Issues and Design Approach for Product Oriented Manufacturing Systems

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Abstract

The Product Oriented Manufacturing (POM) concept here presented addresses competition in today's changing global market of manufacturing companies. It is a challenge to the Function Oriented Manufacturing (FOM) concept supposedly adequate for dealing with demand changes and large product variety without needing reconfiguration. The POM concept evolves from the traditional cellular manufacturing, ultimately aiming at full system integration and coordination for completely processing a product, not parts of it, or a family of similar products, for efficient manufacturing and good customer service. In this respect it is customer order centred. For answering changing demand it draws upon system adaptation exploring several reconfiguration strategies. Due to POM complexity and design focus, a design methodology called GCD was developed and is here briefly described. The first phase, the Generic Design, is emphasized in relation to the others. It is mainly directed to analysing manufacturing companies' demand market position and current manufacturing system in order to evaluate, at a generic level, the suitability of the POM concept for manufacturing. Further design phases explore alternatives of POM systems to reach a POMS suitable solution.

Keywords: Product /Function Oriented Manufacturing systems, design methodology

1. Introduction

In the present global economy, due to competition, companies are compelled to deal with an ever increasing product demand changes. Vital to success of companies under this environment is their ability to adapt manufacturing systems to changes in demand, in order to fit customer requirements on price, quality and delivery time and still maintaining good manufacturing resources utilization. Different forms of such adaptation can be envisaged. For this adaptation it is proposed to depart from a concept here referred as Product Oriented Manufacturing (POM), which focuses production systems on specific products or a family of similar products ordered for the same period. This radically contrasts with the well known Function Oriented Manufacturing (FOM). FOM organizes manufacturing around a set of quite statically arranged independent manufacturing units; each one specialized in carrying out a specific process or manufacturing function. All products must pass through these units, according manufacturing requirements, competing with each other for resources, in intermittent, slow, lengthy and complex control and flow processes. FOM systems (FOMS) have been adopted by industry due to their apparent ability and flexibility for dealing with large variety of products in small quantities without reconfiguration. This, however, is managed at a cost and a service unacceptable under the global economy and competition paradigms of today.

The POM approach has a great potential for overcoming many problems associated with FOM. Apparently an important share of industry, in the manufacturing sector, still ignores this potential. In fact, due to this, or to inertia, FOM is still widely adopted in industry where POM organization could do better. It may also be argued that such adoption might also be due to the companies' difficulty to acceptably evaluate and compare the two manufacturing approaches. To contribute for overcoming this difficulty, and support the whole POM systems (POMS) design cycle, the authors developed a methodology, called Generic-Conceptual-Detailed (GCD) design methodology [1]. This begins by evaluating, at the strategic level, here called Generic, the suitability of using POM for dealing with the company's product demand profile having into account current manufacturing processes and system situation and available market resources.

The GCD methodology specifies three main phases in the design process. In addition to the Generic, it also includes the Conceptual and the Detailed design phases. In the process of aiding the design process the methodology can also guide designers in finding or selecting design methods and tools and obtaining the necessary design data. In the process of seeking good design solutions for POMS, the methodology also takes into account relevant existing restrictions.

In section 2 the POMS concept is developed and a brief review of related concepts and design methodologies are presented. The GCD methodology is briefly described in section 3, giving emphasis to the Generic Design phase. Section 4 contains some concluding remarks and a reference to ongoing work.

2. Product Oriented Manufacturing Systems - POMS

2.1. POMS Concept

A POMS is a manufacturing system configured as a set of interconnected manufacturing units, i.e. typically workstations, cells and functional units that, simultaneously and in a coordinated way, addresses the manufacture of a single product model or a family of similar products, to rapidly respond to customer orders. Manufacturing units of POMS may include collaborating external resources. In POMS a product may be simple, like a part, or complex, like an assembly, having a multilevel product structure with several components, requiring both parts manufacturing and their assembly. The POM concept aims at implementing both the concepts of Simultaneous Manufacturing [2] and One-Product-Integrated-Manufacturing (OPIM) system [3], centred on the linkage and coordination of production of specific customer orders.

According to production requirements, POMS may simply take a form of a manufacturing or assembly cell or be a more complex system. A schematic representation of the POMS concept is shown in Figure 1.

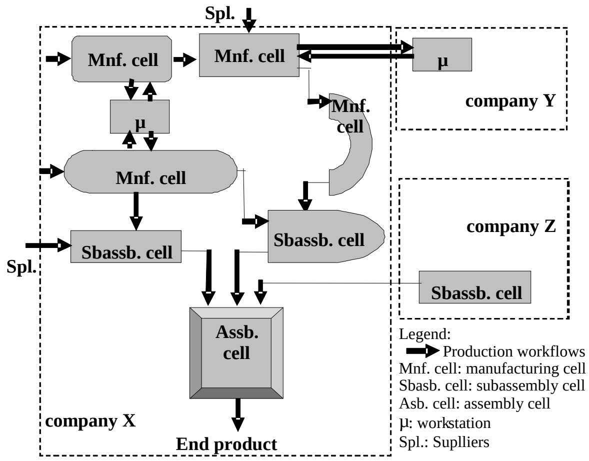

Figure 1. A schematic representation of a POM System

POMS can be seen as a concept suitable, not only for the repetitive production [4], but also for "Make to Order" (MTO) environments. This suitability can be ensured by exploring strategies, techniques and tools associated with Lean Manufacturing (LM) [5, 6] and Quick Response Manufacturing (QRM) [7]. Both LM and QRM favour production systems organization in autonomous units or cells working under integrated coordination.

It is clear that under the changing market of today and due to the product-customer order oriented nature of POMS, for ensuring the high levels of system operational performance, POMS need frequent adaptation or reconfiguration. This reconfiguration can be achieved by exploring alternatives associated with process plans of products [8], manufacturing flexibility of machines, standardization of operating procedures, enlarged skills of operators and also, by exploring strategies, techniques and tools associated with Agile Manufacturing (AM) [9]. AM emphasizes the importance of rapidly changing system configuration for matching processing requirements to product demand changes. AM is also highly dependent on modular production [10], which has been considered essential to product customization [11]. Other requirements for easing POMS reconfiguration have been referred in Alves [12] and Alves and Carmo-Silva [13].

2.2. From Cellular Manufacturing to POMS

Cellular Manufacturing (CM) has been traditionally identified with the manufacture of similar parts or the assembly of similar products, i.e. having similar processing and handling requirements. Because of this CM has been developed with basis on Group Technology (GT) theory [14, 15, 16, 17, 18]. Moreover, CM systems (CMS) rarely have been designed having into consideration the need for coordinating and synchronizing production of customer orders of specific products, from raw materials to assembly. CM usually is mostly used for repetitive manufacturing based on repetitive schemes of parts and assemblies inventory replenishment. Thus the direct and agile response to varying manufacturing requirements of customer orders under MTO and Engineer-to-Order (ETO) has been rarely addressed.

To effectively respond to the market demand challenges of today, CMS need to evolve further to full system integration, coordination and frequent reconfiguration for fitting and efficiently responding to the varying customer order requirements and achieving good customer service. Moreover, being able to economically manufacture a single product, not only groups of similar ones, is a goal to respond to the demand paradigms of today's global market and competition. Moving in these directions means an evolution from CMS towards POMS with a consequent reduction of the use of GT. Contributions to this evolution have been given by Black [19], with the Linked-Cell Manufacturing System concept based on the Toyota Production System [20], and also by Suri [7], with the Quick Response Manufacturing concept where manufacturing functional units coexist with manufacturing cells.

2.3. POMS versus FOMS

FOMS have been considered most adequate for dealing with demand changes and large product variety. However, in practice this is hardly the case. In fact, it has been largely demonstrated that, in spite of being adopted in industry for many years, FOMS do not perform well. They are unable to achieve good use of resources and quickly respond to customer demands, two essential requirements for companies' sustainability and competition ability in the global market of today. There are at least two important causes for this. The first is the lack of manufacturing organization focus on products. The other is the highly intermittent nature of the flow of work during manufacturing cycle due to batch production. 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 satisfying customer orders.

Well known advantages of product focused manufacturing systems, like POMS, 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, POMS provide 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. Under POM systems a close relationship between manufacturing requirements of products and manufacturing system organization is established having in mind the need for frequent reconfiguration.

2.4 Methodologies for manufacturing systems design

Due to complexity of manufacturing systems, their design or redesign usually requires appropriate design methodologies. Although multipurpose design methodologies may be used for manufacturing systems design, better results and effectiveness are likely to be achieved through methodologies conceived for specific design purposes. For example, the Axiomatic Design Theory (ADT) [21], which may be seen as multipurpose design methodology, may be used for designing manufacturing systems. However it is not of the authors' knowledge that it has ever been directly used for such purposes. Instead, it has been used as a basis for developing some less general methodologies applied to manufacturing systems. This approach has been adopted by Suh et al. [22], Babic [23], Cochran et al. [24] and Kulak [25] for conceiving design methodologies for manufacturing systems in general. These, and particularly those addressing CMS design, such as those put forward by Burbidge [17], Monden [20], Black [19], Massay et al. [26], Suri [7], Silveira [27], Hyer and Wemmerlov [28], Kulak [25] and Fraser et al. [29], are naturally useful for POMS in spite of not being specifically oriented to that. In fact, and in general, they do not comprehensively address the need for system integration, coordination and reconfiguration, neither fully address the whole cycle of POMS design, from strategic to operational design, as does the GCD methodology. Although some difficulties may arise from using other methodologies for POMS design rather than GCD, this methodology can be applied to cellular manufacturing with success.

3. The GCD methodology for POMS design

The GCD methodology is organized around three major design phases, namely the Generic, the Conceptual and the Detailed phase. The authors recognize that this methodology shares some common features from the Black methodology [19] for Integrated Manufacturing Production System (IMPS) and from the Suri methodology [7] for QRM systems. Distinguishing features of the GCD methodology is its orientation to system reconfiguration and the spread of design functions, from strategic to operational level with exploration of conceptual manufacturing arrangements or configurations, at cell design and workstations design, instantiated at detailed design level. System adaptation or reconfiguration is needed according to customer order manufacturing requirements. Design roles, frequency and design players, were identified for each design phase in Alves and Carmo-Silva [13] and are briefly referred below.

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 ongoing 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 period production requirements changes. Some Detailed design tasks essentially address operation and production control, with adjustments to work scheduling and allocation, including adaptation of manning levels at manufacturing cells or stations; other tasks deal with manufacturing system physical reconfiguration within the same Conceptual configuration recommended at Conceptual design. Conceptual design needs to be carried out before Detailed design or redesign can go ahead. It takes place when substantial changes in product mix occur, or changes in production processes or capacity take place. This is likely to call for a re-evaluation of the conceptual cells to recommend, which impacts the physical arrangement of the POMS defined at Detailed design. Conceptual cells are explained below, in section 3. 2.

In the design process several decisions at strategic, tactical and operational levels, are made and used successively and iteratively in each POMS design phase. The complexity of this decision process is better dealt with computer aid. Because of these the authors have been designing and building a decision support system to implement the GCD methodology. At the moment a prototype of a Computer Aided system for POMS design has been built [8, 12, 13, 30]. This prototype includes a database, updatable on a continuous basis, a knowledge base for design methods and tools and some interfaces and aids needed for easing the design process.

3.1. Generic Design

At this phase of design a fundamental evaluation must be made which is essential to proceed with all the subsequent POMS design activities. This evaluation aims at ensuring that the POM organization is suitable for responding to market requirements having into account competences, manufacturing processes and resources and company and market restrictions.

For this, at a first stage, the POM and the FOM organizations are compared against each other. This starts by identifying a selected range of products whose production wanted to evaluate under these concepts. An inconclusive decision about this, leads us to consider the hybrid concept of POM and FOM. Essentially this tends to result in a mix of FOM organization, usually at parts production, with cellular manufacturing. Although the GCD methodology can help in this system design the true POM concept tend to be partially lost. The strategy behind it may however be taken as farther as it is advantageous, in economical terms and customer service. If such a hybrid situation is proven unsuitable the FOM concept may have to be adopted.

It is important to point out at this stage that the POM concept, although mainly exploring CMS it may share different combinations of organizational concepts.

Three main interrelated design activities at the Generic design phase can be identified: Strategic Production Planning (A11), Analysis of Company and Market Manufacturing Situation (A12) and Generic Manufacturing System Selection (A13). The choices at this design phase are determined by many factors relevant to the company manufacturing strategy, being particularly relevant: 1) the production requirements resultant from product forecasted demand spectrum and behaviour, 2) the market available resources and services, and 3) the company present manufacturing position and situation mainly related with resources, processes and organization. It is also necessary that product variety and volumes of production be identified. Thus, six criteria were established for the selection of the Generic Manufacturing System: Product/Quantity analysis, current and aimed production system configuration, production response strategies to market requirements, such as MTO and others, product demand and production system existing problems. Each criterion was evaluated through a Decision Table [31] or Weighted Factor Analysis [32] being the alternatives the POM/FOM system. Combining the relevant values of all important variables the authors reached 96 combinations. Only 18 reflected real feasible combinations worth analyzing [12]. The suitability of POMS and FOMS for each of the 18 combinations was established based on a final Decision Table [31]. Some results are summarized in Table 1. Getting POMS as a result for the Generic Manufacturing System, is done, at this phase, a first level analysis of similarities of production.

3.2 Conceptual Design

The main and fundamental purpose of conceptual design is selecting, from sets of predefined possibilities, conceptual cells and workstations to be instantiated later, at detailed design phase, into the real POM system. Thus, two main activities need to be carried out at conceptual design: Conceptual Cells Selection (A21) and Conceptual Workstations Selection (A22). The set of possible conceptual cells that can be chosen includes the basic ones and their shared cell counterparts, non-basic, described in Silva and Alves [33, 34].

Table 1.
Decision table for Generic Manufacturing System selection

Some possible results	**R1**	**R2**	**…**	**R7**	**…**	**R18**
P/Q analysis result						
POMS	**X**	**X**				
FOMS				**X**		
Non-Conclusive Response						**X**
Selected generic configuration						
POMS	**X**					
FOMS		**X**		**X**		**X**
2 Responses	**POMS**		**…**	**FOMS**	**…**	**FOMS**
Production strategy						
ETO, ATO, MTS (POMS)		**X**				
MTO, MTD (POMS/FOMS)						
Demand strtucture						
Stable/unstable, regular/irregular, quantity variety (POMS)		**X**				
Unstable, irregular, variety (FOMS)						
Current production system						
POMS		**X**				
FOMS						
Problems identification		**X**				
Action	**POMS**	**POMS 83%**	**…**	**FOMS**	**…**	**FOMS**

3.3 Detailed Design

It is at the Detailed Design level that frequency of design is large. In fact, in theory, system reconfiguration should be carried out every time a new product order needs to be released for production or, in the least, by short planned periods of undisturbed production. This may aggregate a few customer orders of the same product or of similar products. The following activities are defined at Detailed Design phase: Formation of Families of Parts, Subassemblies and End Items (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). A detailed explanation of these is presented in Carmo-Silva and Alves [34], showing the operational cells evaluated at the second design activity of this phase, namely, the instantiation of conceptual cells. A case study showing the application of GCD to a company is presented in Silva and Alves [35].

4. Concluding remarks

Companies must be able to efficiently manufacture and quickly deliver good quality products, timely satisfying customers' requirements. To achieve this, a holistic approach to manufacturing is necessary. This can be provided by POMS, dynamically configured or adapted according to market demand changes.

Due to the many aspects needed to consider, design complexity and also the lack of available methodologies for specifically designing POMS, from strategic to operational design, the GCD methodology was developed and described. The Generic Design phase was emphasized. It is recognized that the methodology only can be useful if it is implemented in practice. This requires improving the prototype that is being built and enriching its knowledge base. The authors are working on these aspects together with the gathering of industrial data for validating the methodology.

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