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A Review of Design Methodologies for Manufacturing Systems

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ABSTRACT

This paper presents a review of design methodologies for manufacturing systems, with focus on Product Oriented Manufacturing Systems (POMS). POMS organization is discussed and compared against function oriented manufacturing. The methodologies for manufacturing systems design are described and grouped in three classes: generic, specific and product oriented focused. Several methodologies in the first class are referred. They tend to be suitable for whatever kind of product that is necessary to develop or design, including manufacturing systems. Usually, they arrive to a general, conceptual first approximation manufacturing system solution, which need refinement. Manufacturing systems specific methodologies are more objective being able to offer a clearer picture of the manufacturing system ultimate solution. A number of them are reviewed. The product focused class of the manufacturing systems design methodologies is divided in two groups: methodologies for designing new manufacturing systems, referred as construction methodologies, and methodologies for reengineering or reconfiguring existing ones. A few methodologies are referred and a methodology referred as the GCD methodology is explained in more detail due to its particular focus on POMS design. Through it a better understanding is given of the POMS design needs. The GCD methodology is also put in perspective in relation to other reviewed methodologies.

INTRODUCTION

A manufacturing system transforms inputs, also referred as production factors, which typically are grouped in materials, men, direct and indirect means of production, energy and information, into outputs, usually goods and/or services, information and waste.

Designing manufacturing systems is a process of fitting the manufacturing system configuration and operation to manufacturing needs arising from market demand. Although needing important organizational efforts, this fitting is a requirement for high productivity and system efficiency and for improving order delivery and customer service. To reduce organizational and economical efforts from such fitting, faced with today's continuous change in market demands, a frequent and efficient match of manufacturing system configuration to such changes is required. The objective is to quickly respond to product variation demands in an effective and efficient manner. Due to complexity of manufacturing systems, their design and redesign or reconfiguration are better achieved through suitable design methodologies.

The paper presents a review of manufacturing systems design methodologies and the GCD methodology [1]. This is put in perspective in relation to other methodologies.

The next section discusses general organization structures of manufacturing systems. The third section describes and relates different manufacturing systems design methodologies. Before the concluding remarks, the paper briefly describes the CGD methodology and highlights important differences in relation to reviewed methodologies.

GENERIC CONFIGURATIONS OF MANUFACTURING SYSTEMS

The most common classification of the manufacturing systems has been based on their organizational structure and layout. Thus, manufacturing systems are usually grouped in two generic classes: Function Oriented Manufacturing Systems (FOMS) and Product Oriented Manufacturing Systems (POMS). Typical production arrangements, normally associated with these classes, are, respectively, Job-Shops (JS) and Flow Shops (FS). Nevertheless, the relation between these concepts is not necessarily bi-univocal, i.e. it may exist JS which are POMS and FS which are FOMS.

Function Oriented Manufacturing Systems - FOMS

Normally, FOMS are manufacturing systems with flexible and universal equipment, typically organized in functional units or departments, by manufacturing processes, for the manufacture of a company's full range of products demanded by the market, Figure 1. Due to its apparent flexibility, FOMS have been considered most adequate for dealing with product demand changes and large product variety. However, in practice this is hardly the case. It has been largely demonstrated that, in spite of being adopted in industry for many years, FOMS do not perform well and has been considered obsolete for many years [2],[3]. FOMS use may be justified due to inertia or difficulties in finding a time and economic window for manufacturing systems reengineering.

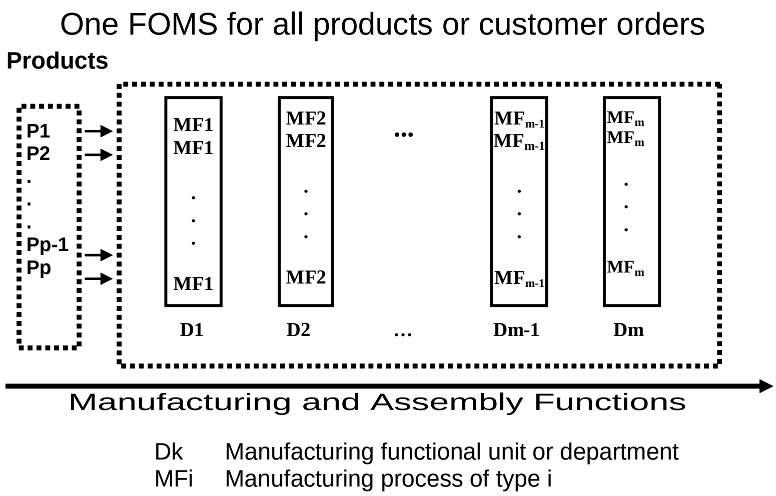

Figure 1: A conceptual view of the Function Oriented Manufacturing System concept organization.

FOMS are unable to meet two essential requirements or objectives of companies' sustainability and competition ability in the global market of today, i.e. to enable good use of resources and, at the same time, quickly responding to customer demands. There are, at least, two important reasons for this FOMS inability. 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 resources and facilities and the second highly hinders the manufacturing systems ability for quickly satisfying customer orders.

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Product Oriented Manufacturing Systems - POMS

A POMS is a manufacturing system configured as a set of interconnected manufacturing units, typically workstations forming manufacturing cells, which simultaneously and in a coordinated manner, addresses the manufacture of a single product model or a family of similar products, requiring the same manufacturing and material handling processes [1][4]. Manufacturing units of POMS may include collaborating external manufacturing partners or resources. In POMS a product may be simple, like a part, or complex, like an assembly having a multilevel product structure, with several components. POMS operating and design strategy seeks to implement the concepts of Simultaneous Manufacturing [5] and One-Product-Integrated-Manufacturing (OPIM) system [6], centred on the linkage and coordination of manufacturing tasks and items for specific customer orders.

A factory based on POMS fits what Skinner [7] named a focused factory. Skinner suggests that a company performs better and becomes more competitive if it focuses activity on specific tasks or products. This improves company productive competences and response capacity to market demands changes.

According to production requirements, POMS may simply take a form of a manufacturing or assembly cell but, conceptually, it is a more complex system, i.e. it includes both parts manufacturing and parts assembly. A view of the Production Oriented Manufacturing System concept or organization is shown on Figure 2.

In practice pure POMS organization may not be economically attractive in many cases. The need to economically explore unique and expensive or bulky equipment for carrying out a particular function, in practice tend to lead to a more general and more common POMS organization, which we may call hybrid POMS organization, where several POMS may have to share one or a few functionally organized manufacturing units.

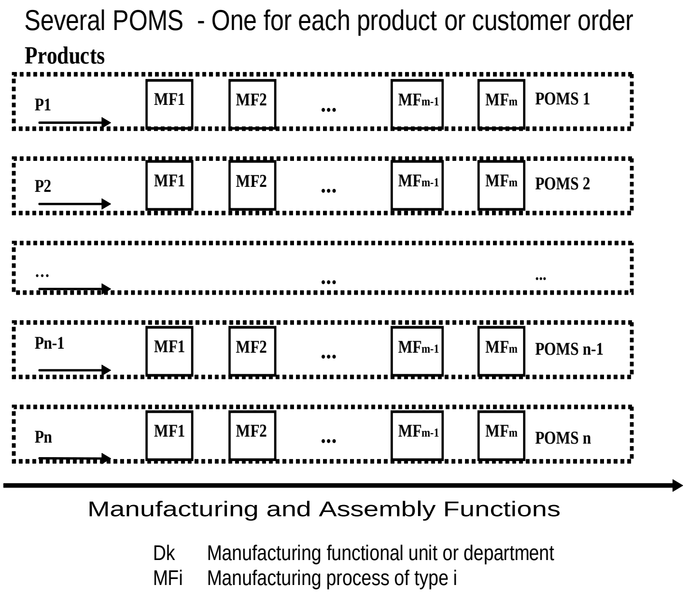

Figure 2: A conceptual view the Product Oriented Manufacturing System concept organization

A schematic representation of a POMS practical instance is shown in Figure 3.

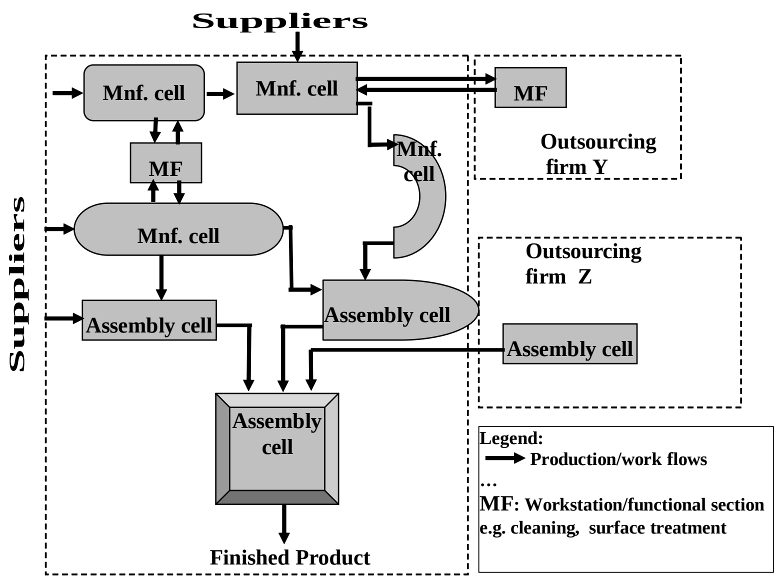

Figure 3: A schematic representation of practical instance of the POMS concept

Frequently POMS do not need to be designed from scratch. Reconfiguration is enough when only the adaptation of a POMS is necessary to suit product demand changes in the short run.

The POMS design and reconfiguration processes must explore processing alternatives of products, expressed in processing plans [8], manufacturing flexibility of machines, standardization of operating procedures, enlarged skills of operators and other design options. We simply may say that strategies, techniques and tools associated with Lean Manufacturing (LM) [9][10], Quick Response Manufacturing (QRM) [11] and Agile Manufacturing (AM) [12], must be taken in consideration. Both LM and QRM favour manufacturing systems organization in autonomous units or cells working under integrated coordination. 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 [13], which has been considered essential to product customization [14]. A more detailed view of requirements for easing POMS reconfiguration have been referred in Alves [15] and Alves and Carmo-Silva [16].

By exploring LM, QRM and AM we ensure, as required, that POMS are suitable, not only for the repetitive production [17], but also for "Make-to-Order" (MTO) and "Engineer-to-Order" (ETO) production environments.

Advantages of POMS

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 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 system reconfiguration.

POMS as an evolution from the CM concept

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 traditionally developed with basis on Group Technology (GT) theory [18][19][20][21][22]. Normally, a CM system is designed for a family of parts without taking into consideration the need for coordinating and synchronizing manufacturing of customer orders of specific products, from raw materials to assembly. To effectively respond to the market demand challenges of today, CM Systems (CMS) need to evolve 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 [23], with the Linked-Cell Manufacturing System concept based on the

Toyota Production System [24], and also by Suri [11] with the Quick Response Manufacturing concept where manufacturing functional units coexist with manufacturing cells.

DESIGN METHODOLOGIES FOR MANUFACTURING SYSTEM DESIGN

There are several approaches and methodologies to design, some more formal, others less, some more general and others more specific. For example, the Axiomatic Theory of Design (ATD) [25] is an example of a formal general approach to design. According to Suh: *"Design may be formally defined as the creation of synthesized solutions in the form of products, processes or systems that satisfy perceived needs through the mapping between the Functional Requirements (FR) in the functional domain and the Design Parameters (DP) of the physical domain, through the proper selection of DPs that satisfy FRs"* [25].

In addition to ATD, other design approaches of generic application include the Extended General Design Theory by Tomiyama and Yoshikawa [26], Robust Design of Taguchi [27], Theory of Inventive Problem Solving (TIPS) by Altshuller [28], Workshop Design Konstruktion school (WDK) by Hubka and Eder [29] and Total Quality Development (TQD) by Clausing [30]. These last three approaches and the ATD are described and compared by Tate and Nordlund [31]. General approaches to design are, in some cases referred as theories of design.

In general, design methodologies are intended for guiding the designer in the design task and for reducing the complexity and effort in the design process [32]. Essentially they structure the design process in a sequence of design steps leading to solutions that satisfy user requirements, i.e. design objectives. Thus functional specifications are initially determined, having into account several types of restrictions, typically of technological, economical and organizational level, and then, based on them and on further information, alternative design solutions are generated and submitted to an evaluation process.

A methodology does not search for solutions. It shows the best way to approach specific problems, searching the paths to reach solutions, including guidance in the search process and in the collection of data/information for better decisions, at a specific moment in space and time [33]. Design alternatives are generated, at each design phase, based on data, methods and tools that a design methodology effectively points out and helps to access and use in an organized and timely manner, towards reaching a solution to a design problem.

Frequently designers do not like to use design methodologies. There is a belief that they tend to have a limited contribution to design efficiency and effectiveness. This may be due to the attempt to use a methodology to tackle all phases of complex design problems in a coupled way. This tends to lead to a complex process, involving many tools and activities whose coordination, and process and solutions traceability, become difficult. This also hinders flexibility to make design changes [34].

There are design methodologies which are focused on a domain or a specific class of problems or products. Others, on the other hand, are of wider application. The wide application of a methodology to design problems may be seen as its main weakness. This is because they are not as appealing to designers as are domain or problem specific methodologies. The design solutions that they offer tend to be more conceptual than real and final design solutions to problems. Additionally most designers tend to have difficulties in using them comfortably; only experts are likely to do so. However we may argue that such wide application of a design methodology may be also its main advantage. This is particularly so due to its suitability for conceptual design. Thus, for example, used at a meta-design level a general methodology can even support the design of more specific or focused methodologies. This was the case of the application of the ATD of Suh to the development of quite a few methodologies for production system design as reported and developed by Carrus and Cochran [35], Cochran et al. [36][37], Cochran and Dobbs [38] and Suh et al. [39], the Babic [40] and the Kulak [41]. Other examples are the production systems design methodologies of Rao and Gu [42] and REALMS methodology [43].

The orientation of a methodology for the design in a specific problem area makes it more practical, quick and effective to reach viable and real design solutions.

It is in the design process that manufacturing systems operating performance is ensured. For this, design must be rational, structured and also detailed. This contributes to avoid errors that at the solution implementation level can be costly. So, POMS design should be based on methodologies which satisfy such requirements. Moreover, the relevant elements, i.e. data, tools and methods necessary for designing and the provision for generating suitable alternatives at design phases should be ensured. Under this POMS specific design area, a set of POMS alternative system conceptual configurations should be included in the framework of the design methodology as a means to easy the process of solution generation and evaluation to reach an effective and efficient manufacturing system configuration. This can enhance a POMS design methodology. POMS methodologies that do not provide a view on possible arrangements for study and analysis or that are too focused on a specific physical or operational arrangement may not ensure the operating performance levels that otherwise could be achieved for a POMS.

In the following section some focused methodologies on POMS design are discussed.

Design methodologies for POMS configurations

The design of POMS have traditionally been approached within a myopic view, i.e., without a holistic system design view. This started with the seminal work on Group Technology (GT) by Mitrofanov in 1959 [44], useful for designing GT Cells. More recently, an approximation to an integrated manufacturing system design view is becoming popular. A few methodologies following this trend have been developed. Due to their popularity, importance and, to a great extent, their suitability for POMS design, the following methodologies deserve special reference: PFA - Production Flow Analysis (PFA) methodology [18], Toyota Production System (TPS) [24] and Integrated Manufacturing Production System (IMPS) [23].

The methods and techniques, procedures and approaches or frameworks that can be used for helping the manufacturing systems design task are all here referred as methodologies. In addition to the above referred, others which may also be included in the POMS focused class, here either referred by name or author(s) name include: Ingersoll Engineers [45], Massay [46], Quick Response Manufacturing (QRM) [11], Silveira [47], Babic [40], Hyer and Wemmerlov [48], Kulak [41] and Fraser et al. [49].

The POMS design methodologies have different design purposes and are supported by specific or dedicated design mechanisms. Thus, e.g. some are oriented to reengineering or reconfiguration of manufacturing systems and others to design new systems, referred as construction methodologies. Examples of the former include the PFA, TPS, Black, Suri, Kulak and Fraser. All these aim at improving performance of existing manufacturing systems, though system reconfiguration. Of the latter class of methodologies we can mention the Ingersoll Enginners, Massay and Silveira methodologies. The methodologies can also be organized by industrial sector. For example, the PFA and Ingersoll Engineers methodologies were initially designed for the metalworking sector, although, according the authors, they may be extended to other industrial sectors. The TPS, Black, Massay, Suri, Silveira, Hyer and Fraser methodologies, being more generic, are suited for manufacturing systems design of other industries. These methodologies are briefly described below.

PFA methodology

The PFA methodology, developed by Burbidge in 1963 [18], is a methodology for the implementation of GT in a company. According to Burbidge, before PFA, GT was based on classification and codification of parts based on technical drawings, for grouping similar parts. Apparently, this approach was not satisfactory for forming manufacturing cells because of the difficulty of forming machine groups to allocate to part families and forming dedicated manufacturing cells. PFA uses a different strategy. It identifies part families and the machine groups to form cells on the basis of manufacturing information analysis contained in the processes plans of each part. The process plans list all the operations necessary to manufacture each part and the machines or others workstations used for carrying out processing. PFA includes other specific procedures used to change a function oriented process organization into a product oriented organization. This means that PFA is used to reengineer or convert a FOMS system into a manufacturing system of interconnected GT cells. Usually the new arrangement tends to be quite static. Reconfiguration or coordination of work of associated with specific customer orders is not a matter of concern to PFA methodology.

The PFA methodology follows the following five step procedure, which essentially aims to simplify materials flow in the company as a whole, from inter-factory level to tooling level in manufacturing cells or lines:

1. Company Flow Analysis, CFA – to simplify the flow between plants or company divisions;
2. Factory Flow Analysis, FFA – to simplify the flow inside the departments;
3. Group Analysis, GA – to plan the division or reorganization of the departments in GT cells;
4. Line Analysis, LA – to simplify the materials flow inside each cell;
5. Tooling Analysis, TA – to simplify and reduce the frequency of the setup processes of the machines.

Usually due to the need to handle large quantities of data PFA is better implemented by means of software tools and access to product and production data bases. Some such tools have been developed by McAuley [50], King [51] and Chan and Milner [52].

PFA has been applied to many examples of reengineering FOMS batch production into cell based manufacturing systems.

TPS methodology

The Toyota Production Systems (TPS) design methodology described in Monden [24] is based on the integration of four essential requirements or principles, i.e. Just in Time (JIT) production, autonomation [53], flexible workforce and creativity. This integration is requires the implementation of the:

1. Kanban system to reach the JIT production
2. levelling mix production,
3. minimization of setup time to reduce the lead-time,
4. operations standardization in order to level the production and balance the system,
5. system layout according the production flow, of work and materials, predominant,
6. multi-skilled operators to reach and facilitate the balancing process of system,
7. operators motivation and involvement in the continuous improvement of the processes,
8. visual control implementation to reach the quickly inspection,
9. implementation of communication systems between the departments to promote the total quality control systems.

At the extreme, production flow leveling means synchronized one piece flow [53].

Black methodology

Integrated Manufacturing Production System (IMPS) is the name used by Black [23] for systems that have JIT production. For this reason, IMSP methodology is similar TPS methodology. The Linked-Cell Manufacturing System (LCMS) is the operational configuration designed by the IMPS methodology. This design methodology intends to convert an existent factory in a "factory with a future", using the author words, following ten steps:

1. form manufacturing and assembly cells,
2. reduce or eliminate the set-up,
3. integrate the quality control,
4. integrate the preventive maintenance,
5. standardize the productive flow for the final assembly,
6. link cells (Kanban),
7. reduce the WIP,
8. spread IMPS to the suppliers,
9. automat and robotize,
10. computerize.

Essentially, the methodology guides to the JIT philosophy and TPS implementation [55]. It is applied to reengineering existing systems impacting main and auxiliary production services, including accounting, procurement and sales and delivery.

Suri methodology

The methodology for Quick Response Manufacturing (QRM), developed by Suri [11], is applied through fifteen steps. The first two focus the need of involvement of the top managers and the responsibility and management allocation for the QRM project. The third step consists of selecting the goods and services subject to the QRM. A focus is put on those with long lead times. At the same time, the objectives to be achieved are established. QRM project team is formed in steps fourth and fifth with the assignment of responsibilities to each team member. The sixth step is to analyze the existing system. An important part of this is performance measurement. Step seven refines objectives and details QRM system reengineering project activities. The eighth step collects and analysis detailed data. The ninth generates alternative solutions to the problems, aiming at reduction of lead-times. Proposed strategies and solutions are then discussed with top managers at the tenth step. The remaining steps are related with the formation the team for implementing changes, step 11, and the technical training of operators that will work on the QRM cells. These are formed at step 12. The QRM cells implementation and the evaluation and measuring of results comprise steps 13 and 14, respectively. Step 15, the last, is the repeats the design process for others projects.

The QRM implementation is about the reorganization of production systems, extended to procurement planning, capacity planning, lot sizing strategy, and other functions. QRM methodology is applied to existing systems.

Hyer methodology

Hyer methodology, according Hyer and Wemmerlov [48] is a framework for planning and implementing cellular manufacturing. This methodology has 13 steps. The first five have to do with the problem awareness, strategic position, manufacturing capability studies, vision and goals formulation decisions to continue the project. The next three steps deal with the initial cell planning and calculus of cost/benefits for the cells. In the ninth and tenth step the detailed design is carried out, followed by the implementation of the cells (step 11). The last two steps are related with the improvement and evolution of the cells and the final evaluation of the planning process design.

Kulak methodology

The Kulak methodology [41] is based on the ATD and addresses the design of production cells. The design process involves four steps and a feedback mechanism for continuous improvement, i.e., to evaluate and improve the design based on pre-selected performance criteria. The process begins with a preliminary phase of team selection followed by analysis of the production processes. In the second step cells are formed based on the principles of ADT, followed by cell implementation. Finally, performance evaluation, based on selected criteria, is done. If the solution obtained does not respond to the expectations attempts are made to improve the solution.

Fraser methodology

Fraser et al. [49] propose a methodology, involving six phases: feasibility, project team, cell design, human factors, reorganization and installation and, finally, continuous improvement. The 1st phase has to do with the strategic issues, mainly with the identification of the reasons for the change. The 2nd deals with the team project formation and the need of involving all in this project. The 3rd phase, is concerned with cells formation. The human factors phase – phase four – focus on selection, training and rewarding operators for the cells. Reorganizing and installing new layout is carried out by 5th phase and, finally, the 6th phase focus on the continue improving procedure.

Ingersoll Engineers methodology

Ingersoll Engineers methodology orients the company in the implementation of Flexible

Manufacturing Cells (FMC) [45].This involve essentially five distinct phases. In the first phase is considered the strategic position of the company in order to evaluate in which way the FMC could influence the business strategy. If this expected influence is positive and based on the objectives to reach it is made the development of FMC configuration. Such development bases on the technical and economical analysis of possible configurations. This is in the second phase that treats also of how to present and convince the top management to adopt the FMC configuration and their involvement in the process. In the third phase are approached the special considerations about cells, i.e., technology application, handling, warehousing and transport systems and the utilization of industrial robots and are discussed the quality level and the control systems if machines, cells and production. The fourth phase of this methodology deals with the detailed planning, cells implementation and results measures. The fifth and last phase tries to reach Computer Integrated Manufacturing (CIM) systems.

This is also a methodology that embraces and involve all sectors of the company but could also be applied to the conception of new systems, being necessary a careful and long planning. This has to be done in this manner because only doing this it is possible having successful cells [45].

Massay methodology

Massay methodology [46] uses an approach of holistic systems design. This facilitates the evaluation of the total system being developed. This approach uses available tools and techniques and could, according to the author, being easily adopted by production systems designers.

The Massay methodology is recommended for both new systems design and reengineering aiming at improvement of existent ones. This methodology is structured in the following four phases: analysis, conceptual design, integrated design and detailed design. These phases are developed sequentially with feedback between consecutive phases.

In the analysis phase data relative to parts to produce are is collected and processed for parts families' formation. The identified families, the production quantities, the process plans and the production schedules defines the required capacities and cells' capacity and provide the inputs, such as information about manufacturing equipments needed, for carrying out the next design stage, i.e. the conceptual phase. Here, the architecture of the system is defined with basis on the operations and the operations processing sequence, represented in a flow diagram. The proposed conceptual system resulting from this phase, is an integrated CMS with a few cells. The integrate design phase is further divided in five steps whose objective configuring cells and the system as a hole. Then alternatives configurations are evaluated against performance criteria. The best solution is selected and used in next phase, i.e. detailed design. The objective of this is attending all the specifications and dimensional details of the selected alternative. The output of this phase includes also design documentation namely detailed design drawings and systems detailed specifications.

Babic methodology

As the Ingersoll Engineers methodology described early, Babic [40] proposed a methodology for Flexible Manufacturing System (FMS). This methodology is based on the ATD and is developed in four phases the process design: 1) specification of the operations to be processed on the system, 2) definition of the functional requisites, 3) FMS design and, finally, 4) performance analysis using the simulation.

Silveira methodology

Silveira [47] presents a methodology for implementing production cells. It is structured in three phases: The first, the preparation phase, which includes system analysis and preparation for the new layout, the definition phase of the new layout and the physical implementation of the new layout and management systems. In the first phase data are collected, the team in charge of changes is formed, design objectives are defined, a pilot area to implement the cells is selected and support techniques, like techniques for the setup time reduction, are implemented. In the second phase methods for the cells formation are chosen, data for the methods application are collected, production cells are formed, production capacity is defined and system layout is designed. In the installation phase, the third, cells implementation is planned, operators and machines are assigned to the cells. Then, system management and performance analysis follows.

Final considerations

Generic methodologies may address manufacturing system design in spite of not being focused on this area. The result of this is that design solutions tend to be general or conceptual, requiring further handling to treat detail and reach to real design solutions, Typically, further design steps outside the methodology are required. To reduce such efforts manufacturing systems oriented methodologies are required and have been developed as reviewed. These are more explicit and straightforward in guiding the designer to workable alternative solutions and ultimately, through a recommended evaluation process, to choose one. In particular they focus on known and tested configurations of manufacturing systems of types such as CMS, FMC and FMS and POMS, from where one is chosen and adjusted according manufacturing requirements. For this reason, they are more objective, reducing the range alternatives from where to select. Some of such methodologies have been developed from generic ones.

Some methodologies lead to solutions that are operational configurations of manufacturing systems, i.e. the physical and system operational configuration is solved or designed together.

Table 1 presents the summary of the methodologies described showing application areas or design solutions.

GCD METHODOLOGY FOR POMS DESIGN

Although quite a few methodologies for POMS design are available, it may be argued that no one alone is capable of dealing with the whole design needs and complexity of POMS design. For example, the integration of both physical arrangement and production control towards integrated materials flow coordination of customer orders is not clearly addressed by the methodologies studied. This is though an important requirement of design in the customer oriented global market of today. Moreover, the departure from a set of fundamental conceptual cells for POMS design would easy the POMS design process. Thus, the designer could be led to discover good system solutions through intermediate choices of conceptual components, i.e. cell and workstations, according patterns of demand and processing.

Table 1. Summary of design methodologies

Class	**Methodology**	**Solutions/Artifacts**
Multipurpose or Generic	– *Extended General Design Theory* – *Robust Design* – TIPS – WDK – Axiomatic Design Theory – TQD – ...	– *Consumer Products* – *Process* – *Tools* – *Machines* – *Production Systems* – *Information Systems* – ...
Manufacturing Systems Specific	– *Rao and Gu (1997)* – *REALMS* – *MSDD* – ...	– Manufacturing System
POMS Focused	– PFA – TPS – Black – Ingersoll Engineers – Massay – Suri – Babic – Silveira – Kulak – Hyer – Fraser – ...	– POMS system configuration

With basis on this thinking the authors went ahead with developing yet another POMS design methodology, i.e. the GCD methodology [1] [15]. As the designing task progresses the GCD methodology prompts the designers to use mechanisms, methods and techniques proposed by other methodologies, e.g. IMPS, QRM or PFA, or available from other sources, namely from web services, which can serve well the complex POMS design task.

The GCD methodology is strongly focused on POMS design and is organized around three major design phases, namely the Generic, the Conceptual and Detailed. This is linked with the strategic, tactical and the operational analysis and synthesis of the production system design with focus on POMS. The methodology seeks to assist frequent production system reconfiguration for system adaptation to product demand changes. It uses a hierarchical approach to design.

Other 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 proposed according to customer orders manufacturing requirements. Design roles, frequency and design players, were identified for each design phase in Alves and Carmo-Silva [16].

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. Due to this the authors are involved in the development of computer Aided Design System to implement the GCD methodology,

To some extent, the GCD methodology shares common features with the Black methodology for Integrated Manufacturing Production System (IMPS) and from the Suri methodology for QRM systems.

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 either the pure or the hybrid 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 of design, the POM and the FOM organizations are compared against each other. This starts by identifying a selected range of products whose production is required and must be generally evaluate under both POM and FOM organizations. If both pure or hybrid POMS are unsuitable for carrying out production the FOM concept should most likely be adopted and no further POMS design steps need to implemented. Other methodologies should then be used. If on the contrary POMS organization is proved to have a potential for success then POMS design continues.

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.

Conceptual Design

The main and fundamental purpose of conceptual design is selecting conceptual cells and workstations, which are instantiated later, at the detailed design phase, for configuring the POM system. Two main activities need to be carried out: 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 [4][56].

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 [4], 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 [57].

The GCD methodology Computer Aided Design System

Due to the complexity of design and need for massive data handling in POMS design a Computer Aided Design System is being developed to implement the methodology. At the moment a prototype of such system is in an advanced stage of development [8][15][16][58]. This prototype includes a database, updateable on a continuous basis, a knowledge base for design methods and tools and some interfaces and aids needed for easing the design process. However, the prototype is not yet in a state capable of being applied in practice. Further refinement is required mainly to enlarge the design and evaluation methods base and interfacing with information systems.

CONCLUDING REMARKS

Designing manufacturing systems in general and Product Oriented Manufacturing Systems in particular, is a very complex task. This involves many activities, data, information, restrictions and decisions and a considerable number of methods, mechanisms and techniques. Many academics and practitioners recognize the importance of having design methodologies for helping in this complex design task. A suitable methodology for this can be of great benefit for speeding up the design process and also for more quickly generating good POMS design solutions towards improving performance of operations and customer service of a company in today's global market.

A number of methodologies were briefly presented, described and related, focusing on their capability for dealing with POMS design requirements. POMS design methodologies are also aggregately compared with the authors' GCD methodology. Having in mind the need for practical application of the GCD methodology a software prototype, integrating an extendable knowledge base on design and evaluation methods, is already at an advanced stage of development. The authors are still working on these aspects together with the gathering of industrial data for validating and enhancing the both the methodology and the CAD prototype.

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