A Computer Aided Design System for Product Oriented Manufacturing Systems Reconfiguration

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Abstract

Product Oriented Manufacturing Systems (POMS) are systems designed for variable product demand markets, and dynamically reconfigured for the manufacture of a single type of product or a family of similar products at a time. POMS systems can take several forms and result from exploring the use of flexible resources, a variety of new design philosophies, technologies and approaches to manufacture, including Cellular, Lean, Agile, Quick Response and Fit Manufacturing. In this paper a computer aided design system for the design and reconfiguration of POMS is addressed. A characterization and description of the structure and components of the design system, including a database, a user interface and a knowledge base and the description of some important data sets, are presented.

1. Introduction

It is recognized that the best performing manufacturing systems are those designed to suit specific manufacturing requirements of a product or a family of similar products, i.e. are Product Oriented Manufacturing Systems (POMS). The manufacturing system concept totally opposed to this is the one organized in functional departments, i.e. Functional Oriented Manufacturing Systems (FOMS) and, therefore theoretically able to manufacture any product variety. These systems tend to have poor system performance and provide poor customer service.

In the past, the decisions in favour of POMS were easier to take than today. Usually due to large production quantities, stable demand environment and reduced competition, POMS were established and remained unchanged for quite a few years. So, system reconfiguration was rarely required. Nowadays, due to high product demand variety and continuously increasing competition there is a need for fast and easy design of POMS to adapt them to meet customer changing requirements in an efficient and effective manner. This design process is oriented to the manufacture requirements of one product or a family of similar products, at a time. Unless POMS design is efficient and quick in achieving good configurations, which can be rapidly and easily implemented in practice, the advantages associated with POMS cannot be fully explored and, consequently, opportunities for maintaining a good customer service and competitive position in the market place can be lost. The use of FOMS could be sought as a good alternative to overcome such difficulties. However the requirements for fast delivery increased quality of goods and services and reduced cost of production do not favour FOMS either. This is why fast design or reconfiguration POMS is many times the way to follow. Moreover the POMS of today must be based on new technologies, reusable flexible resources and new approaches to manufacture, operation and control.

To be able to quickly attain good POMS designs and fast reconfiguration, computer aided design systems directly addressing POMS design must be used. Reported computer aided design systems (CADS) applicable to POMS tend to be restrictive, not focussed or unstructured. Thus they either implement a specific approach to POMS design, such as Production Flow Analysis [1], are developed for a wide spectrum of manufacturing systems without specifically focussing on POMS [2,3], or essentially are based on libraries of programmes to implement a given approach to design. Examples of CADS based on such approaches are those reported by Luong et al. [4] Mahadevan and Srinivasan [5] and Irani et al. [6].

In this paper a framework and an associated computer aided system directly addressing the designing of POMS, here called Computer Aided Design System for POMS (CADS_POMS), are proposed. They are based on a design methodology, referred to as the GCD (Generic-Conceptual-Detailed) methodology, developed by Silva and Alves [7]. The CADS_POMS eases data handling and the iterative design process and, at the same time, provides access to several methods and tools suitable for carrying out the design functions. This is done through a knowledge base and suitable interfaces. The knowledge base can be seen as repository of design and evaluation methods accessed and used at several design phases.

In the next sections a characterization of the Product Oriented Manufacturing System (POMS) concept is first presented and then the Computer Aided Design System for POMS and its framework are described. In the last section some concluding remarks are put forward.

2. Product Oriented Manufacturing Systems

A Product Oriented Manufacturing System (POMS) is defined as a set of interconnected flexible manufacturing workstations or cells, usually involving people, which simultaneously and in a coordinated manner address the manufacture of a product or a family of similar products, subject to frequent reconfiguration to be adapted to manufacturing requirements of different products or product families. A product may be simple, like a part, or complex, having a product structure with several levels. A set of cells that does not work under coordination towards synchronized production of end items, does not form a POMS. A paradigmatic example of Product Oriented Manufacturing System (POMS) is what Black [8] calls a linked-cell manufacturing system. Many manufacturing systems currently referred to as JIT, lean, flexible and virtual manufacturing systems may also be seen as POMS. Product Oriented Manufacturing (POM) can also be associated with concepts such as focused factory [9] and One-Product-Integrated-Manufacturing (OPIM) put forward by Putnik and Silva [10].

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. Today, these can benefit from intranet and internet based technologies, a prerequisite of the widely discussed Virtual Enterprise concept [11]. This approach to the virtual configuration of manufacturing systems was initially introduced in 1982, by McLean, Bloom and Hopp [12], and studied by several authors afterwards such as McLean and Brown [13], Drolet, Montreuil and Moodie [14] and Ratchev [15].

Although POMS lends itself to large quantities and small variety product requirements, it is particularly important in today's market environment to seek viable POMS for the "Make to Order" (MTO) and "Engineering to Order" (ETO) environments. This viability is ensured by exploring the reuse of flexible manufacturing resources and the organizational philosophies, techniques and tools associated with Lean Manufacturing (LM) [16], Agile Manufacturing (AM) [17], Quick Response Manufacturing (QRM) [18] and Fit Manufacturing [19]. Both LM and QRM favour production systems

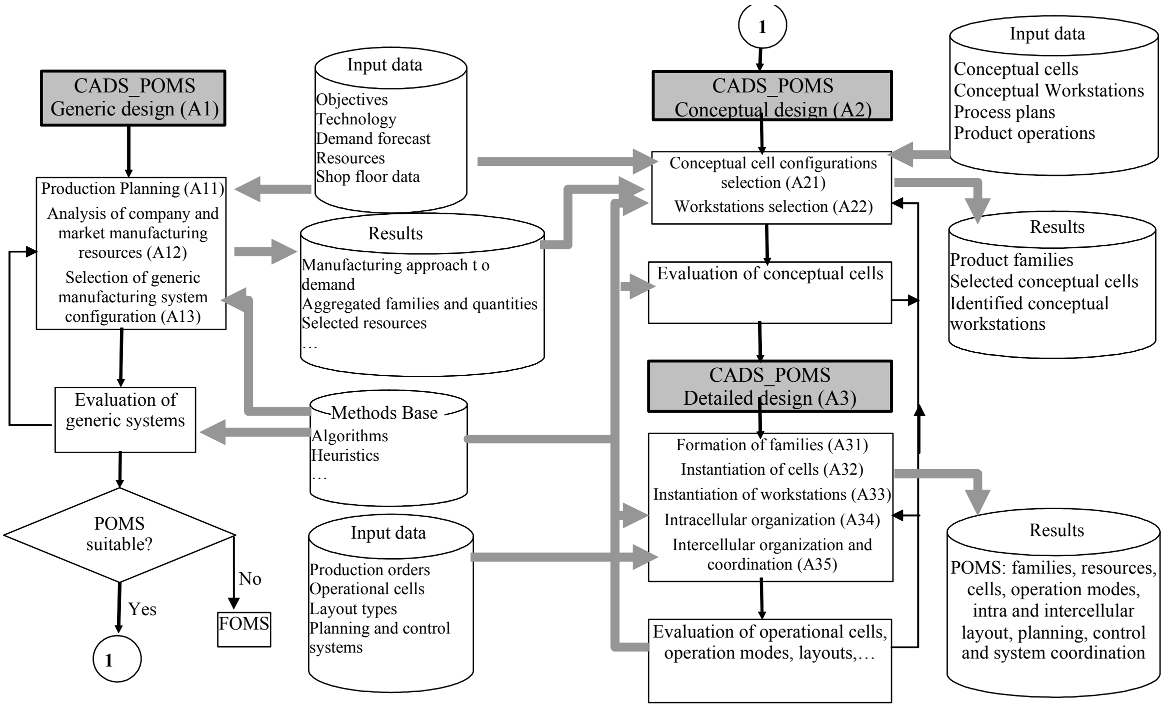

Fig. 1. CADS_POMS design Framework.

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.

3. Computer Aided Design System for POMS

3.1 CADS_POMS components and structure

The CADS_POMS framework is based on the Generic-Conceptual-Detailed (GCD) methodology for POMS design developed by the authors Silva and Alves [7]. A simplified representation of it is shown in Fig. 1.

The GCD methodology essentially puts forward a hierarchical multilevel and iterative design process for POMS and, at the same time, presents the designer with the set of design alternatives and parameters, which must be evaluated at each stage. This design process is extended to find production control and work coordination solutions, within and among cells, for complete product manufacture and assembly. Naturally, the design options and parameters are initially dependent on customer needs and derived functional requirements, as well as on the company objectives and restrictions.

In the design process aimed at reaching good solutions for both organizational and operational configurations of POMS several decisions at strategic, tactical and operational level must be taken. The first is to decide, based on market requirements and the company's internal and external environmental restrictions, if POMS are a viable alternative to manufacturing systems configuration. Only an affirmative answer to this question allows further POMS design.

In the GCD design methodology, all relevant data and restrictions are considered and a range of methods are used in the POMS design process. Under this methodology the design process is organized in three main phases, namely the generic, conceptual and the detailed one, and includes several design stages and activities. However important the GCD methodology may be, it can be of little use if not supported by a computer aided design system. This is done through the CADS_POMS that supports design activities from strategic planning to the POMS organization and workflow control mechanisms definition. The main components of CADS_POMS are a database, a methods base and a user interface with several menus and windows (Fig. 2). Software interfaces are also used to access and use several methods or algorithms for performing design functions and evaluating alternative design solutions.

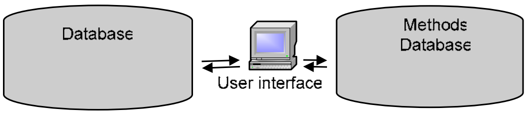

Fig. 2. Main components of the CADS_POMS

The database includes all relevant data for POMS system design. To design POMS very important data are the products data and manufacturing processes of products, as well as data about manufacturing resources used.

The methods base can be seen as a knowledge base providing the methods to be used at different POMS design phases. At the present stage of development of the CADS_POMS this knowledge base is centralized and provided with a small sample of methods that can be executed to solve POMS design problems. However, the methods base is being enlarged to provide the right tools for obtaining and evaluating POMS solutions at every design stage. Therefore, the CADS_POMS system will be able to quickly access a large variety of methods for efficiently solving the POMS design problems according to the GCD methodology and using data in the database. To further enhance this function a study is under course to evaluate and possibly to implement the methods base as a distributed knowledge base, updateable as new methods can be made available locally or remotely by a community of methods providers in a network of computing peers or servers. One important piece of software to implement this idea is a service interface for easy methods specification, access and local or remote execution through the Internet. This can be particularly important because the CADS_POMS could have several independent implementations, in companies for example, and all share the same distributed knowledge base of methods.

The user interface allows the user to perform several functions. An important one is the introduction of initial data for system design, both related with the underlined design philosophy and with objects, namely products, operations and resources of several types, including machines, which are available for configuration or reconfiguration of the manufacturing system of a company. This is important and instrumental to the main user function, which is to use the design methods in the design process having into account all restrictions and resources available. Additionally, the user plays a strong role in the selection of methods to use for supporting design functions. This means that the user must have a clear idea of the needs, purpose, role and usefulness of each method in order to be able to apply them according to the design process needs.

3.2 Fundamental concepts and data sets

Data in the database is organized for allowing specification of manufacturing processes in a manner that permits the user to fully explore alternative design solutions dependent on both available resources and processing flexibility. Thus a comprehensive specification of manufacturing processes is critical do the design success. The manufacturing process specification involves four levels. First, it is necessary to specify the *process plan* (PP) of each product. Process plans are defined at process planning level and are absolutely necessary as input data to POMS design. A process plan can be seen as a network of sub processes (SP). Each SP changes the processing state of a product and may involve a single or a set of manufacturing operations. An *operation* is an elementary conversion process performed in one product, component or workpiece. A process plan represents all theoretically possible alternative processes for manufacturing a product, i.e. the processes to take a product from an initial state of conversion to a final one.

The set of SP of the PP chosen for converting a product from an initial state to a final one is called an *operation plan* (OP). Therefore, usually a single process plan may specify or imbed several operation plans. So, at a second hierarchical level of process specification, the operation plan for a product has to be chosen or specified. Since, for arriving to an OP, it is usually necessary to choose one among a set of alternatives imbedded in the PP, a decision making process have to be carried out as referred above. In POMS design, this must take into account the design objectives, namely that of efficiently and dynamically reconfiguring POMS. For making a good choice, suitable methods for operation plan selection must be accessed and used, and a lot of user interaction is likely to be required.

Operation plans may provide alternatives for the sequence on which some operations can be carried out. Thus it is necessary, at a third level of manufacturing process specification to define or choose the *operations sequencing plan* (OSP), i.e. the order on which each operation of the OP of a product should be carried out. For an established manufacturing system configuration, this problem is more a problem of scheduling than a problem of system design. However, if efficient system operation is sought than the selection of an OSP for a product may be critical to POMS design.

The last manufacturing process specification level has to do with the choice of workstations to perform each operation of the operations sequencing plan. When a single workstation is available the choice is obvious. However, if more than one exists within a manufacturing system, then alternatives arise. This calls for a workstation selection process. This is also important for manufacturing design because it enables to finally settle the workstations to use in the manufacturing process of a product and, therefore, in the manufacturing system. This sequence of operations associated with the physical workstations that execute them is called *product routing* (PR).

Although a hierarchy of decision process steps can be envisaged from process plans to product routings, all, or at least some of the decision process steps may have to be integrated and solutions obtained in an interactive way. This is mainly performed during the Conceptual Design (A2) and Detailed Design (A3) of the GCD methodology.

To be able to specify PP and ultimately define PR, the processing operations of products must be specified. In the CADS_POMS, processing operations of a product result from the instantiation of generic operations, according to the physical transformation or assembly required to manufacture the product. This instantiation process is carried out by a process planner based on a number of parameters and operation attributes. The result is input to the database for POMS design. This data is likely to be reusable for several POMS design problems in the same manufacturing technological environment if production is to be repeated. This data can be used by the POMS designer who interacting with design methods can proceed to the choice of OP, OSP and ultimately PR. In a garment manufacturing environment, as an example, generic operations include cutting, sewing and attach zips. Operation attributes and parameters include the number of needles, number of threads, machine type, operator type and batch size.

To systematize the manufacturing process specification procedure and avoid data proliferation, in the Microsoft SQL relational database used, a table is defined for specifying operation attributes and parameters, referred to as the *characteristics* table. Another table contains the list of generic operations to be instantiated with data from the characteristics table for each product to manufacture in the system. A critical set of data in the database used by the CADS_POMS is shown in Fig. 3.

The machines table includes a list of all the machines that can be used for POMS design or reconfiguration. These include not only those available at the company but also those that can be acquired if necessary through buying, leasing or borrowing. Thus machines which are likely to be acquired in the market may also be listed. All these machines have attributes and processing characteristics which are listed in the characteristics table. Thus, both operations of products and machines in the system share the same characteristics table for its characterization or definition. This approach to machines and operations definition permits to identify, through a matching process, which machines can perform which operations. This matching process together with the already defined operation plans enables to choosing product routings. These are central to the specification and design of a POMS system. Whenever a POMS system has to be used to manufacture several products their processing requirements must be taken simultaneously into consideration for such choice.

4. Conclusion

Designing product oriented manufacturing systems (POMS) is a very complex task. Usually it cannot be carried out in an efficient way without computer aid. In this paper the framework of a computer aided system for POMS design, called CADS_POMS, is presented and briefly described. The framework is based on a POMS design methodology called GCD methodology and developed by the authors.

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 evaluation at several design stages. The system design capability is both highly dependent on user interaction and on the availability of design methods. Apparently, it seems to exist advantageous that the knowledge base take a distributed form. This can be particularly important because the CADS_POMS could have several independent implementations, in companies for example, and all share the same distributed knowledge base of methods. Moreover it could be

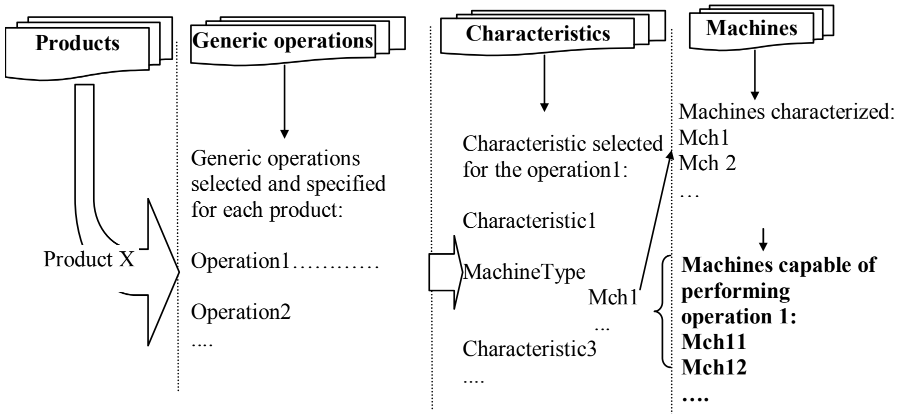

Fig. 3. Fundamental data sets for POMS design.

updateable as new methods could be made available local or remotely by a community of methods providers in a network of computing peers and servers. This idea is being validated and most probably will be implemented in the near future.

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