Detailed Design of Product Oriented Manufacturing Systems

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ABSTRACT

This paper presents a procedure for the detailed design and redesign of manufacturing systems within a framework of constantly fitting production system configuration to the varying production needs of products. With such an approach is achieved the design of Product Oriented Manufacturing Systems – POMS. This approach is in opposition to the fitting, before hand, of a production system to all products within a company. In this case is usual to adopt a Function Oriented Manufacturing System - FOMS, which, rarely require reconfiguration and apparently can deal with such a variety. The detailed design depart from conceptual manufacturing cell configurations and develops from there, through conceptual cell instantiation, the required detailed manufacturing system configuration needed for efficiently and effectively manufacture a product or a family of similar products. Therefore manufacturing requirements of products, based on available or accessible human resources and technology, i.e. manufacturing resources and know-how, as well as production demand are essential inputs to the design of suitable manufacturing configurations for the range of products to manufacture in a given period.

1. INTRODUCTION

Traditionally a manufacturing cell has been identified as a system dedicated to the manufacture of a family of identical parts. The manufacture based on a setting of such cells is usually referred to as Cellular Manufacturing.

A more comprehensive definition of a manufacturing cell points to a manufacturing system that groups and organizes the manufacturing resources, such as people, machines, tools, buffers, and handling devices, dedicated to the manufacture of a part family, or the assembly of a family of products, with identical or very similar manufacturing requirements. Therefore important economies of scale can be obtained producing for economies of scope, i.e. for a variety of products.

This approach of identical or very similar processing of similar objects is known as Group Technology (GT) (Gallagher, 1973). It is for this reason that manufacturing systems based on cells are frequently associated with GT. Burbidge (1989) referred also that the GT objective is: “to form small organizational units which complete all the set (or family) of products or components which they make, through one or a few major processing stages, such as metal founding, machining and assembly, and are equipped with all the machines and other processing equipment they need to do so.”

Although Cellular Manufacturing System (CMS) can have a beneficial impact on manufacturing operations of an enterprise, the full benefits of such product-oriented approach to production can only be realized when overall production is considered, as Burbidge (1989) defines above. This means that, good production of parts or the assembly of products alone does not mean necessarily effective advantages for a company as a whole. It is important that customer full orders are quickly satisfied under high quality and good use of manufacturing resources.

Moreover, CMS are rarely designed having in consideration the need for parts production coordination for making complete products or meeting customer orders of end items. Thus, the need for quick response to customer requirements, which is recognized as an important strategic objective, is not taken explicitly in full account. This limitation however has been addressed in recent years through a variety of systems interlinking a number of cells that are called here as Product Oriented Manufacturing System (POMS). Paradigmatic examples of POMS are what Black (1991) calls a linked-cell manufacturing system and Quick Response Manufacturing system as referred by Suri (1998).

Then to effectively answer these challenges CMS must evolve to Product Oriented Manufacturing System (POMS). This approach is in opposition to the production system that in theory produces all products within a
company: a Function Oriented Manufacturing System - FOMS, which, rarely require reconfiguration and apparently can deal with such a variety. However, it is well known that systems of this kind are not efficient neither effective to manufacture any particular product of the range that might appear. The main reason is because this type of systems is not efficiently adapted to the production requirements of each product individually. In fact they are addressed to the manufacture of the whole range of products within a factory, requiring that, at the same time, a large variety of product share all manufacturing resources available. This creates conflicting interests in the use of resources that are bound to make the system inefficient and non effective. The required fitting of the system to each product in particular is not achieved and, therefore, production and service to customer inefficiencies tend to arise.

So, it is the objective of this paper to present POMS concept and the detailed phase of the Generic, Conceptual and Detailed (GCD) methodology for design Product Oriented Manufacturing System (POMS) summarized in Silva and Alves (2002). In the detailed design is realized the conceptual configurations instantiation selected in the Conceptual design. In this way the production system detailed specification is realized, clearly defining the production cells to implant, their layout and the management and operation mode that are described in the following sections. The section 3 presents an academic study showing the application of different activities (if we have space…). The final section presents the conclusions.

2. PRODUCT ORIENTED MANUFACTURING SYSTEM (POMS)

A POM system is defined as a set of interconnected manufacturing resources and cells that in a coordinated and synchronized manner address the manufacture of a product or a range of similar products, including the necessary assembly work (Figure 1). A product may be simple, like a part, or complex, having a product structure with several levels. When the product is simple, POMS may simply take a form of a cell. Otherwise it configures a coordinated set of interlinked cells. This coordination of work among manufacturing resources or cells is one of the most distinguishing aspects of POMS. A set of cells that does not work under coordination towards synchronized production of end items, does not form a POM System.

At a local scale a POMS can be seen as a network of balanced flow lines or manufacturing cells. This balancing explores flexibility of machines and enlarged skills of operators. These factors are considered by design methods as inputs to arrive to physical and operational systems configurations which are effective in achieving company objectives dependent on available manufacturing resources. The resources can be distributed in space and may be put together, in a localized site, or, alternatively, organized into virtual POMS. This approach to the virtual configuration of manufacturing systems was initially introduced in 1982, by McLean et al. (1982), and studied by several authors afterwards such as McLean and Brown (1987), Drolet et al. (1996) and Ratchev (2001).

The enlarged view of the POMS concept includes logistic operations, mainly when production resources are distributed in space. Today, these can benefit from intranet and internet based technologies, a prerequisite of the widely discussed Virtual Enterprise concept (Camarinha-Matos, 1999). Truly, to be successful, production under this concept must be able to fully and dynamically consider and involve resources available to a company, over a time period, locally or globally, either belonging to its own or to potential production partners. Eventually, autonomous cooperating cells or agents, offering services, available in the market, could be selected for configuring large POM systems.

Dynamic reconfiguration of POMS, under changing market requirements is, most probably, necessary. This necessity is also justified due to the dedicated nature of POMS to specific mix of products which, changing over time, calls for new arrangements to ensure high levels of operational performance.

Although POMS lends itself to large quantities and small variety product environments we are particularly aiming at viable POMS for the “Make to Order” (MTO) and “Engineering to Order” (ETO) environments, where frequent system reconfiguration is required. This viability is ensured by exploring the organizational philosophies, techniques and tools associated with Lean Manufacturing (LM) (Womack, 1990), Agile Manufacturing (AM) (Kidd, 1994) and Quick Response Manufacturing (QRM) (Suri, 1998). Both LM and QRM favour production systems organization in multifunction autonomous units or cells working under integrated coordination for achieving production objectives. AM emphasizes the importance of rapidly changing system configuration for matching processing requirements from product demand changes. Product Oriented Manufacturing (POM) can also be associated with concepts such as focused factory, advanced by Skinner (1974), and systems OPIM (One-Product-Integrated-Manufacturing) put forward by Putnik and Silva (1995).
3. DETAILED DESIGN OF POMS

The proposed methodology for POMS design, identified as the GCD methodology, was structured in three design phases or functions, namely the Generic, the Conceptual and the Detailed one. It was presented with the support of the IDEF0 modeling technique (FIPSPUBS, 1993) in Silva and Alves (2002).

Design of POM systems is a dynamic activity at all levels. However, it is at this Detailed design level that frequency of design is large. In fact, in theory, this system reconfiguration should be done every time a new product order needs to be released for production, or, in the least, be done by short planned periods of undisturbed production. This may aggregate a few customer orders of the same product or of similar products.

In order to reach a viable POMS solution is necessary develop some interrelated activities that constitute the Detailed design phase. This vision of design is partially shared by Arvindh and Irani (1994) that argue that such activities or problems are closely interrelated and must be solved integrated and iteratively. They identified four classes of problems to be solved in the design of cellular manufacturing cells, namely: machine group and part family formation, machine duplication, intra-cell layout and inter-cell layout. They go on proposing a method for cell design based on this integrated approach.

In addition to the design problems pointed out by Arvindh and Irani (1994), operation problems must also be solved. These have to do mainly with production control including scheduling. With this in mind the detailed design of the GCD methodology include five activities: parts selection and/or families of parts formation, (A31); conceptual cells instantiation (A32); workstations instantiation (A33); intracellular and organizational layout of each cell, including the control process definition and the productive activity coordination and the equipment and software selection for workflow control, manipulation, transport and storage (A34) and, the last one, intercellular and organizational layout of the global POMS and coordination constituted by the cells (A35), figure 2. This figure does not show all the entries (inputs and restrictions) necessary for or that restrains the activities. In generally all the activities are realized iteratively and interrelated. Each one of these activities could be divided in tasks presented in each section.

In the operative process definition and in the cells management, the objectives equationed include: good use of the means, good workgroup balancing, reduced work in process and lead times. In this way, several studies have to be realized for the correct specification of the cells and of the system completely, as well as their operation and management in the manner of obtain these objectives. In this process, a typical aspect is determine the parts mix to launch simultaneous or sequentially in each cell and in each production period.

3.1. PARTS SELECTION AND/OR FAMILIES OF PARTS FORMATION

The activity A31 - Parts selection and/or families of parts formation has to do with work to be carried out in the short time. It must deal with an in depth analysis of processing requirements based on actual production orders and existing sources of manufacturing capacity or services, in doors or outside the company. This activity is simplified due to first level clustering analysis of production done before at conceptual design. This first level clustering could guide to the product families for the formation of cells.

A product family is a set of product that shares the same processing requirements or some other features. Sometimes forming families it isn’t the principal objective or the single way to embrace the cellular manufacturing. The shop floor has, more often, problems and poor performance that could indicate a different approach to production. Problems like the difficult in achieve the deadlines or frequent high WIP of some parts; the high effort of reconfiguration or the poor involvement of operators are strong reasons to adopt cellular manufacturing. The minimization of the set-up problems, quality defects and reconfigurable efforts are only a few operational objectives achieved by the cellular manufacturing (Wemmerlöv and Johnson, 2000).

3.2. Conceptual Cells Instantiation

With the part families it can be possible obtain also the machines groups, e.g. applying one method like the Rank Order Clustering (ROC) (King, 1980, 1982). If this didn’t happen this activity must reach to the machines groups. The instantiation of conceptual cells is also a objective of this activity. The conceptual cells considered are based on the workflow namely direct, direct with bypassing, inverse, inverse with bypassing and repetitive workflow (Silva e Alves, 2004). The table 1 summarizes these conceptual cell configurations. These conceptual are divided in two different groups according to the independence of processing: the basic cells and the non-basic cells. The basic cells are self-contained, i.e. the resources are totally dedicated to its parts family only and non–basic cells are not self-contained, it means that they share resources with other cells. It can be said that basic configurations correspond to independent cells and the non-basic to dependent cells.

Table 1: Schematic representation of the Basic and Non-basic conceptual cell configurations

<table>
<thead>
<tr>
<th>Conceptual cell configurations</th>
<th>BASIC CELLS (BC)</th>
<th>NON-BASIC CELLS (NBC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Workstation cell (SWC)</td>
<td>GFC</td>
<td>SGC</td>
</tr>
<tr>
<td>Pure Flow Cell (PFC)</td>
<td>SPFC</td>
<td>SPFC</td>
</tr>
<tr>
<td>General Flow Cell (GFC)</td>
<td>SGFC</td>
<td>SGFC</td>
</tr>
<tr>
<td>General Cell (GC)</td>
<td>SGC</td>
<td>SGC</td>
</tr>
</tbody>
</table>

The identified conceptual configurations embrace quite a few instances that have to do with resource combination and flexibility of workstations. Thus the nature and quantity of manufacturing resources let them be main resources, such as machines, or auxiliary resources, such as operators and tools involved in each workstation, originate different instance types of each conceptual configuration and puts different problems to be solved at both design and operation of CMS. These instance types are called operational configurations. Examples of operational cells are: JIT cells (JITC); quick response cells (QRC); flexible cells (FC); virtual cells (VC) and agile cells (Silva and Alves, 2001). The table 2 matches the conceptual cells with the operational cells.

Under the title of JIT cells there are various configurations such as Toyota sewing system (TSS) (Reece Corporation, 1990, Kalta et al., 1998); modular manufacturing system (MMS) (Black and Chen, 1995, Black and Schroer, 1994, Schonberger, 1996); flexible work group (FWG) (Chen, 1998); one-piece flow (OPF) (Sekine, 1993); unit production system (UPS) (Chen 1998); semi-autonomous workgroups (Badham and Couchman, 1996, Niepce and Molleman, 1996, Van Hootegen, Huys and Delarue, 2004, Jonsson, Medbo and Engstron, 2004); linked cell manufacturing system (LCMS) (Black, 1991); and quick response sewing system (QRSS) (JETRO, 1990). This title was given because these configurations are projected to attain the objectives of JIT philosophy, i.e. defects zero; set-up times zero, stock zero, handling zero, breakdowns zero, production times zero and one piece flow. What this really means is elimination of waste in all forms.

Table 2. Matching conceptual cells with operational cells

<table>
<thead>
<tr>
<th>Conceptual Cells</th>
<th>Basic Cells</th>
<th>Non-Basic Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWC</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>PFC</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>GFC</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>GC</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>SSWC</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>SPFC</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>SGFC</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>SGC</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Basic cells and direct flows are objectives of this activity so the formed groups must be analysed in order to reach these objectives. In the Conceptual phase it was selected the conceptual cell configuration. If these were basic cells exists four configurations that can be chosen, as can be seen in table 2, if were the counterparts three can be chosen. If in this groups exits inverse flows it can be eliminated from the alternatives, the JITC and QRC from the basic and the JITC from the non-basic cells. Of course reviewing the parts sequence it could be possible reach to basic cells by eliminating the exceptional elements or duplicating the machines in both cells. The figure 3 presents a diagram flow for help in taking a decision for one operational configuration.

If the groups aren’t yet formed it isn’t possible select the configuration based on the workflows. However knowing the objectives of the company, the selection can be made based on that because, additionally to the difference between the configurations in the table 2, there are others that suit them for specific situations. This means that these differences are to be in account when select one of them. This may be put in a table showing the different rank for each difference in each configuration, being 5 the most important (table 3).
value comparison between alternatives. If one alternative
weight and the rank, and, finally total the values obtained
to 10 (10 being the most important), by multiplying
the differences the evaluation factors. One configuration
Weighted Factor Analysis (WFA) (Nyman, 1992), being
This table can also be used for the application of
Weighted Factor Analysis (WFA) (Nyman, 1992), being
is a clear winner, the decision is easy. If the values are
very close, the evaluation process must continue adding
more factors and re-evaluating or eliminating the obvious
losers and re-evaluating.
Moreover, cell efficiency and effectiveness, being
highly dependent on cell operation, is also influenced by
the configurations of each workstation in a cell. Workstations may be configured in different ways
according to manufacturing requirements and objectives.
They may be simple, provided with a single machine to
carry out a single manufacturing function or be more
complex involving three other situations which may be
combined, namely having a) parallel processors, b) multiple resources or processors and c) multifunction
processors (Figure 2).

Table 3. Differences between operational configurations

<table>
<thead>
<tr>
<th>Evaluation factors</th>
<th>JITC(1)</th>
<th>UPS</th>
<th>QRC</th>
<th>FC</th>
<th>VC</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Predominantly) direct flows</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>(Higher) production rate</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>(Higher) product variety</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>(Minimize) manual handling</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>(Minimize) wait times</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>(Minimize) set-up times</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Operators involvement</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Polyalency</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Cultural and organizational investment</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Reconfiguration easiness</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>One piece flow</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Total automation preference</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

(1) Includes TSS, OPF, FWG, MMS, L-CMS configurations

This table can also be used for the application of
Weighted Factor Analysis (WFA) (Nyman, 1992), being
the differences the evaluation factors. One configuration
can be selected after weighting each factor on a scale of 1
to 10 (10 being the most important), by multiplying
weight and the rank, and, finally total the values obtained
for each configuration, arriving at an overall numerical
value comparison between alternatives. If one alternative

Figure 3. Diagram flow to select the operational configuration

In the figure 3 it can be seen the relevance of the
nature of workstations in the selection of the operational
configuration, particulary between the QRC, FC and VC.
This nature of workstations selected or identified in
the company came from the previous phase, the Conceptual
phase.

The results from this activity are the machines groups,
the cells number, the operational elements, the shared
machines type and the selected operational configuration.

3.3 WORKSTATIONS INSTANTIATION

The number of workstations and of their
manufacturing resources together with detailed
arrangement of each is done by activity A33. This
involves a detailed knowledge of the available, main and
auxiliary, pieces of equipment for choice, not only for
processing but also for handling, transport and storage.
Operators should also be selected, based on skills and on
cell operating modes. Activity A33 makes, therefore, the
necessary adjustments to the workstations selected at the
conceptual level, having in consideration existing
manufacturing resources and results of detailed load
balancing.

The number of operators and the level of replicated
auxiliary equipment, such as tools, together with their
dynamic utilization within cells may substantially affect,
not only the cell capacity and manufacturing flexibility,
but also the manner how cells can be operated. Therefore
auxiliary resources largely determine the performance level of manufacturing cells (Silva, 1988, 1997). The figure 4 presents a diagram flow to help the designer to calculate the number of machines and operators needed attending to the operation times of each operation to be done in the cell.

The results of this activity are the cell size in number of machines types and operators, the operator’s allocation to cells and then to the machines, the optimal location of shared machines, the identification of incompatible machines or processes, the product mix in the cells and, finally, the workstations number obtained through the balancing exercise using a adequate method (Wild, 1972, Scholl, 1995).

3.4. INTRACELLULAR AND ORGANIZATIONAL LAYOUT

Although the conceptual configuration chosen restricts cell arrangements that can be made, there is still a need to clearly define intracellular detailed organization. This involves precise location of workstations, machines and auxiliary devices, including workstation decouplers (Black and Chen, 1995). A clear definition of how work and people flow within a cell is also required, being possible to evaluate several layout configurations (Arvindh and Irani, 1994), such as the well known U shaped one, which should fit into the conceptual configuration chosen. Moreover, operating cell modes exploring strategies such as teamwork and time-sharing resources (Suri, 1998), rabbit chase, TSS and working balance (Black and Chen, 1995), should be considered for implementation.

3.5. INTERCELLULAR LAYOUT OF THE GLOBAL POMS AND COORDINATION

Finally the POM system can be reached. This culminates with the activity A35 dealing with the total system integration and organization. An important part of this is the selection of the POM intercellular coordination and production control system. This should focus on inter-cells workflow towards the manufacture of each product order or each family of similar product orders. This coordination and control system should explore the push and pull paradigms and novel combinations of them such as the POLCA (Suri, 1998), the DBR (Goldratt, 1986), the CONWIP (Spearman, 1990) and SYNCRO-MRP (Hall, 1981) systems, to mention only a few.

4. HELPFUL HINTS

4.1. FIGURES AND TABLES

4.2. REFERENCES

4.3. ABBREVIATIONS AND ACRONYMS

Define abbreviations and acronyms the first time they are used in the text. Do not use abbreviations in the titles unless they are unavoidable.

4.4. EQUATIONS

5. FULL PAPER SUBMISSION

6. SUMMARY

REFERENCES


Reece Corporation (1990) “World Class Manufacturing for the Sewn Products Industry” Catalogo


Author One, Author Two, year, Title of Paper, Source, Vol. xx, No. yy, pp. first page-last page.


Wang, L., Sams, R., Yorner, M., Xi, F., 2000, Web-Based and Sensor-Driven Device Monitoring and Control Using Java 3D, Proceedings of 1st World Symposium on Group Technology and Cellular Manufacturing, pp. 772-781,