PRODUCTION SYSTEMS DESIGN – A PRODUCT ORIENTED APPROACH AND METHODOLOGY

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Abstract: Production systems design is critical to achieving manufacturing performance and objectives. Although generic approaches to this design are available they may not be able to objectively address specific manufacturing configurations. Here it is argued that product oriented manufacturing (POM) organization offers advantages in relation to the function oriented one. Based on this, a methodology specially addressing POM systems design, and prototype of a Computer Aided Design System based on the methodology were develop. A brief description of both is presented.

Keywords: manufacturing_systems, design, methodology, reconfiguration

INTRODUCTION

In the present global economy, due to competition, companies are compelled to deal with an ever increasing product demand variety.

Function Oriented Manufacturing (FOM) Systems – FOMS - have been adopted in industry for many years due to their apparent ability and flexibility for dealing with large variety of products in small quantities. However, FOMS do not perform well. They are unable to achieve good use of resources and quickly respond to customer demands, two requirements for companies' sustainability and competition ability in the global market of today. There are two important reasons for this. The first is the lack of manufacturing focus on the products. The other is the highly intermittent nature of the flow of materials during manufacturing cycle. The first reason has a severe impact on utilization of manufacturing means and facilities and the second highly hinders the manufacturing systems ability for quickly responding to changes in demand.

Due to these reasons, manufacturing systems organization focused on manufacturing requirements of products, not on manufacturing functions, is a good concept to explore as a means for overcoming the problems associated with FOMS. Here, such a concept is referred as Product Oriented Manufacturing - POM. Under POM systems a close relationship between manufacturing requirements of products and manufacturing system organization is established.

Well known advantages of product focused manufacturing systems are their better and more efficient use of manufacturing resources, speed of production and ability to deliver products faster and of comparatively higher quality than FOMS. This is mainly due to their configuration for dealing with specific manufacturing requirements of each product or family of similar products. Moreover, POM organization provides a much better environment to respond to demand changes. This is because, a clearer view of each product and related manufacturing process is offered with this organization. Due to this, when demand changes the system provides a much better understanding of what accordingly has to be changed in manufacturing. Therefore POM constitutes a better environment for quickly respond to product demand changes.

The suitability of manufacturing systems for high product variety environments is linked to the quickness how they can be adapted to manufacture different products. This, essentially means, quick system reset-up or reconfiguration.

This paper is focused on manufacturing system reconfiguration, presenting in section 2 the POM system – POMS concept. Section 3 presents a summarized view of the Generic-Conceptual-Detailed (GCD) methodology for POMS design or reconfiguration, developed by the author, and in section 4, a Computer Aided Design System for POMS design - CADS_POMS - is briefly described. The final section presents some concluding remarks.

PRODUCT ORIENTED MANUFACTURING SYSTEMS - POMS

POMS Concept

A Product Oriented Manufacturing System – POMS, is defined as a set of interconnected manufacturing resources and/or cells that in a coordinated and synchronized manner address the manufacture of a particular product or a range of similar products, including the necessary assembly work. Fig. 1 schematically illustrates the concept.

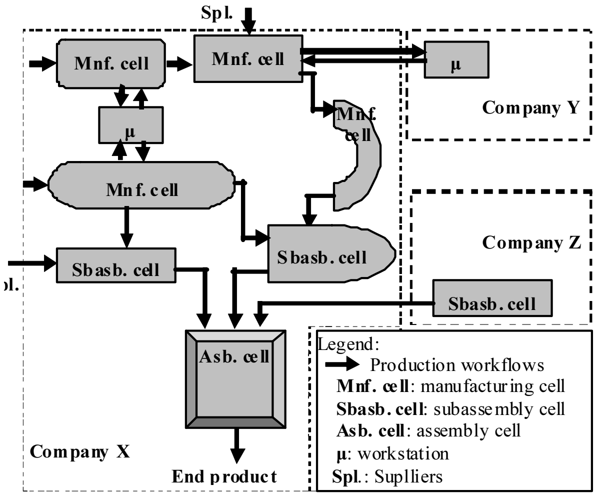

Fig. 1. A schematic representation of a POM System

In POMS 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. For complex products several cells and or resources may be required. The coordination of work between manufacturing resources or cells is an essential requirement of POMS.

Requirements of POMS and design strategies

The resources available for POMS may exist distributed in space and may be either put together in a localized site or, alternatively, organized into virtual POMS. To be successful, production under this concept must be able to fully and dynamically consider and involve resources that are locally or globally available to a company, over a time period, either belonging to its own or to manufacturing service providers. Therefore, not only internal resources to a company, but also, external ones should be considered in the POMS reconfiguration process. The approach to virtual configuration of manufacturing systems was initially introduced by McLean, Bloom and Hopp [1], and studied by several authors afterwards such as McLean and Brown [2], Drolet et al. [3], Ratchev [4], Ko and Egbelu [5] and Slomp et al. [6] Today, POMS can benefit from intranet and internet based technologies, a prerequisite for the widely discussed Virtual Enterprise concept [7][8].

At local scale, a POMS can be seen as a network of balanced manufacturing resources and cells. This balancing must explores alternatives of manufacturing associated with process plans of products [9], manufacturing flexibility of machines and enlarged skills of operators, which are also requirements of POMS.

One underlying requirement in today's market is the need for frequent adaptation of manufacturing systems to changing manufacturing requirements due to product demand changes. This, together with the dedicated nature of POMS to specific products, means that, for ensuring high levels of system operational performance, POMS need frequent reconfiguration. To achieve this it is important to draw upon design strategies such as modular production system design [10][11][12][13], modular production [14] and standardization of equipment and operating procedures.

The POM concept lends itself to large quantities and small variety product environments, as well as to repetitive production [15]. Nevertheless it can also be seen as a viable concept to the "Make to Order" (MTO) and even "Engineering to Order" (ETO) environments. This viability can be ensured by exploring strategies, techniques and tools associated with Lean Manufacturing (LM) [16], Agile Manufacturing (AM) [17] and Quick Response Manufacturing (QRM) [18]. 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 to matching processing requirements from product demand changes. AM is also highly dependent on modular production [14], which has been considered essential to product customization [19]. Product Oriented Manufacturing - POM can also be associated with concepts such as focused factory, advanced by Skinner [20], and systems OPIM (One-Product-Integrated-Manufacturing) put forward by Putnik and Silva [21].

Reasons for adopting POMS

Traditionally a Cellular Manufacturing System (CMS) has been identified as a system dedicated to the manufacture of a family of identical parts. A more comprehensive definition of a manufacturing cell refers to a manufacturing system that groups and organizes the manufacturing resources, such as people, machines, tools, buffers, and handling devices, for the manufacture of a part family or the assembly of a family of products with identical or similar manufacturing requirements. This has its origins in the Group Technology concept [22][23].

CMS rarely have been designed having into consideration the need for coordinating and synchronizing production, from raw materials to complete assembly of specific customer orders. The strategy has been to decouple production and relying on inventories at different production stages, from parts manufacturing to full assembly, based either on a MRP aggregation of part needs or on some repetitive schemes of part replenishment inventories.

Thus, the need for quick response to customer orders, which has been recognized as an important strategic objective under the present market competition paradigm, is not frequently taken explicitly and appropriately into full account when designing manufacturing and production control systems. However, there have been movements towards POM direction with proposals of systems design and management approaches focussing on coordinated manufacturing of parts and assemblies towards efficient production and delivery of customer orders. Examples are what Black [24] refers as Linked-Cell Manufacturing System and also the Quick Response Manufacturing concept referred by Suri [18].

Thus, to effectively respond to the market demand challenges of today, CMS must evolve to Product Oriented Manufacturing System - POMS, frequently reconfigured for fitting and efficiently respond to product demand changes.

This approach is radically different from Function Oriented Manufacturing System – FOMS - organization, supposedly adequate for dealing with demand changes and large product variety without needing reconfiguration. However, as it was already argued in section 1, this is not the case.

DESIGN METHODOLOGY FOR POMS

In general, designing systems is a complex task that involves much data and information and requires a variety of methods and tools. Therefore, it is advantageous to have a methodology that guides the designer through design steps showing the required data and methods to use in order to reach design solutions.

This design approach was tried in an industrial case of apparent simplicity in the apparel industry [25]. Difficulties encountered clearly showed the need for a laborious and iterative process of analysis and synthesis to reach an acceptable POMS configuration. This experience was important for developing the GCD methodology [26][27].

Generic-Conceptual-Detailed (GCD) Design Methodology

The GCD methodology addresses the POMS design in three dimensions, namely, the Generic (G), the Conceptual (C) and the Detailed (D) one, corresponding to the three sequential and iterative phases of the methodology.

At the G Design one generic manufacturing system configuration is chosen. A decision has to be made for a FOMS, a POMS or a hybrid POMS. The hybrid POMS usually considers FOM of parts and POM of assemblies and, possibly, of parts as well. The Generic Design is carried out through three interrelated design activities, namely Strategic Production Planning (A11), Analysis of Company and Market Manufacturing Situation (A12) and Generic Manufacturing System Selection (A13). The choices are determined by several factors relevant to the company manufacturing strategy. Particularly relevant are production requirements derived from forecasted demand, available resources and services, and company present manufacturing position and situation. Product variety and volumes of production are also important in the G design phase.

The main and fundamental purpose of Conceptual design is selecting conceptual cell configurations. Conceptual cells are classes of cells, based on the complexity of materials flow, which need to be instantiated with basis on product and process specific information. Additionally, a first approximation to product and part families based on both forecasted and settled customer orders and process plans must be made. Also important at this phase is to specify the nature of workstations and operators. Based on such purposes two main activities must be carried out, namely, Conceptual Cell Configurations Selection (A21) and Workstation Selection (A22). The conceptual cells that can be chosen are the basic ones, i.e. autonomous and independent cells configuring lines, job-shops and single workstations, and their shared cell counterparts, called non-basic [28].

At the Detailed design, instantiation of conceptual cells is done having in consideration customer orders for products. The results are cells which are the building blocks of the POMS to establish. Additionally coordinated control of work among cells for POM is devised. The D design activities have been described in Carmo-Silva and Alves [29] and are: Formation of Families of Products (A31), Instantiation of the Conceptual Cells (A32), Instantiation of Workstations (A33), Intracellular Organization and Control (A34) and POM System Organization and Intercellular workflow Coordination and Control (A35). For carrying these out, a range of methods and tools needs to be used. Important ones deal with the technical and economical evaluation of alternative solutions.

Design frequency and design agents

Design of POM systems is a dynamic activity at all levels. The frequency of design depends on system and resources state and, naturally on product demand and mix changes.

Generic design is clearly carried out infrequently and only when major changes on technology and processes of manufacture and, also, on demand, take place.

Detailed Design is an on going design activity necessary for fitting the system to short term variations of demand or capacity. System reconfiguration, at detailed design level, may have to be carried out every time production requirements changes due to change in product mix to be released. Some D design tasks may have an impact only on operation and production control others may show the need for manufacturing system changes.

Conceptual design needs to be done before detailed design can go ahead. It takes place when substantial changes in product demand and mix occurs, or changes in production process or capacity take place. This is likely to call for a re-evaluation of the conceptual cells to use. This can have an impact on the configuration cells to build.

In the design process several decisions at strategic, tactical and operational levels, are made and used successively and iteratively at each design phase. This design process involves different design agents. In particular, three classes of design agents are identified, namely consulting team, company design team and production control teams. Fig. 2 presents an overview of the design methodology showing design activities and relating them with design frequency, time horizon, flows of information and decisions and design agents involved in the design process.

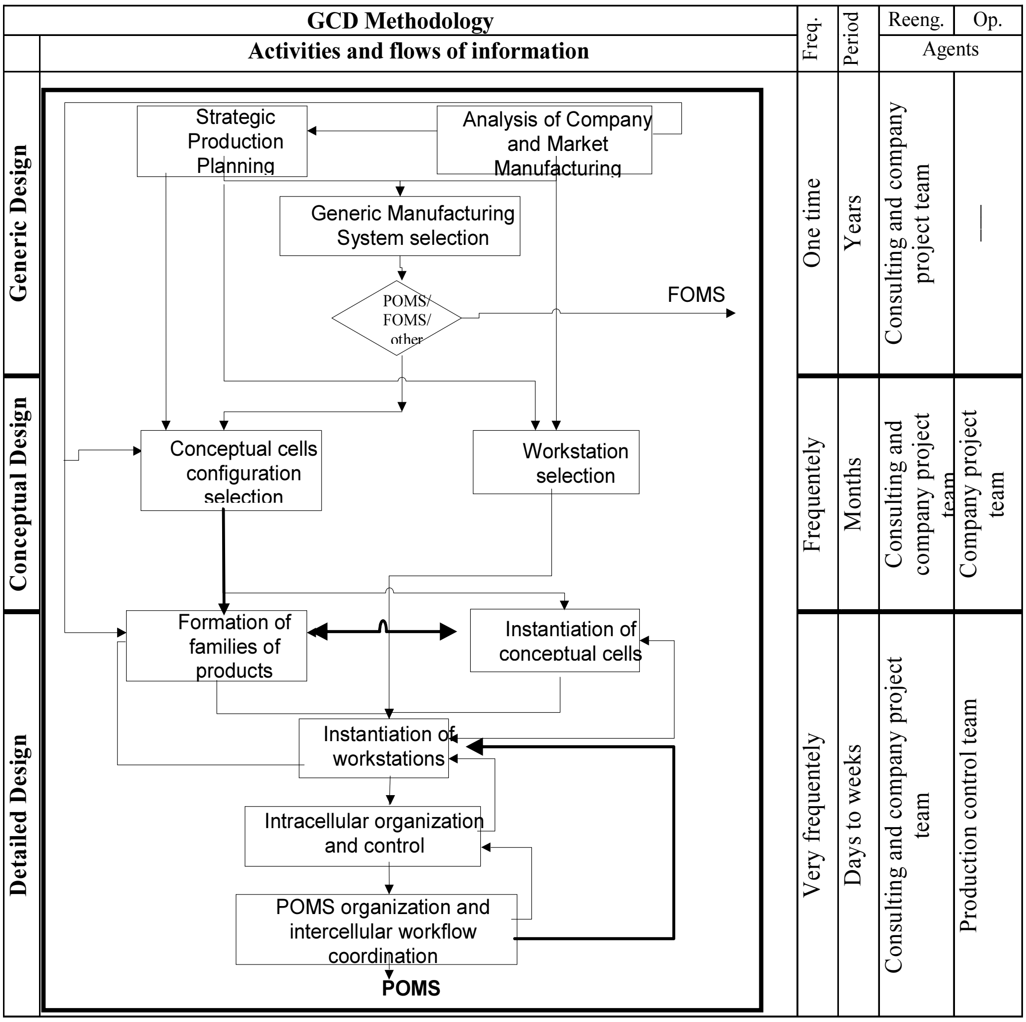

Fig. 2. Overview of the GCD design methodology for POMS and implications

COMPUTER AIDED DESIGN SYSTEM FOR POMS (CADS_POMS)

To be able to quickly attain good POMS designs and fast reconfiguration, computer aided design systems directly addressing POMS design should be used. Reported computer aided design systems – CADS - for manufacturing systems design tend to be restrictive, and not focussed on a particular manufacturing concept. They implement general approaches or methodologies addressing manufacturing systems design in general [30][31] without any focus on a particular concept such as POMS. Another approach addresses particular design aspects of manufacturing system, like the works reported by Luong et al. [32] and Manzini et al. [33] or using libraries of available methods [34][35].

Here a Computer Aided Design System for Product Oriented Manufacturing System - CADS_POMS - developed around the GCD methodology, presented in Carmo-Silva et al. [9][36], is shortly described.

The Microsoft SQL relational database was used. The main fundamental elements of the CADS_POMS system is a database, a user interface and knowledge base that holds design methods for system design and for evaluation at several design stages. The system design capability is both highly dependent on user interaction and on the availability of design methods.

The critical set of data used by CADS_POMS is shown in fig. 3.

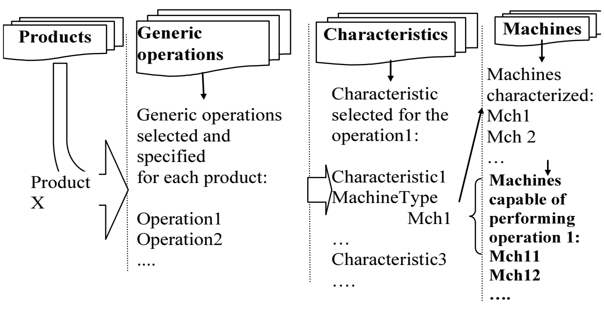

Fig. 3. Fundamental data sets for POMS design

For each product a process needs to be specified based on generic manufacturing operations. Each operation has a number of characteristics or attributes whose values are different according product manufacturing requirements. The attribute values are important for selecting manufacturing resources, namely workstation or machines. For this selection a matching procedure between machine and operation characteristics is implemented. This is an essential step for machine selection and ultimately to build the POMS to manufacture a given product or a family of products.

CONCLUDING REMARKS

Designing POM systems is a complex task requiring a methodology for framing the steps that should be followed in the design process and, at the same time, showing constraints, data, tools and methods that should be considered or used at each step. The GCD methodology, summarily described in this paper, addressing the POMS design interrelated functions, is a contribution to this.

The complexity and iterative nature of the design process points to the need for a computer aided tool to carry it out. This led the authors to specify and develop a prototype of such a computer aided system for POMS design, called CADS_POMS, briefly described in this paper and based on the reported GCD methodology.

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