29

Design issues of an integrated software workbench supporting the manufacturing systems design process

M. Garetti[†]*, A. Bartolotta*[†]*, E. Corradi*[†]*, M. Rabe*[‡] *and A. Raimondo*[§]

[†]*Politecnico di Milano*
piazza Leonardo Da Vinci 32, I-20133 Milano, Italy

[‡]*IPK Fraunhofer Gesellschaft*
Pascalstraße 8-9, D-80636 Berlin, Germany

[§]*Candy Elettrodomestici,*
via privata E. Fumagalli, I-20047 Brugherio (MI), Italy

Abstract

This paper describes an ongoing research project, funded by the EC, Esprit program, aiming at developing a "workbench" for the computer-aided design of manufacturing systems. The system provides an user-friendly and powerful environment in which tools supporting the conception, design and evaluation of manufacturing systems will be integrated in a common framework. The workbench has its foundation on a descriptive method of the domain of manufacturing systems (based on the object-oriented methodology), enabling the description of all the aspects of a generic manufacturing system. The paper gives a general overview on the project: after a short introduction on the drawbacks of the current IT tools supporting the manufacturing system engineering process, the logical architecture of the software workbench is presented; then the expected benefits arising from the employment of the system are underlined.

Keywords

Manufacturing system engineering, object-oriented modeling

Computer Applications in Production and Engineering. F. Plonka and G. Olling (Eds.)

1 INTRODUCTION

Manufacturing systems engineering (MSE) is a recently recognized multidisciplinary engineering function covering all traditional forms of engineering concerned with production: it ranges from design of manufacturing systems, to logistics design, to flow control philosophy selection, to production organization. Recently the need for frequent restructuring of manufacturing systems and for faster new product-to-market cycles is calling for MSE process optimization. Really today the manufacturing system engineering process is still poorly formalized and requires relevant effort and time for the production engineer to deal with, while speed, accuracy, co-ordination and integration of this activity with other business processes could have dramatic impact on overall company performances. An interesting survey, conducted in the UK (Devereux *et al.*, 1994) over a sample of 50 organizations, discovered that only about half of the sample actually uses a formal, structured method when restructuring their operations, mainly a method developed in-house, then concluding that there is no existing single widespread design method currently in common use.

The survey also revealed that there is a widespread usage of some tools and techniques in the design process. Due to the multidisciplinary nature of MSE, available tools come from different disciplines: i.e. from manufacturing technology (such as group technology and production flow analysis), from operations research (such as queue theory or scheduling algorithms), from system theory (such as Petri nets and control theory) and from computer science (ranging from simulation software, to concurrent programming techniques, to simple tools such as spreadsheets).

So while in the product design area CAD/CAM/CAE technologies provide powerful and comprehensive support to the design process, and in the production management area a lot of IT tools are supporting the production planning process, a lack does exist in the MSE area where it is not available a single approach yet, offering a complete framework (a "platform") to handle the brain intensive work of design for a modern manufacturing system. At a large extent, the MSE process continues to be left to the intuitive judgment of the production managers' mind. In the meantime, production decentralization and internationalization of enterprises, involving remote plants and distributed engineering offices, all stress the importance of a standardized and integrated approach to the MSE process. Last but not least, the absence of a MSE platform means the lack of a method to store in a suitable manner data on manufacturing systems architecture, entailing a missing link between product design and production management processes (while these processes structurally share a great amount of data with the MSE process).

In this context, an integrated system enabling the management of all relevant information and knowledge associated with the manufacturing system design is needed.

1.1 Related work

Ongoing projects, strictly related to this research subject are briefly outlined herewith.
In the USA, at the National Institute of Standards and Technology (NIST), work on 'Computer-Aided Manufacturing System Engineering' is underway since 1992. The NIST project is aimed "at advancing the development of software environments and tools for the design and engineering of manufacturing systems"; such an environment "will improve the productivity of manufacturing/industrial engineers", who would use it "to design and implement future manufacturing systems and subsystems" (Mc Lean, 1993).
At the Oklahoma State University an underway project, funded by National Science Foundation, involves the conceptualization and development of an integrated, object-oriented modeling and analysis environment for aiding manufacturing engineers in the detailed design and rapid configuration of discrete part manufacturing systems. The environment should provide the integration of a variety of appropriate analysis and optimization tools which lye in different domains (Mize *et al.*, 1992).
At the Ohio University, a research team has designed a virtual environment for manufacturing systems design, integrating the many existing manufacturing systems design tools; the suggested architecture for the Integrated Manufacturing Systems Design (IMDE) co-ordinates the design and modeling on familiar design tools, thanks to a unified meta-model (UDMM), containing the entities and relationships commonly shared among the tools included within the environment (Koonce *et al.*, 1996).
Although the basic principle addressed by these projects, i.e. to provide some kind of support to the designer of manufacturing system, is basically the same, the projects present different focuses: the IMDE project focuses on communication mechanisms among the different manufacturing systems design tools, able to facilitate the sharing and exchange of information between them and ensure the consistency and coherence among the different data models; the project, developed at the Oklahoma State University, focuses on the kernel of the system, an object-oriented modeling environment that emphasizes model reusability; the NIST project addresses ambitiously a more global environment, that includes tools not strictly related to the manufacturing system design, like hazardous analysis, budget planning, benchmarking tools and so on, focusing on the technical issues and incompatibilities which hinder the interaction between commercial software packages.

2 SYSTEM ISSUES

2.1 Modeling and re-engineering of the MSE process

The objective to enhance production engineer's work productivity can be achieved by re-engineering the manufacturing systems engineering process, through the use of a suitable computer-aided software workbench. Therefore the manufacturing systems engineering process has to be examined, according to a model-based approach: sub-processes must be identified and each sub-process has to be modeled in terms of input-output specifications (Spur *et al.*, 1996). This kind of analysis leads to the identification of main process weaknesses and to the proposal of a re-engineered MSE process when supported by a computer-aided workbench: these requirements lead to the definition of tools and models necessary to support the designer in the MSE process.

2.2 Formal representation of manufacturing systems

As widely described in the following sections, in order to effectively support the designer in the manufacturing systems engineering process, many tools and models were identified. In fact, during the design process several models are developed; all these models are abstractions (with different objectives and at different levels of detail) of the same reality: the manufacturing system under design. The idea is that, through an analysis of the manufacturing systems domain, it is possible to identify the building blocks of a generic system, which can be used to build these models. From this consideration, the need to develop a descriptive method of the domain of manufacturing systems, which enables the definition of a structure of objects (building blocks) describing a generic manufacturing system, becomes evident. So a formal method to describe all relevant aspects of a generic manufacturing system is necessary. This descriptive method can also provide the semantic unification necessary for the sharing of information among the different tools/models that have to be integrated.

The concept of 'manufacturing entity structure'

The descriptive method we propose allows to define a structured representation of the domain of manufacturing systems (that we call *manufacturing entity structure,* MES), i.e. an unifying abstraction enabling the management of all relevant information and knowledge associated with the process of manufacturing systems design. In other words it can be considered as a *metamodel* of the manufacturing systems domain: it contains not only the type of entities, i.e. the building blocks of the models, but also the relationships among the entities; it specifies the format for the entities, the attributes and the relations it contains, defining a standardized data format for manufacturing systems description.

The descriptive method defines three different aspects of a manufacturing system:

1. the *structural aspect*: it contains the structural (static) definition of the system including workers, production facilities (including tools, jigs and fixtures), material handling equipment and other supplementary devices;
2. the *technological aspect*: it defines the transformational (functional) view of the system, considering the conversion process of the factors of production;
3. the *management aspect* defines the operating procedures of production, constituting the so-called management cycle, i.e. planning, implementation and control.

Each aspect only captures some features of the manufacturing system reality, whereas the whole system is exhaustively described by putting the three aspects together. The *manufacturing entity structure* contains the building blocks for the modeling of all the three aspects above explained.

As regards the implementation of the descriptive method, the object-oriented approach presents characteristics that make it particularly suitable to meet the requirements of the manufacturing entity structure, as already discussed in detail previously (Bartolotta and Garetti, 1996). In fact, the object-oriented paradigm provides an excellent approach to manage and express complex systems: the concepts of encapsulation and inheritance provide the object-oriented approach with characteristics of flexibility, realistic view, extensibility and reusability, all characteristics necessary for the descriptive method of the manufacturing systems.

3 THE SYSTEM LOGICAL ARCHITECTURE

In figure 1, the software architecture of a workbench implementing the descriptive method is reported. It is mainly a logical architecture: apart from the interfaces to external system (in particular CAD and simulation), the kernel of the system, named CAMSE (*Computer-Aided Manufacturing Systems Engineering*), accessed through the user interface, contains a series of logical modules corresponding to the functionalities provided by the system. Accordingly the system logical architecture should be seen as a set of tools the designer will freely use in his activity. Let's illustrate this picture considering the involved data structures first and the logical modules performing the various functions afterwards.

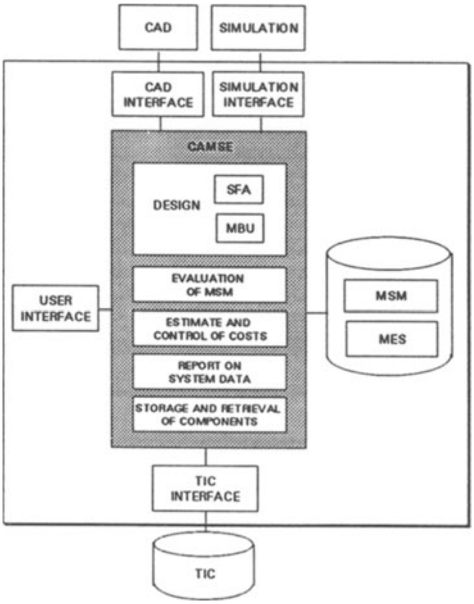

Figure 1 The system logical architecture

3.1 Data structures

Two different data structures have been depicted in the logical architecture: the *system database*, internal to the architecture, and the *technical information catalogue*, external to the system.

System database

The persistent part of the database stores the *manufacturing entity structure* (MES), i.e. all the building blocks, to build the different models of any manufacturing system, while the temporary part of the database contains the models, called *manufacturing system models* (MSM), built during the design process instancing the classes contained in the MES.
In spite of this distinction between temporary and permanent part within the system database, the designer has the possibility to enrich the object structure of the database, during the operative use of the system, both with basic objects, called *components*, not included in the MES, and with composite objects, called *subsystems*, which are aggregates of basic objects particularly frequent within a specific industry.

Technical Information Catalogue

An archive of information on manufacturing systems, subsystems and components stored in different formats, as an electronic format, or as a pointer to traditional archives (folders, floppy disks, etc.) is provided as a consulting support for the plant engineer.

3.2 Logical modules

The following is the list of main modules obtained identifying the needs of MSE.

A. Design

Within the design module, the following modules are established:

- a *system flow analysis* (SFA) module, that, starting from data on products to be manufactured in the production system (production mix, bills of material and process plans), will allow the generation of the model of the production flow within the manufacturing system, that we will call *system flow model*;
- a *model building and updating* (MBU) module supporting the designer in the construction of the manufacturing system models by properly selecting objects from the MES and setting their links.

B. Storage and retrieval of Components

This module is necessary to store and retrieve information about manufacturing systems, subsystems, components. This module must provide the designer with the possibility to customize for a specific industry the content of the databases, foreseeing the possibility to add new classes (both components and subsystems) at the MES or new links to documents.

C. Evaluation of Manufacturing systems Models.

This module must allow the interfacing to external systems, like queue theory or simulation tools, able to evaluate the performances of the *manufacturing system models.*

D. Estimate and control of plant costs

Such a module must allow to estimate the costs of the designed production system.

E. Report on System Data.

This module is necessary to make information available as input data external systems (procurement, detailed design, etc.).

4 THE REVISED MSE PROCESS

Before describing how the design process can be performed through the use of the proposed workbench, it should be cleared that it doesn't mean to provide the designer with a rigid methodology for manufacturing system design, due to the consideration that the methodologies followed in each company can be very different and proprietary, but the workbench must offer a framework supporting the design activity, i.e. a logical route the designer can follow during the design activity.

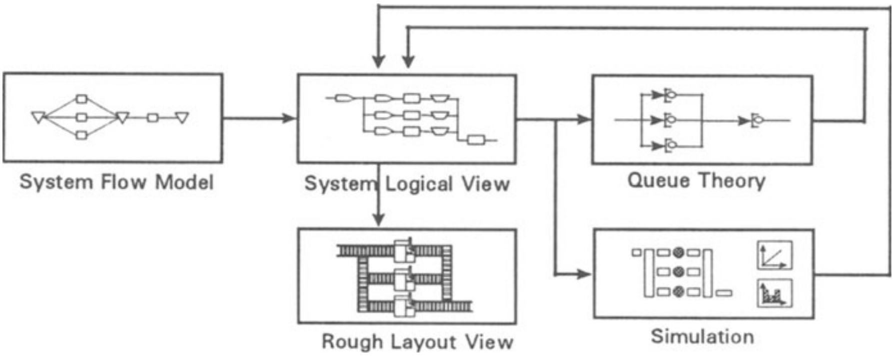

Figure 2 General description of the MSE process supported by the proposed software workbench

Within the workbench environment, the manufacturing systems design process is seen as carried out in some steps, in which several models, more and more detailed, of the manufacturing system are generated and evaluated and a satisfying solution is identified through an iterative process (see fig. 2).
In particular two different type of models are foreseen:

- *system flow model* (SFM): it will model the production flows, generated on the basis of data on production mix, bills of material and process plans of products to manufacture/assemble, giving information about the required production capacity for each kind of required resource and on the quantity of material flow linking production resources;
- *manufacturing system model* (MSM): it is the object model of the manufacturing system, of which two different views are foreseen: i) the *system logical view* (SLV), representing the logical view of the manufacturing system model in terms of logical objects and relationships among them (described by choosing symbolic icons representing specific machines, handling systems and other plant elements from the "catalogue" of objects corresponding to different plant components, technological and management methods); ii) the *rough layout view* (RLV) representing the physical view of the manufacturing system, obtained through the embedding to the logical view of further data for layout drawing.

Once the *manufacturing system model* is defined, its performances shall be evaluated through the link to external computer tools, like queue theory and simulation. On the basis of the results coming from their evaluation, the models will be modified and refined, until a satisfying solution is obtained.

5 EXPECTED BENEFITS

After having outlined the architecture and the functionalities of the proposed approach, that we are suggesting for the design of manufacturing systems, let's describe the expected benefits:

- *reduction of the effort of creating and evaluating the model of a manufacturing system*: a large library of reusable components and subsystems could be created for configuring plant models at different levels of detail for specific purposes, then plant configuration could be developed by properly selecting previously stored objects from library;
- *enforcement of standardization in manufacturing system design*: the knowledge-base of the software workbench could be used for urging the designer to choose standard components during the project development;
- *enhancement of coherence and co-ordination among different engineering teams*, whether they are dislocated in different geographical sites (multi-site design), or they are working, in a design site, on modules of the same manufacturing system: in fact, referring to a common database, every design team could be easily acquainted with the ongoing projects developed by other teams;
- *minimization of the retro-fitting and fine tuning associated with implementation of a manufacturing system*: the possibility of carrying out a fast computer-aided analysis and evaluation of a designer idea could entail presumably a better-quality solution; it's then foreseeable that failures occurring during the phase of start-up/runtime of a manufacturing system (up to 100 times more expensive to correct once a system is installed) could be significantly reduced;
- *reduction of the time spent in re-design and reconfiguration of manufacturing systems*: once made the one-time strain of creating the initial base model of a manufacturing system, the incremental effort to make a change in the current plant, such as the introduction of a new machine, could be slight, thank to the possibility to utilize and update the model previously stored;
- *reduction of inconsistency and redundancy of manufacturing system data*: during the development of the manufacturing system engineering process, the same common base representation could be employed by different modeling tools;
- *encouragement of production engineers in the direct use of modeling/analysis tools*: the software workbench could provide the access to model utilization by designers, who typically aren't modeling specialists, but have a very good knowledge of the manufacturing system to be analyzed;
- *enhancement of integration between product design and production management tools*: information on product details and routing could stem directly from CAD/CAM/CAPP packages; while plant data, such as machine type, machine throughput, buffer dimensions, could be automatically forwarded into production planning packages (i.e. master production schedule, material requirements planning, short term scheduling).

6 REFERENCES

Bartolotta, A. and Garetti, M. (1996) Object-oriented representation of manufacturing systems: trends and perspectives. *Proceedings of the Advances in Production Management Systems conference*, IFIP, Kyoto

Devereux S., Smith P., and Wood D.(1994) A survey of the use of design methodologies for implemented change in manufacturing companies in the United Kingdom. *International Journal of Manufacturing System Design*, 1(1), 51-58

Koonce, D. A., Judd, R. P. and Parks, C. M., (1996) Manufacturing systems engineering and design: an intelligent, multi-model, integration architecture. *International Journal of Computer Integrated Manufacturing*, 9(6), 443-453

McLean, C.R. (1993) Computer-Aided Manufacturing System Engineering, in *Advances in Production Management Systems* (eds. I.A. Pappas and I.P. Tatsiopoulos), Netherlands: Elsevier Science.

Mize, J. H., Bhuskute, H. C., Pratt, D. B. and Kamath M. (1992). Modeling of integrated manufacturing systems using an object-oriented approach. *IIE Transactions*, 24(3), 14-26.

Spur, G., Mertins K. and Jochem R. (1996) *Integrated Enterprise Modeling,* DIN, Germany.

The authors fully agree on the contents of the paper. However, M. Rabe wrote the section 2.1, A. Raimondo wrote the section 4, while the rest of the paper is due to the joint work of the other authors.

This work has been supported by the EC project "Plantfaber: An integrated software workbench as a tool for the re-engineering of the Manufacturing System Engineering Process", co-sponsored by the European Commission, IV Framework Program - DG III- ESPRIT program. The partners of the project are two industrial users (Candy Elettrodomestici (I) and Convey Satafim (E)), two research institutes (MIP of Politecnico di Milano (I) and IPK Fraunhofer Institute of Berlin (D)) and two software developers (LIPRO from Berlin (D) and Spaziosystem (I). The Plantfaber project started in May 1996 and is due for October 1998.