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Simulation-based planning and control of production fractals

Dr. W. Sihn
Fraunhofer Institute for Manufacturing Engineering and Automation (FhG-IPA)
Nobelstr. 12, D-70569 Stuttgart, Germany, phone: 49 711 970 1964, fax: 49 711 970 1002, e-mail: whs@ipa.fhg.de

Abstract

In order to increase their competitiveness, companies optimize their manufacturing processes by adapting structures to the requirements of technology and market. On the other hand, they try to fulfil specific requirements by extreme customer orientation and manufacturing on demand. This leads to new organizational structures and manufacturing systems. Appropriate organization forms, such as the fractal company, are distinguished by high flexibility, rapid adaptability and exploitation of human potentials. However, these manufacturing companies also require appropriate PPC-systems (Production Planning and Control system) or, rather, new methods of PPC. In addition to high planning reliability, these systems have to ensure high flexibility, distributed processes of planning and decision-making, general orientation towards common goals, and an information flow that conforms to the requirements. The most important elements of such a PPC-system are long-range analysis of the production structure, medium- and long-range planning for the entire production area, short- and medium-range coordination among production fractals and short-range shop-control inside the fractals. At the Fraunhofer Institute for Manufacturing Engineering and Automation, simulation-based systems are being developed to support the planning and control of such organization forms within production. The user is put into the position of planning job orders reliably and optimizing production, concerning cost and schedule reliability, by making use of the advantages of decentralized structures.

Keywords

Fractal Company, Decentralized Production Planning and Control.

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1 INTRODUCTION

In order to remain competitive, enterprises are forced to optimize their production processes by constantly adapting to the highly dynamic environment. In today's economy, companies are facing increasing competition and high cost pressure in an ongoing globalization of the market. The product life time, the quantities, and batch sizes have decreased. At the same time the service life of products and the number of variants has risen continually. Complex corporate joint ventures and a radical change in customers' behavior represent further evidence of an increasing complexity. A shift is recognized from a sales-oriented market to a customer-oriented market. More and more, customers expect services and products to be tailored to their specific needs. High price/quality and high service/delivery performance is expected from the supplier (Matthyssens, 1994). In Figure 1 the essential characteristics of the market conditions are shown.

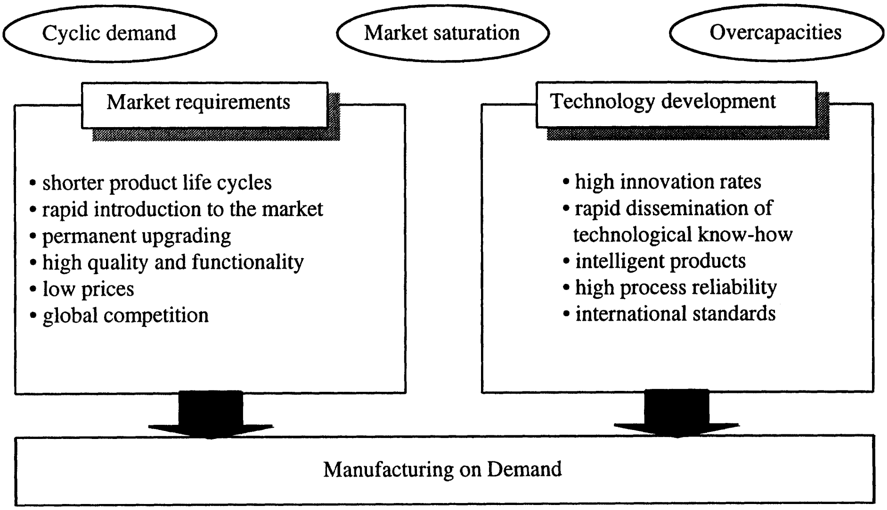

Figure 1: Customer-oriented manufacturing under turbulent market conditions.

Corresponding to the turbulent market conditions, flexibility has become an important factor in the development of new production concepts such as, for example, the Fractal Company (Warnecke, 1993). The concept is based on small but powerful and dynamic manufacturing units, the fractals, which operate in a very customer-oriented way within a production network. Manufacturing on customer demand requires flexible production facilities which can quickly adjust to the market changes.

The management of the production of these fractal manufacturing networks is the key to a companies' competitiveness. Besides an adapted product structure there are two important aspects to be met when realizing this type of production:

1. Production structure based on the system technology in order to obtain a comprehensive and autonomous performance optimization.
2. Integrated, decentralized production planning and control (Zaepfel, 1989) in a flexible and dynamic manufacturing network.

2 FRACTAL PRODUCTION

Manufacturing enterprises are traditionally structured on the basis of labor division. Their structure still follows the philosophy of optimization through detailed planning and application of the classical methods of factory focusing on the goal of maximum utilization of the existing resources as regards technical capability and time. For the first time, the philosophies of the fractal (Warnecke, 1993) or agile enterprise (Noaker, 1994; Kidd, 1994) are breaking with this tradition as they favor self-organization and self-optimization: The employees themselves are responsible for the layout of the performance centers.

Figure 2 illustrates the principles of the fractal factory as defined by Warnecke (Warnecke, 1993). Each business unit acts as an autonomous factory which is integrated within a communication network. In the view of organization the business units are similar. They optimize themselves and are integrated in a hierarchical system of objectives and managed in an organization network.

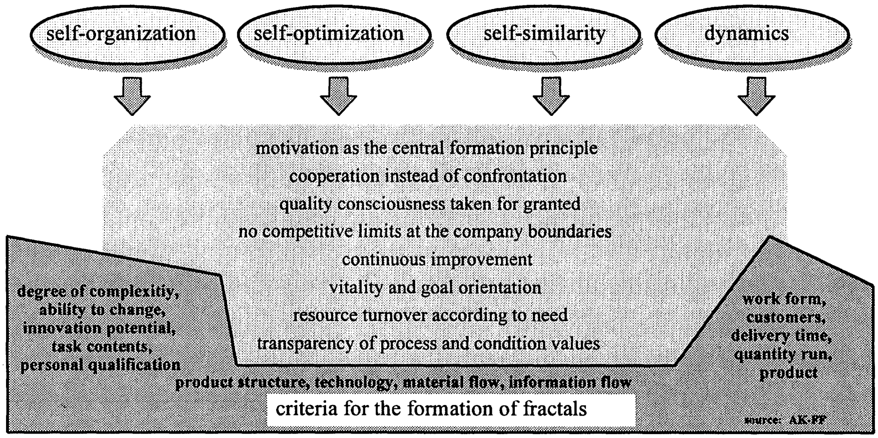

Figure 2: Principles of the Fractal Factory (Warnecke, 1993).

A field of production such as the mechanical production, is a complete system consisting of several subsystems, for example the manufacturing cells. The subsystems again can be divided into further subsystems. They are linked with each other according to certain laws like the workpiece or tool cycle. The methods of Total Quality Management (TQM) are applicable to the customer-supplier relationship between the individual elements.

Today, some enterprises are already entrusting the suppliers of the machines and facilities also with their operation including the provision of technology, tools and equipment as well as the personnel. Thus, the machine supplier himself becomes an operator. In this value adding process, he takes the responsibility for the utilization and optimization as a provider of services with the machines produced by himself.

3 FRACTAL PRODUCTION PLANNING AND CONTROL

Market demands for short delivery times make planning and control of multi-stage, customer order-oriented production difficult and complex. So far, neither rough scheduling PPC-systems nor disjoint local control stations, based on conventional forms of production organization, have been able to manage the enormous coordination effort for planning multi-stage linked production. Thus, the objective was to develop an integrated system from globally coordinated planning and short-term production control with distributed cooperative local control stations, on the basis of the Fractal Company concept. The expected benefits of such a system are reduced inventories and lead times, and an increase of the delivery reliability. In the past few years, the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA), Stuttgart has developed a system architecture which meets these demands. A prototype is currently being used successfully in the industry.

4 SYSTEM ARCHITECTURE

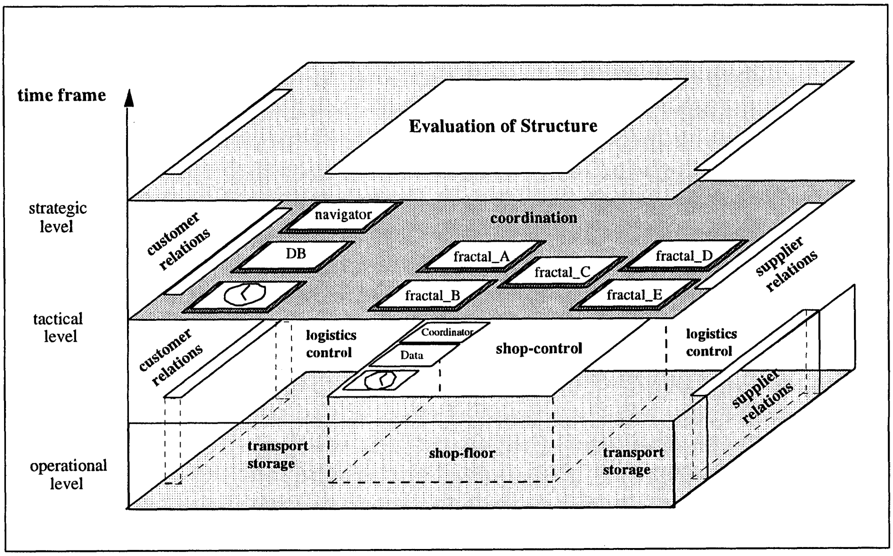

Figure 3: Planning levels.

The system architecture for the production planning and control of fractals consists of three levels (Figure 3).

The long-term evaluation of the production structure takes place on the first and upmost level where the intensity of relations among fractals is being analyzed. The degree of intensity is measurable by the number and the nature of planning conflicts. The second level contains an outline model of the entire production. The function of this level is to visualize a holistic view of the production, in order to determine the overall guidelines for the decentralized units. The function of the third level with its detailed, autonomous models of fractals is to carry out short-term planning and control. The guidelines are transformed into feasible plant programs, changes are issued in case of sudden breakdowns, and conflicts among fractals are resolved.

5 MODELING

The generation of models happens in two steps. The first step is to develop a detailed model of each individual production unit, called a fractal. Subsequently, the outline model of the entire production area derives from these models.

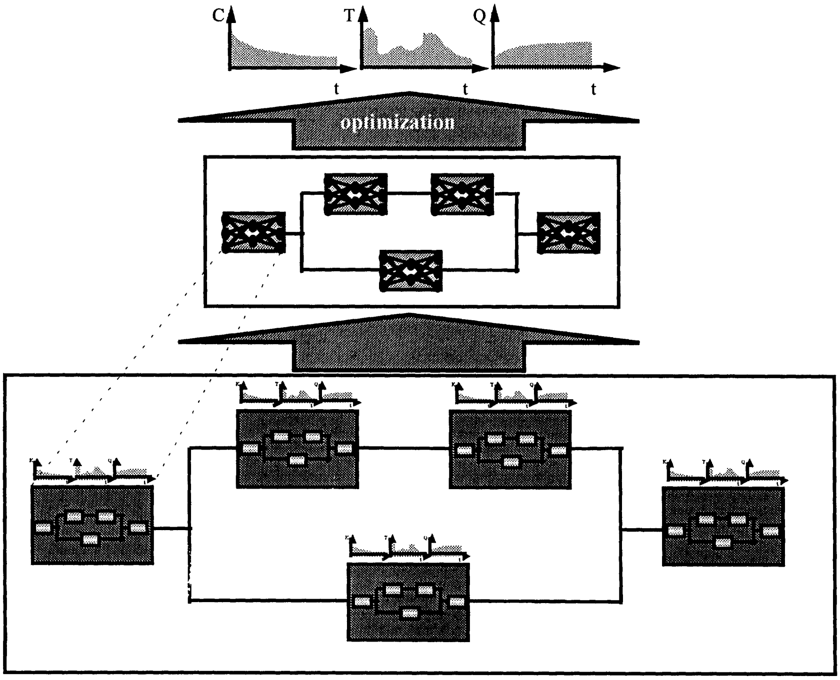

Figure 4: Hierarchy of modeling.

The fractal models are used to represent the production processes within the individual fractals. The fractal models consist of essential elements for the planning and control of production, such as production, transportation and inventory systems, as well as strategies to control the material flow within these systems. They also contain additional functions, such as statistics and various means to evaluate simulation runs. A predefined, configurable fractal model facilitates the user's task to generate a fractal model.

After the individual fractals have been modeled, the outline model of the entire production area is set up. Here, too, a predefined model of material flow and information flow interfaces exists, of strategies to control the material flow and additional functions, such as statistics and the means to evaluate simulation runs. Translating and aggregating the detailed fractal models in the outline model happens automatically by means of soft-computing algorithms (Figure 4).

A third element in generating models is to build temporary coordination models. In the case of self-organized coordination, a model may consist of two fractal models. This modeling type is prompted by conflicting planning operations of fractals with direct customer-supplier-relations. The components of the coordination model correspond with those of the fractal model.

6 PLANNING PROCEDURE

In contrast to the modeling procedure, the planning cycle starts with rough planning in the production model (Figure 5).

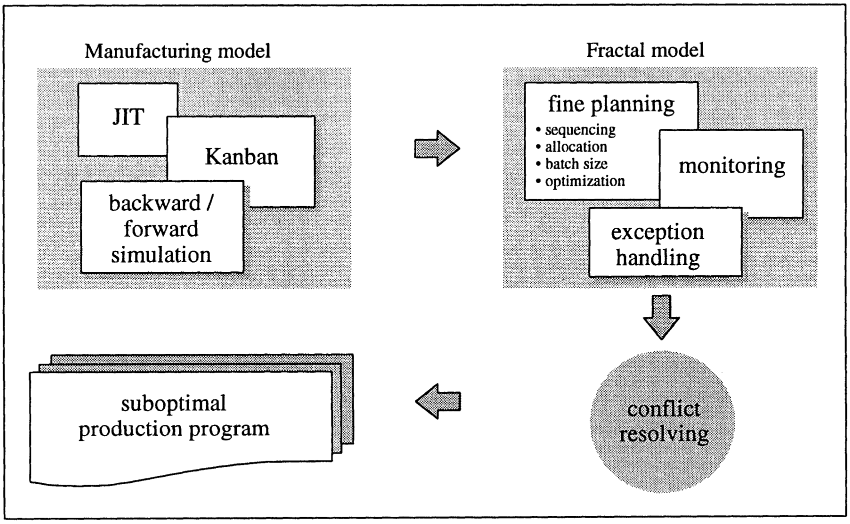

Figure 5: Planning Procedure I.

The main function of rough planning is to schedule customer orders. In a backward scheduling operation based on delivery dates, the latest possible planning date is determined. The resulting order sequence is used as a basis for a subsequent forward simulation to schedule the fractal orders, while taking into account the current stock situation within the fractals. A fractal order is equivalent to a 'time window,' defining the time during which a customer order is processed in a fractal.

The fractal order is used as a guideline for detailed planning in the fractal model. In general, this provides sufficient freedom for planning and scheduling, so that the fractal planner is able to achieve internal optimizations. The rough planning process is followed by detailed planning in the individual fractal models. If it is not possible to find a planning variant satisfying the overall guidelines (i.e. time allowances for fractal orders) during detailed planning, this might affect the schedules and planning of subsequent fractals. In this case, the coordination model comes into effect, which has two strategies available to resolve the conflict. The first one is called Program-controlled coordination: it combines all planning variants of conflicting fractals (generating a disposition window that considers both fractals) to find out the optimal combination still complying with the overall guidelines (Figure 6).

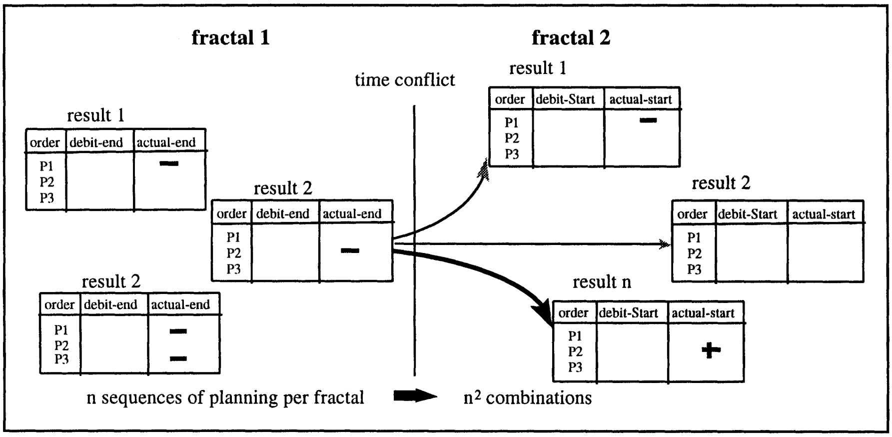

Figure 6: Program-controlled coordination.

If there is still no solution to be found without neglecting the overall guidelines, then the second strategy for problem-solving becomes effective. It is based on a method called Self-organized coordination. The fractals now make use of a model containing all elements of the conflicting fractals that are relevant for the period of conflict. The target of this joint planning act is to comply with the combined disposition window of both fractals.

7 BENEFITS AND APPLICATIONS

The advantages of the described system for the planning and control of production fractals are, for the most part, a result of its architecture.

Much of the modeling, model maintenance and planning tasks is shifted to the production area. This increases flexibility and up-to-dateness of the planning system when changes in production occur. The know-how existing in the production area can be exploited for planning operations. With the distribution of planning activities over several production units, a simultaneous run of planning processes is achieved that results in an accelerated planning procedure. Since the fractal staff themselves determine the planning results, the planning is more accepted and more reliably fulfilled. The scope of action is enhanced by transferring planning responsibility into the production area and, in effect, stimulating a continuous improvement of the production process.

The automatic generation of a model for the entire production area ensures that a global optimum is pursued. Enveloping complex structures into fractals leads to more transparency and facilitates the analysis and evaluation of production.

Clearly defined customer-supplier-relations among the fractals have the effect that weak points are discovered on time. The tool to settle conflict situations (cooperation model) supports the user in eliminating the deficiencies and also promotes cooperation and the common understanding that solutions can only be found in a joint effort.

A practical example illustrates the benefits of the described system: In a large European enterprise the networking of decentralized units through information technology changed the whole planning system from an accumulation of disjoint production units to a customer-oriented planning cosmos. Increased planning reliability and the early recognition of conflicts and bottlenecks together with the simultaneous problem-solving support of the planning system created the necessary foundation of trust for a stronger networking of production. Transparency and orientation of all planners towards customer demands had an impact on the management ratios of the considered enterprise.

A more consistent networking of local planning units and the global coordination of planning resulted in a 30 % reduction of work in progress. Since production in the described enterprise is aligned to customer orders, the reduction of work in progress-inventories is directly connected to a reduction of lead times (by 30 %) and delivery times. As the work in progress amounts to the value of $ 100 to 150 million, the reduction of inventory already results in savings of several million dollars each year.

It is important to make sure that the utilization of the plants and the total throughput is not affected negatively by the above described measures. The consideration of technological restrictions within the global planning coordination even achieved and improved composition of batches and reduced the percentage of set-up times. At the same time, the early recognition of conflicts and the common target alignment increased the schedule reliability for customer orders. In the past, very few customer orders were delivered on time to the finished products storage. Today, a delivery reliability of over 90 % has been achieved. This, in return, affected the distribution, so safety buffers between the customer due date and the delivery to the finished products storage hardly exist any more. Inventories could be further decreased, resulting in a very positive effect on the capital tie-up costs at the end of the value creation process.

Due to the improvement of these performance measures, the enterprise became more flexible and agile on the market and economically more efficient in production. The described optimization of logistics parameter induced IPA to advance the architecture that has been described above. At present, the focus of work is engaged in a heterogeneous and international production networks. Companies are particularly interested in the rapid adaptability of these networks.

8 CONCLUSION

This paper describes a strategy for future production based on the idea of fractal and agile enterprises. The actual aim is to realize a type of enterprise operating very closely with the market and only on customer demand at the shortest delivery times possible. To achieve this, the adaptability of the capacities to specific demands has to be increased, and the production planning and control has to be modified correspondingly. Thus, the objective was to develop an integrated system from globally coordinated planning and short-term production control with distributed cooperative local control stations, on the basis of the Fractal Company concept. The expected benefits of such a system are reduced inventories and lead times, and an increase of delivery reliability. In the past few years, the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA), Stuttgart has developed a system architecture which meets these demands. A prototype is currently being used successfully in industry.

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BIOGRAPHY

Dr. Wilfried Sihn is the director and head of the Corporate Management Department at the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA) in Stuttgart and Vice-President of the International Society of Agile Manufacturing. Dr. Sihn has been with IPA since 1982 and has worked on over 200 research and industrial projects. During the last years he has been principally involved with the concept of the 'FRACTAL FACTORY'. He is member of the editorial board of the 'International Journal of Agility' from the 'International society of Productivity Enhancements (ISPE)' and guest editor of the 'International Journal of Technology Management (IJTM)'.