of the enterprise was in the design, the R&D, and the knowledge of its product. It does not mean that standard components and modules cannot be manufactured by another company. In this situation, the enterprise no longer needs to worry about manufacturing the product, nor about order, store and handle every component of the modules. It reduces the space needed for production as well as the space for storing and handling the parts. Overall, outsourcers are often specialists of their specific module. They then become better at doing it, meaning a lower cost and a higher quality. In this sense, in this case study, suppliers became integrators who manufactured complete modules, ready to plug, and of high quality.

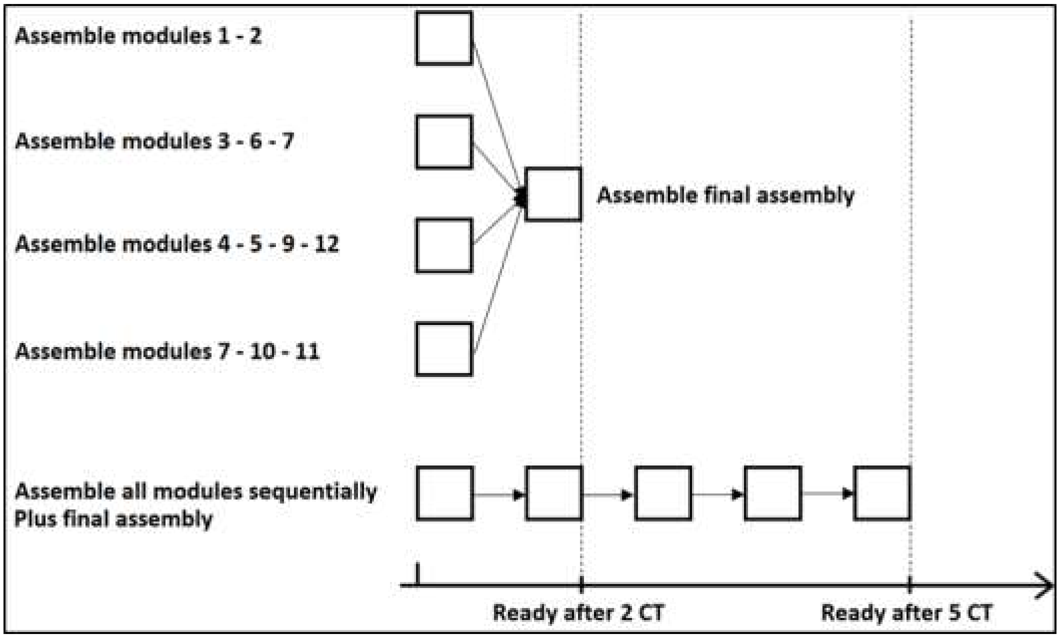


Figure 12. Parallel lines vs Sequential workstations.

For both the enterprise and its outsourcers, knowing that variations in the products and the volumes of each module can occur, it was important to develop a layout that could support these changes. This is where dynamic cellular manufacturing systems (DCMS) become interesting. DCMS can manufacture modules and feed a mix line. All the work is then done in parallel and in the most flexible way possible. This system ensures that the cells are used for the best option, at the right time and by the right number of workers, and the size of the manufacturing cells ensures that it is possible to work either alone or in teams of 2 in a single cell. This would then help to properly respond to the changes in demand.

With all the considerations mentioned above, layout alternatives were developed, improved and finally approved. A line balancing system and a different handling system were also proposed in order to optimize the efficiency of the plant and to respond better to the actual and future customer's demand.

Implementation

Structure and Human Resources

The implementation phase started with an important meeting where all the potential actors were present. The meeting was necessary to make sure that everyone was feeling concerned and motivated, and that they understood the objectives of the project as well as their respective roles during and after the implementation. It was also a good opportunity for all members to clarify uncertainties and preoccupations about this whole project. The implementation started after the meeting.

Since the enterprise is mainly specialized in assembling, moving workstations consisted of moving tables, hand tools and racks. The first problem encountered was the decentralization of the material. At the beginning, besides the one manufacturing cell, all the components were kept in the warehouse and brought to the assemblers by a clerk. The autonomous cells require a fair amount of many different components really close to the work table. Despite what had been understood from the ERP seller, the ERP system could not sustain this type of decentralization. At first, every component had its assigned place, and the system knew the exact amount of each component in real time. Due to the programming of the ERP system, the decentralization forced the storekeeper to quit knowing exactly "how much is where." Responsibility was then assigned to the assemblers, so that they consume exactly what they need and how much they need for assembling one or another product. They had to indicate every part used in the ERP system so that the storekeeper could know exactly "how much is available."

The resistance to change was also a constant consideration, even if the employees were involved in the process from the very beginning of the project. The employees were consulted for almost every important change in production. Phases regarding the mood of the employees could, however, be noted. On some days, everything would be fine, and on some other days, nothing worked. On a day-to-day basis, everyone could not see all the changes implemented. Motivation had to be consistently stimulated. When problems occurred during the implementation, punctual teams were built up so they could discuss the problem using the DMAIC method. This method ensured that the problems were well understood, the potential solutions analyzed, implemented and controlled. Throughout the project, a human and an active listening component were put in place in order to ensure that the changes were understood, accepted, and integrated.

On a day-to-day basis, priorities were not always easy to set. When issues occur in a plant, it is hard to stay blind to them. For example, when an assembly does not seem to work properly, or when a customer asks for the impossible, it is hard not to address the issue. On a day-to-day basis, it may be hard to take some time for continuous improvement, but goals were set and a time frame was given. All the actors had to keep that in mind in order to achieve a convenient layout in the time allotted.

Among all the changes the enterprise needed in the beginning, the DCMS was the initial step. With a new layout in place, problems that were first ignored now surfaced. With a new layout, things were getting more and more in control. Things had their specific place where they needed to be. People had their specific role to play. Everything was being restructured and clearer than ever. By taking ownership of the project, employees could rapidly notice particularities that would not go in the "right direction." Due to the quick involvement of all the employees in the process, several were mobilized and stimulated in participating in the improvement of the enterprise. They now had an ear that would listen to them and to their ideas. People now felt they were listened to and that things would change if they spoke.

As the days went by, the DCMS were more and more used, structured and understood. All the tables were set in cells that were fed by racks of parts situated right next to and behind them. The racks were fed by a clerk using a Kanban method. Some custom parts were, however, brought to the assembler via a bin just in time for the new order. In some cases, the assembler had to go get the bin himself in the warehouse. All the bins were nevertheless full and ready to use. A natural balancing was often used in order to improve the overall efficiency, optimize the local bottlenecks, and lower the lead time. Employees were now working in teams instead of on their own. They were now focusing on getting the machines out as quickly as possible, and in good condition. They did not have "their machine" to themselves. Instead, they overlapped the work in order to shorten the lead time, as well as the amount of work in progress.

Performance Control

To control a system's performance, it is important to measure it. In the studied enterprise, some indicators were already used. The lead time, delay to the customer and a ratio of sales by resources were the main indicators measured. Other indicators such as the operation time per task, productive work time, number of errors in the engineering folders, and amount of work in progress were implemented in order to get a better control of the process.

Files, tables and graphics were developed in order to facilitate the analysis. Graphics were updated in real time and displayed on a computer screen directly in the production plant. As the months went by, the indicators became a source of motivation as well as a good way to inspire new improvement projects.

Side Projects

Every day, new issues were faced, and many of them led to a new side project. The first side project was the implementation of the Kanban. Then, many followed so that the new DCMS structure could operate successfully.

Scheduling was one of the main issues in the new structure. At the beginning, scheduling was made by the sellers who would prioritize the most convincing customers. They would then tell the operation director to make his priorities fit in the production process. This way of functioning caused many disruptions in the workflow. The lines were not balanced. The orders were started in a hurry, then stopped because the customer was either not ready to receive his product or the supplier could not ship the special parts quickly enough. The project was then brushed aside to come back as a rush in a few weeks. Employees were overloaded and always moved from one machine to another. During this same period, the operation times were not known by anyone, and the ERP system could not give a convenient scheduling module so that the operations director could do his job properly.

Many tools were developed to sustain the DCMS and the new workflow. Training was given to the operations director so he could better understand the foundations of scheduling. Excel folders and a Gantt chart were developed to help the scheduler in his daily operation. Meanwhile, a contract was given to the ERP programmer to develop a new scheduling module for the system. The new module was implemented in the last month of the project.

On the other hand, the quality system was non-existent at the beginning of the project. Nonconforming parts would be brought to the assembler, and it would only be noted at the moment of use, causing important wastes in production. Designers and the assemblers also made occasional mistakes in their work. The errors were generally discovered later in the process, causing breaks and loss of time. Moreover, the aspects of nonconformity were not logged anywhere. It was then impossible to know what happened to which machine and on how many occasions this same problem occurred. The structure brought by the DCMS forced the enterprise to develop a new quality-related system and new quality-related procedures. A logbook and weekly meetings were implemented so it was possible to keep track of the problems, address them and resolve them once and for all.

In order to optimize the use of the employees' time, many changes were made concerning the availability of the material and tools. First, a 5S was made so the new workstation could be in order and well organized. A strong awareness was made in order to keep the new workplace clean. New tool panels were developed and installed on the workstations so the employees ceased looking for their tools in their toolbox. Also, no machine could henceforth be launched if every single part or component was not in the enterprise, as opposed to what was being done initially.

An advanced training was given to several employees so they could now operate more workstations and encourage natural balancing. The initially hidden knowledge was also transferred thanks to that.

Another long-term project consisted in completely reviewing the bills of material and specifications with the customers. There were many subtleties and flaws that the customers took advantage of. They also frequently asked for last-minute changes that the enterprise could not reject. Often the project was already started, and almost finished. The refusal of the customer's change could have led to the complete break of the contract. In terms of the implementation of the DCMS, this project was not yet finished.

In this new system, leadership, communication and team management skills were essential. At the beginning, the operations director lacked some of these skills. Training and education were used so he could learn more about them. Daily and weekly meetings were implemented so the communication would be easier and more frequent. Reports were prepared and sent to everyone concerned. Feedback was made to ensure better understanding of the interlocutors. Finally, performance indicators were developed and shared to keep a good eye on the production's reality.

Globally, all these side projects were necessary to ensure the success of the DCMS. Many of them were already known. Some were exposed due to the changes. Some were small changes that had a considerable impact. For example, a wheel system was developed to facilitate the handling of the machine. This helped to reduce the handling time by a factor of three. The effects of the DCMS are finally not only direct. They affect the way everything is done and have an impact on every other aspect of a production plant.

Results

An interview with the enterprise at the end of the implementation process allowed to discuss the effects of the DCMS on the overall performance. At the end of the 24 months, the lead time went from about 50 hours per customer's order to 38 hours (reduction of 24%). The turnover was improved by 350%. The amount of work in progress reduced by 12.5%). Finally, the time-to-customer delay went from 59 hours to 45 hours (reduction of 23.7%). All these changes were possible with the exact same number of employees and the same plant size.

After the implementation, the enterprise could feel a better overall organization and a better structure in all its operations and procedures, both in terms of engineering and production. They also noted that they had a more efficient and inclusive communication within all departments and a much better scheduling method. The establishment of a continuous improvement procedure and of an effective quality system as well as the complete change of mentality and philosophy were non-quantitative, yet significant results that the enterprise underlined during the interview. Many employees even stated that they now felt “the structure of a big organization,” yet they still felt “the familiarity of a small and medium-sized enterprise.” In other words, they now know they have to be more focused on performance and overall organization, but all this seems possible without disrupting the love they have for their job.

On the engineering side, the team put a completely new structure in place as well as a new way of doing things. Although at the beginning they caused many errors, they are now more aware of the impacts of their errors on production. New procedures were implemented to help them decrease the number of possible mistakes they could do. Having a channel of knowledge sharing, both production and engineering could tell and hear the impact of each other’s work. Weekly meetings between production and engineering now occur. Designers have now almost gone daily at the plant in order to better understand design errors and last-minute changes when it comes to assembly. Time is also given to the engineers and designers to fulfill production tasks and improvement projects so they are not overloaded with common engineering tasks. All these changes caused a significant reduction of errors as well as a better tracking system so they can be solved directly at the root.

To give a better idea of the changes in the engineering department, checklists and procedures were developed and implemented so no designer could forget anything during all their projects. A new procedure of “last-minute change” was also developed so every potential actor concerned by the change knows the impact of the change. They could then execute all the consequent tasks before the last-minute change gets to the assembler. They now hold a weekly meeting to make sure everyone knows the changes, procedures and information concerning their department. At last, meetings with the production team now include all the designers so everyone knows exactly what is said during the meeting. A record is also written and distributed with the minutes of the meetings, as well as a to-do list for the coming week.

Analysis of the Results

The results mentioned in the last sections demonstrated the interest of the DCMS as well as their impact on efficiency and flexibility. They also showed that a dynamic cellular manufacturing system cannot be dissociated from all of the other “improvement tools.” In order to make the DCMS work properly, scheduling, training, quality, handling, engineering and all of these tools were not only helpful, they were inevitable. Since they are all intertwined, there is no logical order in their respective development. It was judged at the beginning of the project that a new layout could bring the necessary structure so that all the other changes could happen in a convenient and organized environment. Naturally, some parts of the implementation of the layout require the interaction of other improvement tools. The necessity of the Kanban method and the decentralization of the warehouse is one example. It became impossible to make the cells work properly without changing the way of managing the inventory completely with the ERP system. The 2 projects were then conducted in parallel so the ERP system could respond exactly to the current and future needs in terms of inventory management. Later, it was realized that the operation times were not precisely determined. This impacted the scheduling system, as well as the line balancing. In order for the newly formed cells to work, the operation times had to be collected and analyzed so that a better planning system could be developed.

It would probably have been possible to lead off the project with another improvement tool. The order and the structure provided by the DCMS were, however, prioritized, which explains the choice to start with the layout.

The DCMS led to the standardization of the products so the cells could be functional. The standardization helped in reducing the lead time by overlapping the tasks due to the newly standardized options the DCMS could assemble. Consequently, the enterprise gained in operational efficiency and reduced the amount of work in progress at the plant. They also generated a reduction in the cost of engineering, as well as in the acquisition and inventory cost of the material. The standardization led to a modular design where the modules are what is built in the dynamic cells. The modules are mostly standard, but can still work out with few differences from one to another. The idea is to limit the differences by proposing as vast, yet reduced, variety of options to the customer.

Besides engineering, the DCMS led to a new scheduling method due to the overlapping. By reviewing the planning system, issues were found and could then be solved. Furthermore, an autonomous cell cannot work properly without good components and tools. This led to the implementation of a quality system as well as the creation of tool panels and trolleys, etc. In short, the DCMS brought the enterprise to a whole new level, in and of itself, by imposing the structural changes they would not have done otherwise.

To summarize, the results after two years of implementation were interesting. A reduction of the lead time by 24% and a gain in the turnover of 350% are somehow attractive. As the months go by, the enterprise always gets better with regards to continuous improvement. It better understands the use of the DCMS as well as its interaction and its close bonds with the other tools. It would not be surprising if they improved these results even more after a few years of use.

Key Success Factors

Besides studying the effects of a DCMS in an enterprise network, this case study helped to establish and validate the key success factors of the implementation of such a project. A list of the key success factors is given here.

- Support and commitment from top management
- Employees’ involvement
- Desire to change and improve
- Employees’ desire regarding personal achievement
- Freedom and autonomy given to the project manager
- Availability of human and material resources
- Listening and active participation of employees and managers

- Integration of all departments in decision-making
- Integration of suppliers in some projects
- Clear and well-defined objectives
- Control and monitoring after each step and each project
- Ongoing communication between all stakeholders

Thanks to these factors, it was possible to considerably improve the efficiency and the flexibility of the studied enterprise. Without these, it would have been substantially more arduous to implement that many improvement projects, and to validate the impact of these tools and their interaction in the studied context.

Managers and enterprises interested in implementing the DCMS or any other improvement project are encouraged to get inspired by this list. The adoption of all of these elements will significantly increase the probability of success of the implementation of the DCMS, as well as its potential results.

Control

At the end of the 24 months, the manager of the enterprise felt that everything was not yet going entirely as he wished. Since this new policy had been adopted fairly recently, he asked for a control phase that would last as long as it takes until he feels they have complete control over the process. Even if many tools had been implemented, that did not mean they had full control over them. It even happened that some of these tools were left aside because either employees did not remember a procedure or they did not have the time to complete it due to an overload of jobs, or they just did not feel the interest of using the tool.

In order to keep track of what had been implemented and to see the evolution of the use, the non-use and the mastery of the different tools, an audit procedure was developed. Visits from a consultant acting as a “mystery shopper” were held one to four times a month to make sure there was an evolution and an improvement in the process. A list of about 20 points of interest that would regroup every single side project as well as the implementation of the DCMS was created so the consultant knew exactly where to look at and what to look for during his visit.

Points like “Correct use of the dynamic cells,” “Line balancing,” “Scheduling method,” “Material availability,” “Quality of raw material,” “Inventory management,” “Use of Kanban,” “Engineering,” “Communication,” “Training and education,” “Performance indicators,” “Management and leadership,” and “Continuous improvement” are examples of what was evaluated during the visits. Every point was rigorously studied by interviewing every potential actor (operations director, engineers, storekeeper, assemblers, sellers, managers, etc.) and by reading different reports and documents that were written in between the visits.

The points were then evaluated considering the implementation project, including the side projects, as well as the newly implemented projects. A report was written and given to the operations director who would transfer every task and information to whom it may concern. A score was given with the report. It would represent the percentage of satisfaction in the use of the implemented tools and the production processes. The manager asked for a score of at least 95% to consider he had control over his processes.

CONCLUSION

In light of this information, it is clear that a DCMS can significantly improve an enterprise's performance as well as its structure, organization and philosophy. The standardization proposed by the DCMS led the enterprise to opt for a modular structure. This greatly changed their way of designing, and they thereby improved their efficiency and profitability even at the design stage. Some of their modules were even transferred to outsourcers, removing the complexity of managing all of their specific parts and their respective quality. The modules henceforth arrived tested and ready to attach to the main machine. Without knowing, they developed a network who assembled ready-to-use modules and who sent them directly to a mixed line. They thus improved their efficiency and flexibility while increasing their quality and adaptability to change and reducing their lead time and product's total costs.

As time went by, the dynamic cells were adapted to better respond to the enterprise's needs. They used one to two people to work on the cells, and the cells would assemble whatever the module the mixed line needed. Some final products were even completely standardized and were sold just-in-time. One or two final products were held in stock, sold immediately and rebuilt to fill in what was consumed. By drastically reducing their delay, the sales of these products increased significantly.

Continuous improvement became part of the company. Every employee thought of new potential projects they could run to improve efficiency. Methods were implemented so that the transfer of ideas was done properly. As the weeks went by, the enterprise always needed to know a little more about the changes brought by the DCMS. The engineering team was more involved in production. Scheduling was always a little more improved in order to better correspond with the enterprise's practices, etc.

The improvement of the performance of an enterprise as well as its network is crucial for their survival within the global competition. The dynamism of the market and uncertainty of the demand requires balancing productivity and flexibility. The DCMS allows to improve both, and this case study helped in better understanding the reality of a real implementation of a dynamic cellular manufacturing system and all its corresponding impacts. Side projects like line balancing, planning and quality systems, engineering design and communication canals all helped in achieving a successful project. The control phase is nonetheless important and has to be conducted so that the changes are maintained. At last, the key success factors mentioned above also have to be considered, understood and utilized to ensure a good progress in the implementation of all improvement projects.

This case study may be used as a guide or an inspirational story to get to know the interest of the DCMS better as well as their impact on an enterprise's performance and philosophy. It also discussed the attitude to adopt in the face of continuous improvement, and a manager interested in implementing the DCMS is encouraged to thoroughly read this case study. By doing so, it is very probable that its overall performance will be significantly improved.

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