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Designing a computer-aided manufacturing systems engineering process

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Abstract

European enterprises are striving for effective business processes to survive in a highly competitive international market. Only dramatic changes in production organisation and enterprise culture can protect from loosing market shares. The reduced product life-cycles require adjusting the manufacturing system nearly continuously to the changing production flow. This adaptation can only be achieved efficiently if the factory planning processes are optimized. Because these processes are of multi-disciplinary character with team members often located at different production sites, the process design is a very challenging task. Surprisingly, the process of manufacturing system engineering, an essential part of factory planning, is poorly formalized and lacks qualified computer support. In this paper we present a new approach to manufacturing system engineering, that is based on a thorough process redesign and the definition of an information system that supports the process continuously, allowing defination of a flexible workflow that incorporates a variety of design and analysis tools. © 1998 Elsevier Science S.A. All rights reserved.

Keywords: Manufacturing system engineering; Business process modelling; Simulation

1. Introduction

Integration in international production networks, short time-to-market, more individual solutions and short product life-cycles determine the competitive situation for the European industry towards the end of the 20th century. Stiff organizational structures with large hierarchies, built from a functional understanding of industrial production are no longer suited for the task of surviving in the market. Business process re-engineering has attracted a lot of interest, especially the idea of radically introducing new process oriented structures. However, experience shows that a single deep cut is sometimes not only very dangerous for the company, but also underestimates the necessity of continuous adaptation. An overall approach is needed that allows living with the changes and adapting processes wherever and whenever needed.

Today's manufacturing technology already offers solutions for flexible production and assembly systems that allow production of tailored products at low costs. However, the reduced product life-cycles require adjustment of even these systems and the production flow at short intervals. This adaptation can only be achieved efficiently if the business processes dealing with factory planning are optimized. While new organisational concepts create more flexibility for resource allocation, powerful tools are needed to design and evaluate new structures. An approach to process redesign has to consider organisational aspects as well as an appropriate support with information technology.

The design and redesign of manufacturing systems, summarized here as manufacturing system engineering (MSE), is an important part of the factory planning process. It is a complex, multi-disciplinary process that involves not only people located at different production sites, but also a variety of tools that support special subtasks of the process. Solutions developed for subsystems by different designers have to be integrated into a single solution. Modelling tools must therefore assist in managing complexity and allow observation of the system model from different points of view.

In our approach we consider layout planning, arrangement of machines, material and information flow

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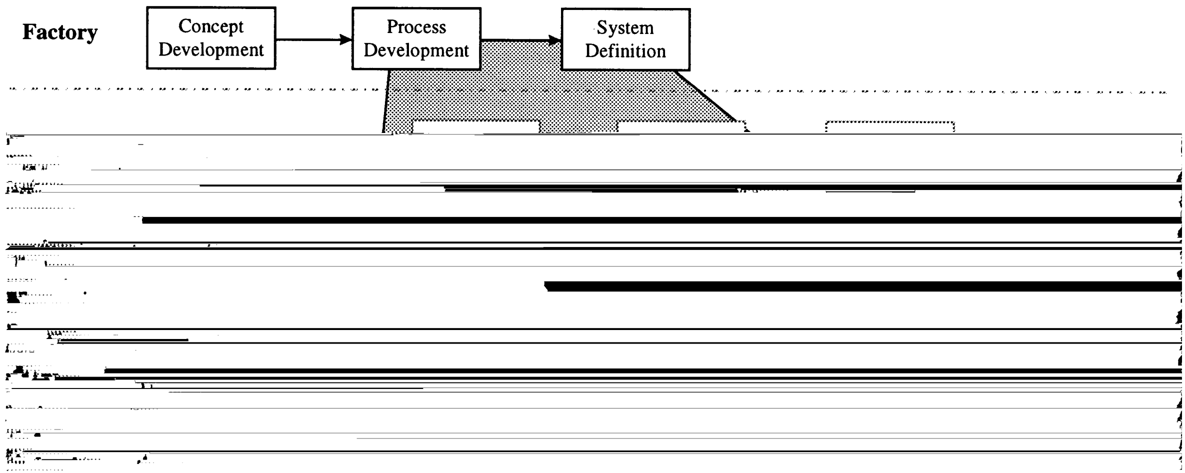

Fig. 1. Major engineering phases.

planning, capacity evaluation as well as the definition of the production organisation part of MSE. Surprisingly the investigation of the state-of-the-art in this field reveals that neither widely accepted methodologies nor a satisfying computer support exists. In contrast with the requirements, many companies follow their own practice, often grown over many years and use a variety of tools that are in many cases poorly integrated. There are only a few approaches to define broader consistent models [1]. As a result, the process is slow and error prone and endangers the competitive position of many European enterprises.

Considering this situation, we address the integration task from the analysis of the engineering process. Starting with the definition of integration requirements, we design a new process that is founded on information system support and relies on simulation for manufacturing system evaluation.

2. The manufacturing system engineering process

Today's MSE process is still poorly formalized and requires significant effort and time for the engineer to deal with it. Furthermore the different tasks linked to MSE are missing a comprehensive, integrated information system support. Even though there is support for some tasks, the quality of the tools differs strongly and data exchange is in most cases impossible. On the other hand, speed, accuracy, coordination and integration with other business processes is greatly needed and promises significant impact on overall company performance [2].

This situation results from, amongst other things, the multi-disciplinary character of the task that brings together different disciplines that traditionally use their own methods and tools. Grown over the years, there are strong reservations to crossing the barrier and performing real teamwork. Therefore the integration process has only started. We can learn some lessons from product design, where CAD/CAM/CAE technologies provide powerful and comprehensive process support. Product definition from the first sketch to the final drawing and, if necessary a 3D-model, can be performed within a single environment. The data is available for different investigations like the finite element method (FEM), for strength and organisational data like bill-of-material can easily be attached to the existing shape information. Standards like STEP (Standard for the Exchange of Product Model Data, ISO 10303) allow data exchange between different tools and a common data storage. In MSE on the other hand, such an integrated environment is still missing, and only first approaches available [3,4].

From our point of view, the MSE process can be subdivided into three partly overlapping major phases, that apply on three levels of detail (Fig. 1):

The concept development phase concentrates on discussion with the internal or external customer to develop a rough idea of the system. This most creative phase has the less formalized results and mainly fixes basic system features with respect to the restrictions derived from the future environment. In many cases, previous solutions that fulfil similar requirements are investigated to find out if they can be adjusted to the actual situation.

During the process development phase, the rough solution(s) from the first phase are refined to a level that allows investigation with analysis tools. If system dimensions are fixed, first contact with suppliers is established to integrate them in the further system definition. Early supplier involvement eases the integration of components in the final phase and is used as one form of concurrent engineering, where components are designed at the supplier during the development of the complete system. Today's support for this phase of the

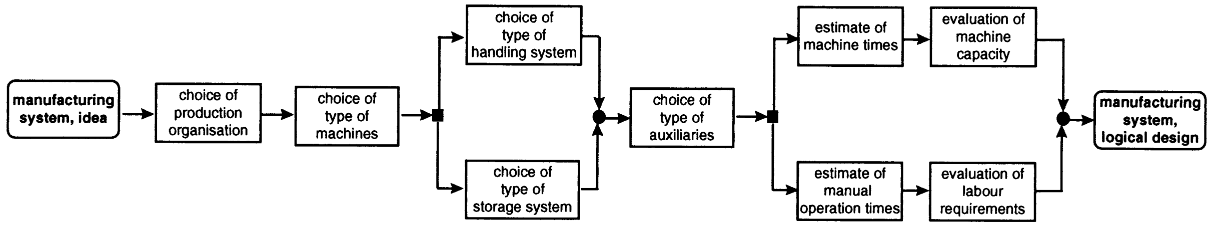

Fig. 2. Core process of manufacturing system design.

engineering process is scattered and requires that the same data is entered into different systems separately. Inconsistencies and mistakes reduce the efficiency of the process and lead sometimes to wrong decisions.

In the final system definition phase, one solution is refined to a detail that allows to start system implementation. This phase is characterized by system integration, where previously identified subsystems are composed to a complete system. Fine tuning of subsystem cooperation and fixing of last details lead to the final system definition and emission of orders to suppliers.

During the concept development phase, the retrieval of existing solutions and a quick survey of the market situation is essential. Access to an electronic archive of former projects with the possibility to retrieve information about these projects using self-defined keys is one of the main requests of the engineers for this stage of an engineering project. Partial reuse of existing solutions would be possible if the information is stored in a format, that can be processed by the planning system. An additional help would be the possibility to use electronic catalogues for technical solutions available in the market. This is important, because a manufacturing system normally is built from many components commercially available and only a few components are custom-made. Using catalogue information to insert component data into a solution by simple 'click-and-drop' functionality would increase the speed of the work significantly. For information system support, that means to consider also the use of the Internet as source of information. Today, suppliers have started to advertise on the world wide web, and one can imagine that catalogue information will be available soon.

Because our interest is more in manufacturing process development and system integration, we concentrate on the overlapping parts of the engineering process. For the retrieval of information, in a first approach we rely on a collection of former projects, stored in a format that is readable for the integrated information system. Searching this 'solution database', the engineer can recall the related data and adopt those parts that seem helpful to him. As the core of the system design process we consider the business process shown in Fig. 2. It includes the choice of production organisation, definition of the types of machines, handling and storage systems as well as the estimate and evaluation of machine capacity and labour requirements [5]. Definition of types of system components give the engineer the possibility to first design the logical system as desired and then match the requirements with existing component solutions. He has then the possibility to adjust the system model with the real solution data and evaluate if major changes are required, or to use the defined parameters as requirements for a tailored component from a supplier.

3. System integration for process support

3.1. Goals

The design of a computer aided MSE process should make it possible for European companies to reach a new level of process quality and performance. We believe that through a thorough analysis of the design steps and a clear definition of information system functionality supporting the engineering tasks it is possible to reach the following goals:

- Reduced effort for creating and evaluating a manufacturing system under design.
- Construction of manufacturing systems from libraries that contain reusable components of different levels of abstraction.
- Work in distributed engineering teams concurrently on different aspects of the same manufacturing system.
- Minimize the effort for fine tuning the manufacturing system parameters and reduce retro-fitting cycles.
- Reduce inconsistencies in the design process and minimise time consuming exchange of data between different systems.
- Avoid misunderstandings resulting from the usage of several models of the same system in different tools.

Derived from these goals, we will describe our vision of the engineering process and define the functionality a supporting information system should offer.

3.2. Engineering Tasks and Workflow

Integration of engineering tasks comes from the linkage of the results of different work steps. To give the engineer the freedom to select the style of work most appropriate to him, the restrictions set by a supporting information system should be minimised. However, some tasks depend on each other and must therefore be performed sequentially.

We consider two main methodologies that may be followed to design a manufacturing system. The first approach, we call layout driven, because it is centered around the physical aspects of the manufacturing system and considers before all the restrictions posed by existing buildings, material flow installations and machines. The second approach, we call process plan driven, because it uses the information about processing times and quantities for the dimensioning of a manufacturing system before physical aspects are considered. In practice, we found that a combination of the two is most frequently applied. The engineer would like to switch between the two approaches to look at the design from both viewpoints and consider the results interchangeably in an iterative design process. Due to the complexity of the problem domain, we prefer a hierarchical approach of model construction that allows to refine the model step-by-step using different levels of abstraction. On each level the engineer should have evaluation functions available that allow him to judge the model and decide if it meets the requirements. With increasing degree of detail, the possibilities of model evaluation are more sophisticated and more precise.

Starting with the layout is usually the case, if a given manufacturing system or factory have to be adjusted to new production requirements. Than the new system has to respect the space available and one goal of the process is to minimise the rearrangement of equipment. Because layout data is often available as CAD-file, an import of this data into the planning system would allow reuse of this information. The CAD-data needed can be subdivided in two categories, one containing the construction aspects like walls, columns or supply installations and the other all components of the manufacturing system, like machines, buffers, conveyors etc. For the components, a simplified representation would be sufficient for planning purposes.

When following a process plan driven approach, the engineer uses product defining information available with bills-of-material and process plans to dimension the manufacturing system. As a starting point he can use the production program and quantities planned for the system. Unfortunately detailed process plans and bills-of-material are not necessarily completely available at the start of the MSE process. A planning system should therefore offer features to define this data in a simplified form to allow the dimensioning of the manufacturing system. Based on process plans it is possible to build a logical system structure that includes material flows and processor types with their respective workload. From this rough system description, a more sophisticated model can be constructed that assigns transporters and buffers to material flows and machines to processors. Dimensioning capacities and defining production rates are the next steps towards a simulation model. Often layout related restrictions like transport distances are neglected in a first investigation. It is desirable to use types of components instead of specific solutions while investigating possible alternatives. Then the system can be dimensioned with an ideal configuration that can be used as measure for the final implementation. In a second step, the parameters derived from simulations studies can be used to select the most suited component available on the market. Adjusting the simulation model with the parameters of the finally selected components makes it possible to judge the quality of the system configuration.

Considering the two possible approaches, integration of engineering tasks can be understood as connection of the logical and the physical manufacturing system model. Combined with the already sketched hierarchical modelling procedure, a process of stepwise refinement of the two models emerges. It is vital that the information system supports an easy connection of logical and physical aspects and maintains the relations consistent.

In order to further reduce design effort, it would be of great help to have functionality that allows definition of partial solutions as building blocks and store them separately. Constructing systems from an already existing solution, that only have to be adapted to given needs, reduces design time and errors and allows the engineer to concentrate on integration aspects. The basic element of the design process is a component, i.e. a machine, a transporter or a buffer that has a set of parameters like capacity, processable products, speed, power consumption for the logical aspect and length, width and shape for the physical aspect. Such a component can be inserted into a new or existing manufacturing system model. By connecting such elements, basic model structures are constructed that represent typical patterns in manufacturing systems. A good example is a manufacturing or assembly cell that combines input and output buffers, a processor, sometimes a test place and an internal material handling system. Complex manufacturing systems can be constructed by combining and adjusting such basic structures. But also complex model structures can be subject to reuse, because typical patterns of combination of basic structures reappear. It is mainly the material flow connection of such subsystems that determines the structures. Line or island oriented manufacturing structures are typical in the production of large lot sizes. The relations be-

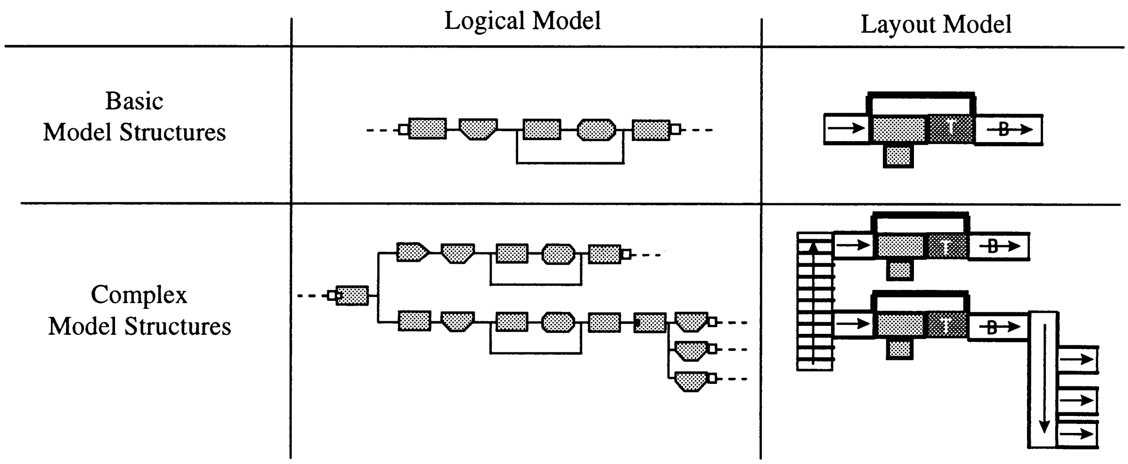

Fig. 3. Predefined model structures for quicker design processes.

tween basic and complex model structures as well as those between the logical and the layout (physical) model are shown in Fig. 3.

3.3. System architecture

The central integration aspect is the manufacturing system model, that is constructed, investigated and updated during the engineering process. It brings together the description of all components of the manufacturing system as well as their relations and interactions. The logical and the physical model are views of the same manufacturing system model. All information needed to design the manufacturing system can be stored in this complete model. We understand the information about the products to be processed, i.e. process plans and bills-of-material in a simplified form as part of the model, because they determine many parameters and are used, e.g. for the simulation. Considering the fact that the documentation of engineering projects and their progress is often on a poor level, the system will allow attachment of documentation to every component as desired and generate reports based on this documentation.

We expect the manufacturing system model to be very complex with many relations between the elements. An object-oriented approach has therefore been selected for the description of the meta-model that will be the base for the implementation. This meta-model describes all classes and their relations that are necessary to store a manufacturing system model. Consistency handling for the model will be described in the methods of these classes, protecting the model to a certain degree from being inconsistent. Anyhow, it is stressed that too rigid a consistency handling will prevent the user from following its own way of designing a system. A certain degree of inconsistency will be therefore accepted by the system and warnings or reports will be available to inform the user about possible errors. The meta-model will probably be implemented with an object-oriented database system (Fig. 4). The functionality will allow connection to CAD-systems for the import and export of CAD-data and to simulation systems to allow the evaluation of the model with an external system.

For the user the information system will present itself as object-oriented too. It will contain basic classes of components used to model manufacturing systems. These basic classes cover all relevant aspects, but are not tailored to the individual engineers needs. Furthermore the main relations between the classes will be implemented, which are either required for certain workbench functionality, or are generic to manufacturing system design. The user has the possibility to derive new classes from the existing ones that are more adapted to his needs. Inheritance is used for the derivation, so the new classes inherit all attributes and methods from the original classes, thus preserving the basic class features needed by the system. We expect that the more natural understanding of the components of a manufacturing system achieved with the object-oriented description will help the engineer to express its ideas in a better way.

4. Conclusions

The business process of factory planning, that includes as an important subprocess the MSE process, has become a critical factor in international competition. The need to adjust the production continuously to the rapidly changing market requirements forces companies to redesign their production systems more often. Only efficient engineering processes create the potential to be among the leaders not only in product, but also in production technology. The lack of formalization and

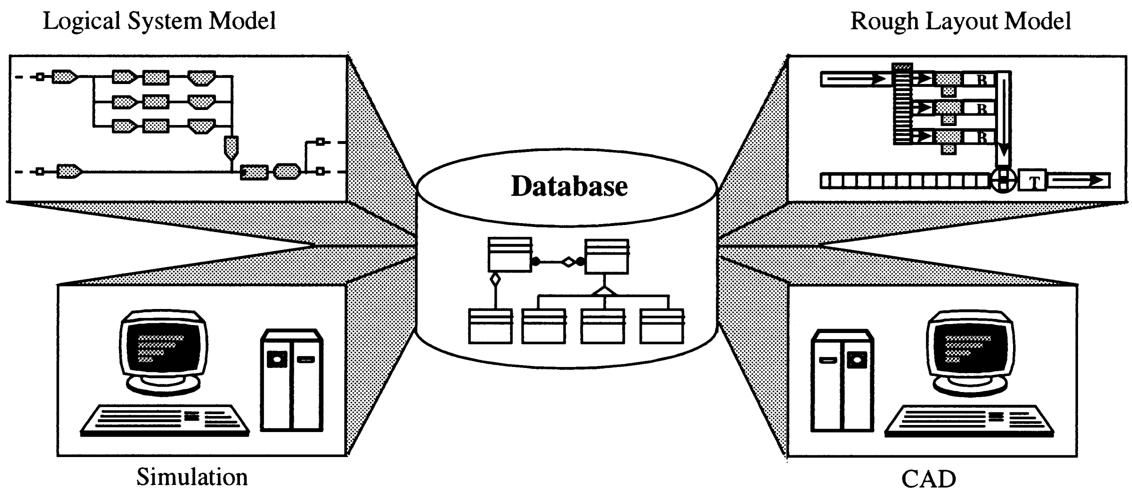

Fig. 4. General architecture of the information system.

integration resulting from the multi-disciplinary character of the task hampers many companies ability to stay competitive on the international market.

Based on an investigation of the main characteristics of today's MSE we design a new process, that considers multi-site teamwork and the use of individual methods of working. Two different starting points for the design task are supported with individual models that represent views on a common manufacturing system model. A stepwise modelling process allows the engineer to define the manufacturing system hierarchically, switching between the two aspects at wish. The use of libraries containing predefined simple or complex components reduces modelling effort. The common model keeps the relations between the different aspects consistent throughout the design process. To ease project documentation, it is possible to attach comments to every component of the manufacturing system model.

The investigation of the MSE process, its main tasks and the model structures needed to perform these tasks lead to the definition of an information system that supports the flow of work, stores the models and allows model investigation from different points of view. This information system is based on an object-oriented meta-model that will be implemented on a OODBMS. Interfaces to simulation systems for model evaluation and CAD-systems for layout data exchange will allow to integration of the system with existing solutions.

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