II.B

Manufacturing and Production Systems

Handbook of Industrial Engineering: Technology and Operations Management, Third Edition.
Edited by Gavriel Salvendy

CHAPTER 10

The Factory of the Future: New Structures and Methods to Enable Transformable Production

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1. THE CURRENT MARKET SITUATION: NOTHING NEW

The renowned American organization scientist Henry Mintzberg has discovered that companies and their managers have been complaining of market turbulence and high cost and competition pressures for more than 30 years (Mintzberg 1998). Market turbulence is thus not a new phenomenon, he concludes, and companies should be able to cope with it.

However, there are only a few practical examples to back Mintzberg's claim. Practical experience and research results differ not because market turbulence forces enterprises to adapt but because the speed of change adds a new dimension to market turbulence. The results of the latest Delphi study show that the speed of change has increased considerably in the last 10 years (Delphi-Studie 1998).

The five charts in Figure 1 show the primary indicators used to measure the growing turbulence in the manufacturing environment. The change in mean product life shows that innovation speed has increased considerably in the last 15 years. This change can be validated with concrete figures from several industries. A recent Siemens survey shows that sales of products older than 10 years have dropped by two thirds over the last 15 years and now amount to only 7% of the company's total turnover. In contrast, the share of products younger than 5 years has increased by more than 50% and accounts for almost 75% of the current Siemens turnover (see Figure 2).

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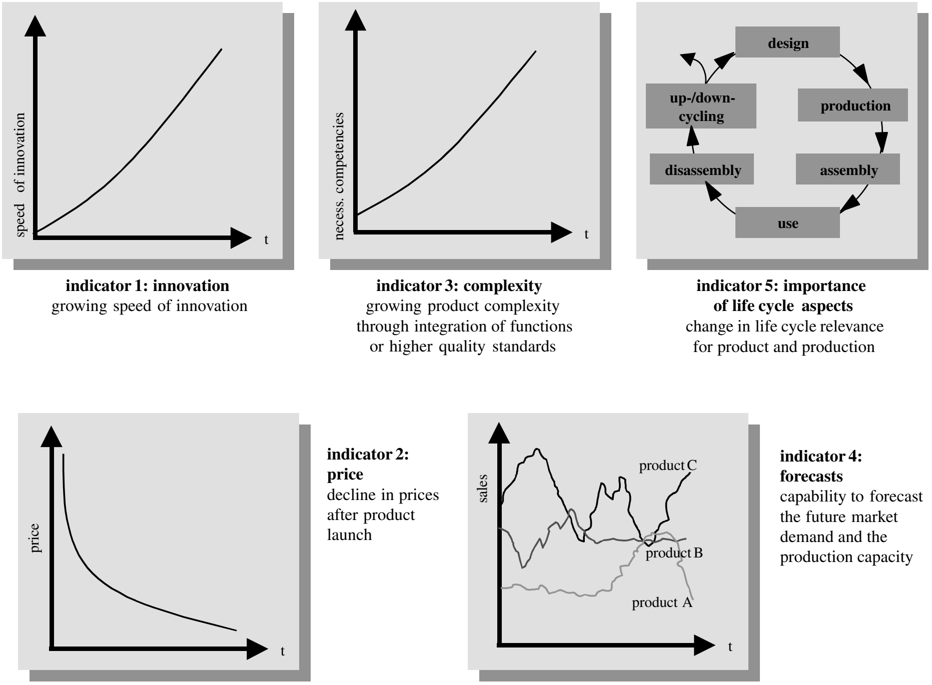


indicator 1: innovation
growing speed of innovation

indicator 3: complexity
growing product complexity through integration of functions or higher quality standards

indicator 5: importance of life cycle aspects
change in life cycle relevance for product and production

indicator 2: price
decline in prices after product launch

indicator 4: forecasts
capability to forecast the future market demand and the production capacity

Figure 1 Indicators Measuring Market Turbulence.

However, long-range studies are not the only means to identify and verify the changes expressed by the indicators. A short-term analysis, for example, can also serve to prove that change is the main cause of turbulence. The aim of one such analysis is to predict the fluctuations in sales for a medium-sized pump manufacturer. During the first half of the year, the sales trend of some product groups

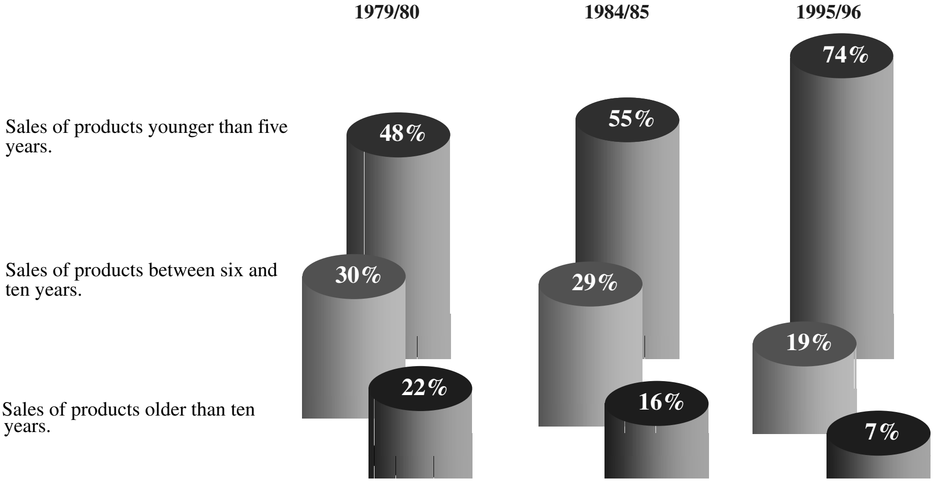


Figure 2 The Changing Life Cycle of Siemens Products. (From Kuhnert 1998)

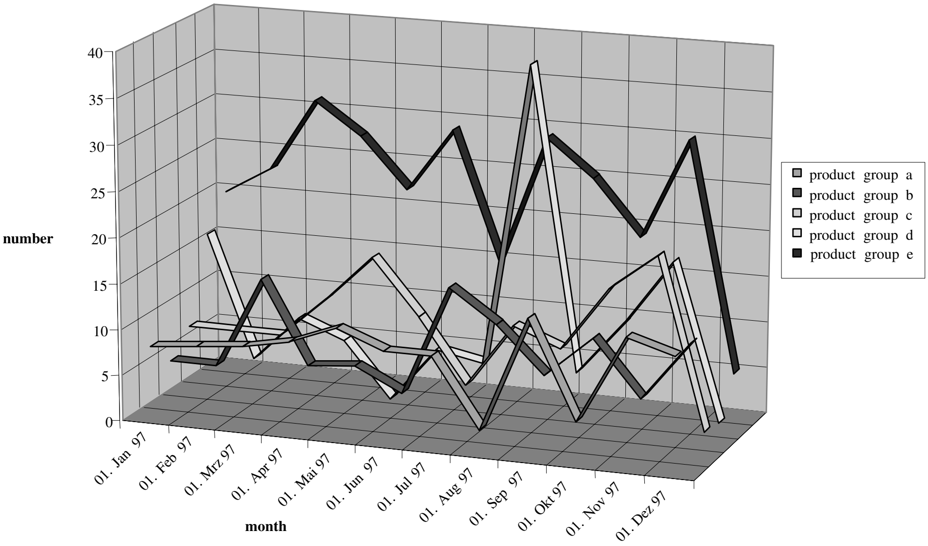


Figure 3 Fluctuations in the Order Entry of a Medium-Sized Pump Manufacturer.

could be predicted based on past results. The forecast for the second half of the year, however, though based on the same procedure, was impossible due to the divergence of monthly sales volume in certain product divisions. Therefore, an enormous adaptation effort on the part of the company was required (see Figure 3).

The overall objective is to raise a company's or factory's *transformability,* the new determinant of corporate market success. Transformability is the ability to adjust rapidly to increased turbulence and recognize changing indicators early enough to initiate proactive adaptation measures.

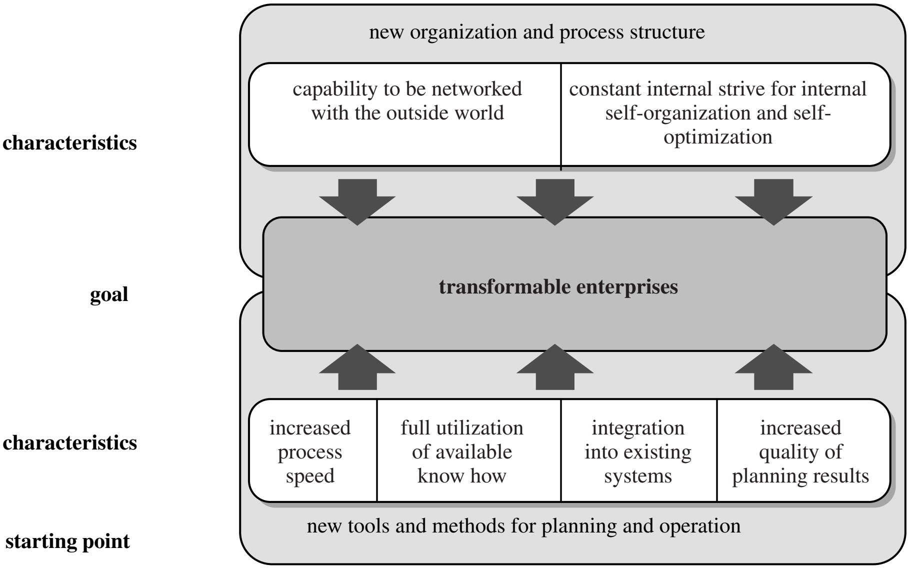


Figure 4 Contributing Factors of a Transformable Company.

2. TRANSFORMABLE STRUCTURES TO MASTER INCREASING TURBULENCE

Recent restructuring projects have shown that a company's competitiveness can be enhanced through improved technology and, in particular, through the efficient combination of existing technology with new company structures.

Factories of the future must have transformable structures in order to master the increased turbulence that began in the 1990s. Factories must also possess two important features reflecting two current trends in structural change: they must be able to enable for external structure networking and self-organize and self-optimize structures and processes internally. External networking helps to dissolve company borders that are currently insurmountable and integrate individual enterprises into company networks. Self-organization and self-optimization are intended to enhance the competencies of the value-adding units in accordance with the corporate goal and thus speed up the decision making and change processes of the enterprise.

3. CORPORATE NETWORK CAPABILITY

Corporate network capability describes the capacity of an enterprise to integrate both itself and its core competencies into the overall company network. This cooperation is continually optimized to benefit both the individual company and the network.

Companies with this capacity find that their transformability increases in two respects. First, they can focus on their core competencies and simultaneously profit from the company network's integrated and comprehensive service range. Second, the information flow in the company network is sped up by the continual networking of suppliers and customers. The advantage of the latter is that companies are provided with information concerning market changes and adjustments in consumer and supplier markets in due time. They can thus respond proactively to technological and market changes. These company networks can take four forms, as shown in Figure 5.

Companies are not limited to only one of the four types. Instead, each company can be involved in several company network types on a horizontal as well as a vertical level. In the automobile industry, for example, it is common practice for companies to cooperate in regional networks with companies on the same value-adding level and at the same time be part of the global supply chain of an automobile manufacturer. In other words, companies do not necessarily have to focus on one cooperative arrangement. Different business units might establish different cooperative arrangements.

Behr is an example of an automobile supplier with high network capability. The company's focus is vehicle air conditioning and motor cooling. Its customers include all the large European car manufacturers. In order to offer its customers a comprehensive service range, Behr is involved in nu-

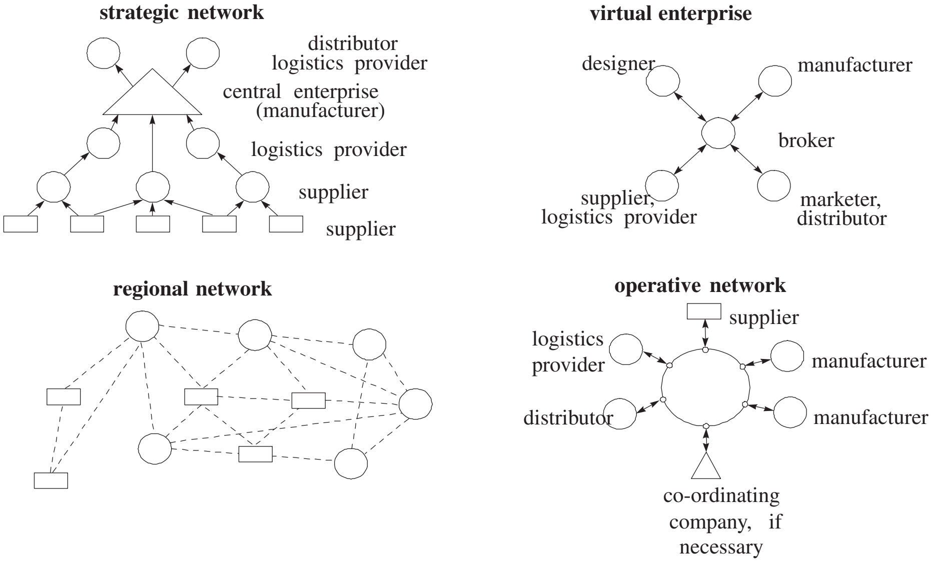


Figure 5 Basic Types of Company Networks.

merous global and local networks. In 1997 and 1998, Behr joined six cooperation projects with other automotive suppliers in which the cooperation partners were distinguished by their expertise, flat hierarchies, and accompanying short information and communication paths as well as similar corporate culture. The aim of the resulting expert network was to pool the necessary system technology and thus improve the position in the core business as well as to prepare the basis for entering new markets for components.

The project management is assumed by the partner with the greatest market share or the most comprehensive business logistics. It is also important that a continual communication flow exist, accompanied by rapid decision making processes and clearly defined interfaces that are well managed and intelligible for the customer. Accordingly, Behr and one of its cooperation partners have taken the initiative to jointly develop and supply front-end modules. The module is composed of the cooling system's heat transfer, the air-conditioning condenser, cooling fan, air deflector, lighting, bumpers, and radiator grill. Together, the cooperation partners are able to provide 75% of the module components. Through this network, Behr was able to increase its market presence and revenue.

3.1. Internal Self-Organization and Self-Optimization

In corporate self-organization and self-optimization, the authority to make decisions is shifted directly to the value-adding units, creating semiautonomous organizational units. Therefore, apart from the actual output process, semiautonomous units have to integrate management and planning functions as well as coordinate functions to ensure global optima and avoid local optima.

The advantages of semiautonomous structures with regard to improved labor productivity have been confirmed by numerous studies and accepted by most experts (Westkämper et al. 1998). Advantages include increased corporate transformability, which can be achieved through a quicker information flow in semiautonomous units, and the involvement of the process owners in the decision making process from an early stage. The latter also leads to better staff motivation, which positively affects transformability.

An important task for semiautonomous organizational units is to coordinate themselves with the common target system in the course of self-optimization (see Figure 7). Making a profit is the main goal of this target system. However, the system must still be coordinated with the interests of the employees. In addition, the goals must affect wages in order to increase the credibility of the goal system.

The Fraunhofer Institute for Production and Automation (IPA) has carried out more than 100 industrial projects in which it applied the principle of the fractal company to introduce semiautonomous organization structures coordinated by means of a common target system. More than 20 of

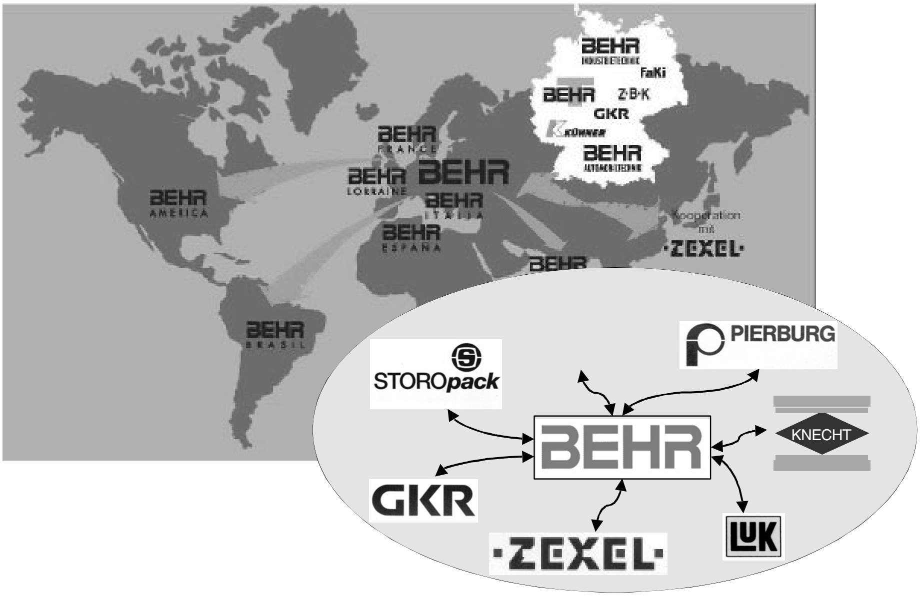


Figure 6 The Behr Company as an Example of a Networked Structure.

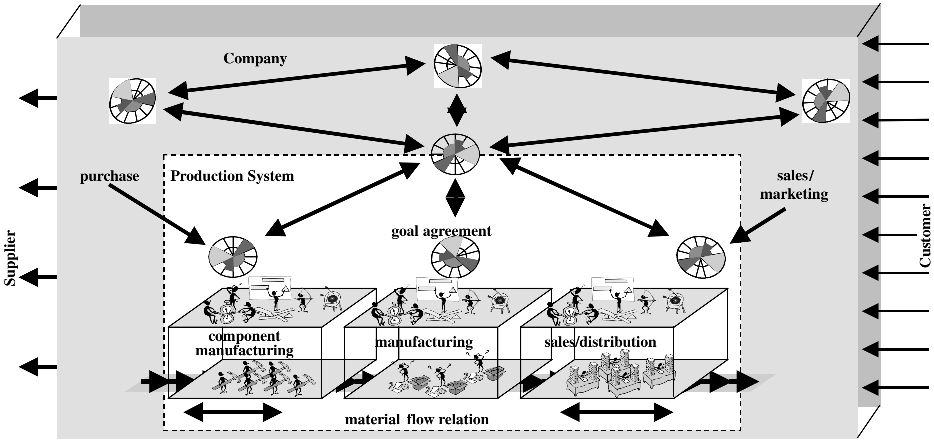


Figure 7 Common Target System to Coordinate Semiautonomous Organizational Units.

these projects have been further analyzed, showing increased corporate transformability and a significant change in organizational parameters.

A manufacturer of packaging machinery was among the companies analyzed. It exemplifies the changes in the organizational structure and the transition to self-optimizing structures. Before the organizational changes were implemented, the company had a classical functional organization structure (see Figure 9). This structure led to a high degree of staff specialization, which was unsatisfactory in terms of the value-adding processes. For example, six departments and a minimum of 14 foremen and their teams were involved in shipping a single packaging machine.

In the course of the change process, semiautonomous units were created based on the idea of the fractal company. These units performed all functions necessary for processing individual customer orders. Part of the new structure included organizational units that focused on product groups for customized assembly processes. The interfaces of the latter no longer serve to carry out individual

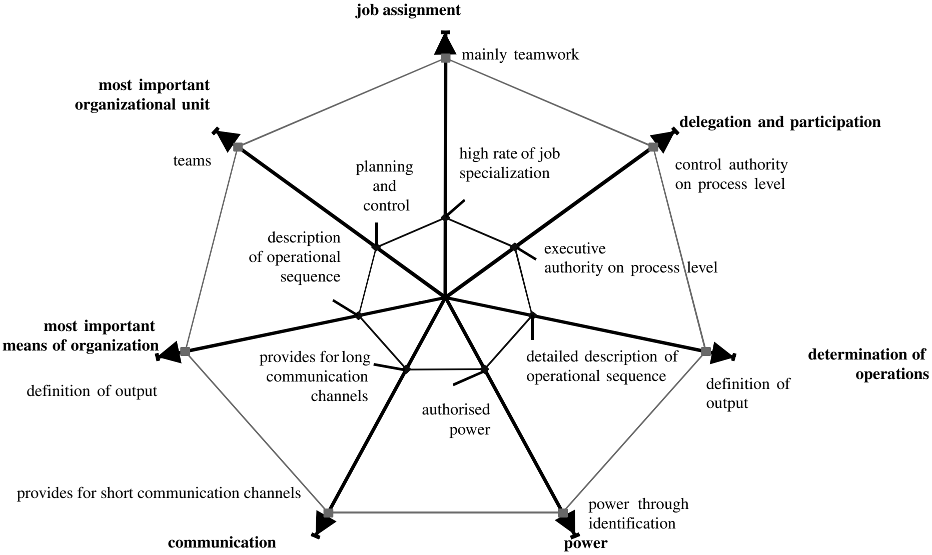


Figure 8 Basic Change in Self-optimizing Structures. (From Kinkel and Wengel 1998)

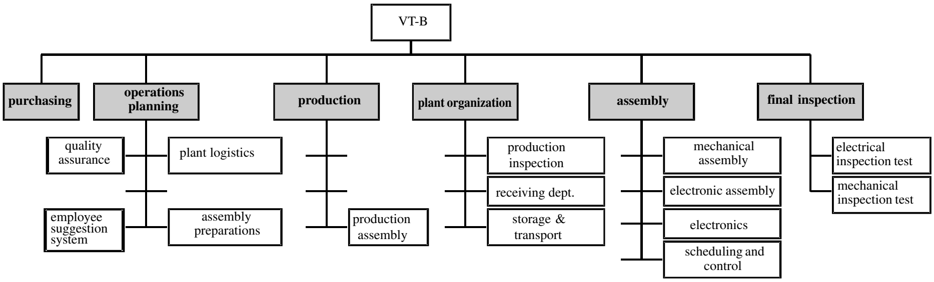


Figure 9 Traditional Corporate Structure Exemplified by a Manufacturer of Packaging Machinery.

customer orders but are instead needed for long-term planning and maintaining the production process (see Figure 10).

Reducing the interfaces in the planning process and at the same time adjusting the planning and control principles to the new corporate responsibility structure cut the cycle time for producing a machine by 60%.

4. NEW METHODS FOR PLANNING AND OPERATING TRANSFORMABLE STRUCTURES

In the future, companies will need new planning methods to increase their transformability and adaptability to a changing business environment. These methods and tools will speed up processes but also increase performance quality and integrate existing methods. The following four methods allow to the transformability of an enterprise to be increased. They differ in the extent of their market penetration, their market maturity, and their operative range. All methods are based on the new corporate structure and attempt to improve the related processes (see Figure 11).

4.1. Process Management through Process Modeling, Evaluation, and Monitoring

If future enterprises are no longer structured according to Tayloristic functions but focus on added value, then new methods and procedures will be required for mapping and evaluating these processes.

To achieve increased transformability, it is necessary to check the process efficiency continuously with regard to the current speed of change. If processes are to be successfully and comprehensively

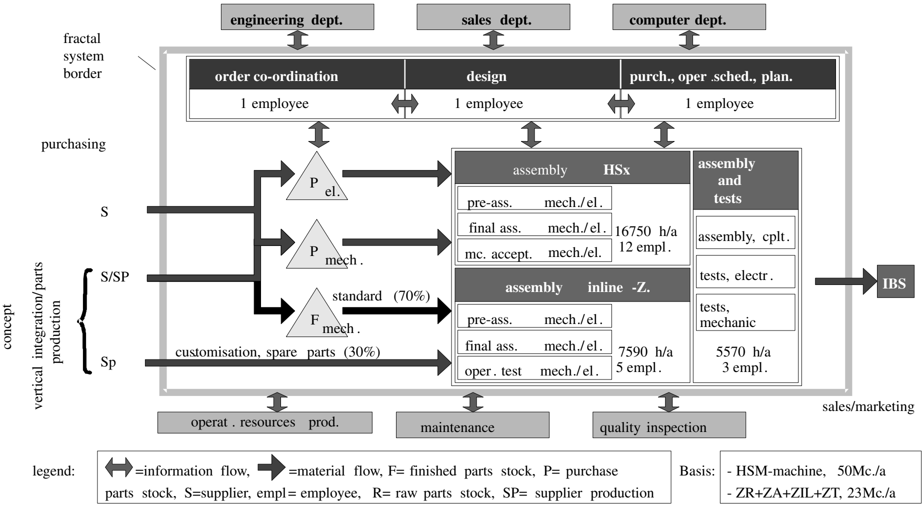


Figure 10 Functional Integration after Transformation.

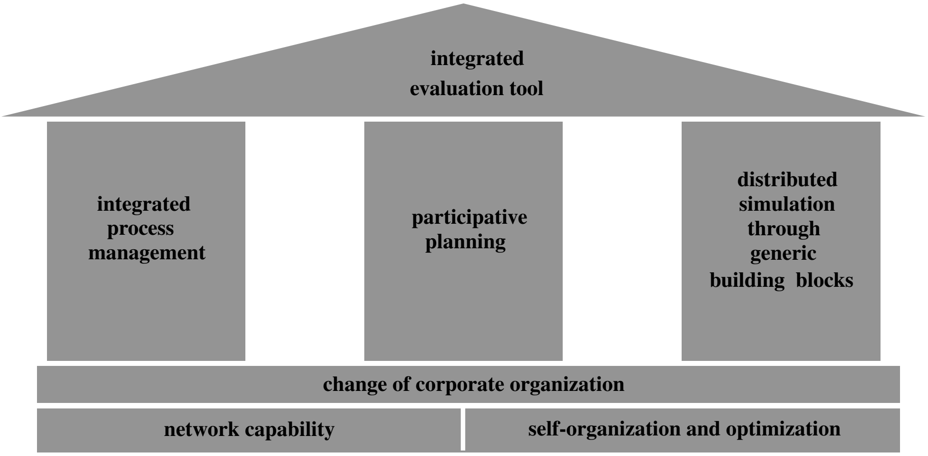


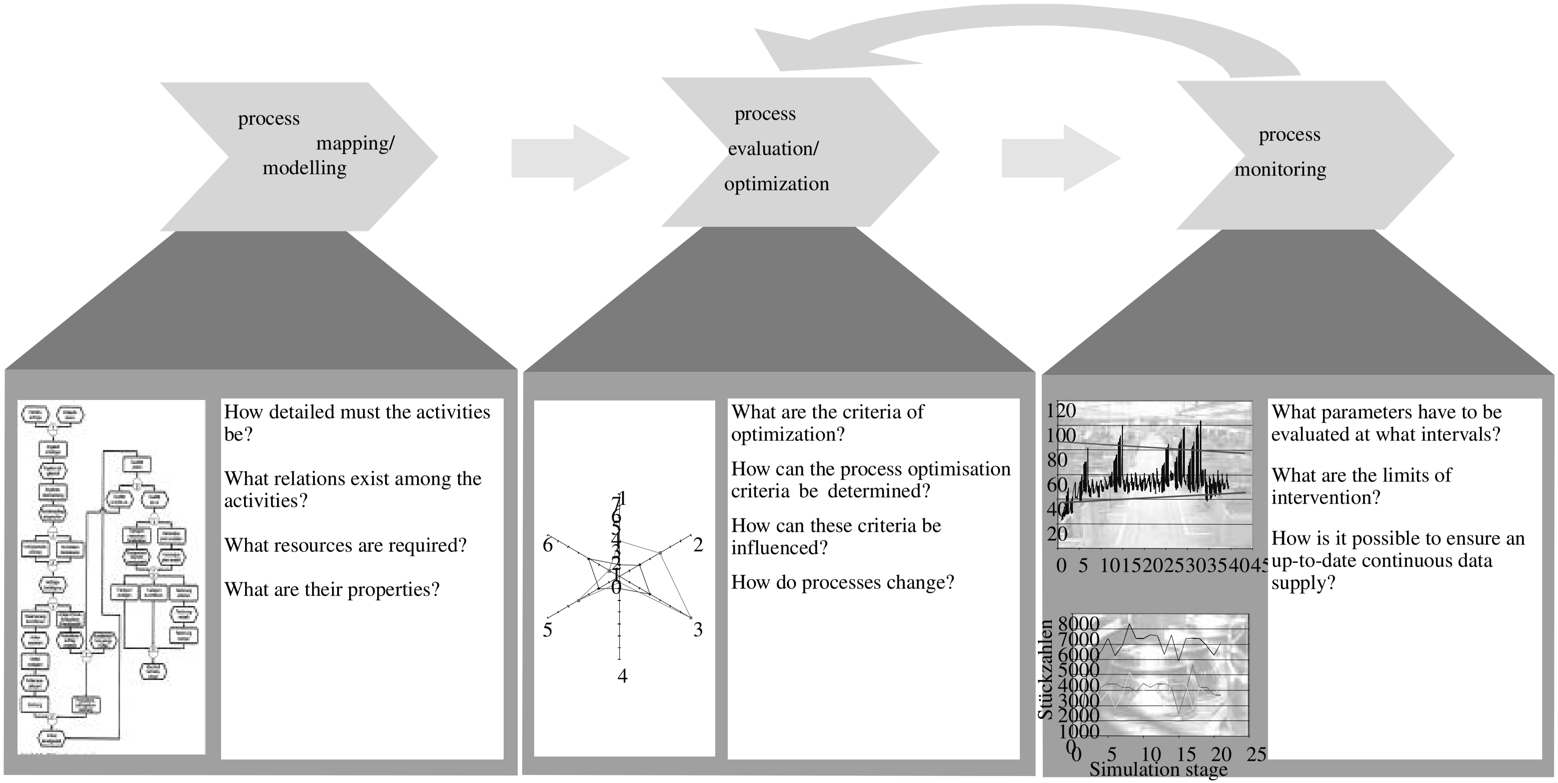
Figure 11 The Structure of the Methods Presented.

managed, it is not sufficient to map the process once but rather use an integrated and holistic approach. It is necessary that process modeling be understood by all those involved in the process. At the process evaluation and optimization stage, the structures of the process model are evaluated and optimized from different points of view before being passed on to the continuous process monitoring stage (see Figure 12).

A great number of modeling tools for process modeling are currently available on the market and applied within companies. These tools all have the capacity to map the corporate process flow using predefined process building blocks. Depending on the necessary degree of specification, the processes can be depicted in greater detail over several levels. Each process module can be equipped with features such as frequency, duration, and specific conditions to enable evaluation of the work flow as a whole. In addition, the process steps can be linked through further modules such as required resources and required and created documents. However, none of the tools can provide specific instructions as to the extent of the models' detail. The specification level depends, for the most part, on the interest of the persons concerned, including both the partners in the corporate network and the semiautonomous organizational units within the individual companies. In any case, the interfaces between the organizational units and the network partners must be adequately specified so that the required results to be delivered at the interfaces are known. However, a detailed description of individual activities in the organizational units is not necessary.

The evaluation and optimization of processes can be based on the performance results provided at the interfaces. Performance results means primarily to the expected quality, agreed deadlines, quantities and prices, and maximal costs. So that the process efficiency and the process changes with regard to the provided results can be evaluated, the immediate process figures have to be aggregated and evaluated in terms of the figures of other systems. This leads to new cost tasks. An important leverage point in this respect is the practical use of process cost calculation and its integration into process management(von Briel and Sihn 1997).

At the monitoring stage, it is necessary to collect up-to-date process figures. Based on these key figures, cost variance analyses can be carried out that allow the relevant discrepancies between desired and actual performance to be determined and illustrated by means of intelligent search and filter functions. The relevant figures are then united and aggregated to create global performance characteristics. Due to the locally distributed data and their heterogeneous origins, monitoring processes that encompass several companies is problematic. To solve this problem, the Fraunhofer Institute developed the supply chain information system (SCIS), which is based on standard software components and uses the Internet to enable the continuous monitoring of inventory, quality, and delivery deadlines in a multienterprise supply chain. The person responsible for the product stores the data of each supplier separately in a database. This product manager is therefore in a position to identify and mark critical parts on the basis of objective criteria (ABC analyses, XYZ analyses) and practical experience. It is then possible to determine dates (e.g., inventory at a certain point in time) for critical parts and carry out time analyses (e.g., deadline analyses for a certain period of time, trend analyses). These analyses are used to identify logistical bottlenecks in the supply chain. Moreover, the analyses can be passed on to the supply chain partners, thus maintaining the information flow within the supply chain.



How detailed must the activities be?

What relations exist among the activities?

What resources are required?

What are their properties?

What are the criteria of optimization?

How can the process optimisation criteria be determined?

How can these criteria be influenced?

How do processes change?

What parameters have to be evaluated at what intervals?

What are the limits of intervention?

How is it possible to ensure an up-to-date continuous data supply?

Figure 12 Model of Holistic Process Optimization.

4.2. Integrated Simulation Based on Distributed Models and Generic Model Building Blocks

Simulation is another important method for increasing the transformability of systems. With the help of simulation, production systems can be evaluated not only during standard operation but during start-up and fluctuation periods. Simulation is therefore an ideal planning instrument for a turbulent environment characterized by specific phenomena. However, in practice, the use of simulation is increasing only slowly due to the need for accompanying high-performance computer systems and reservations regarding the creation of simulation models, pooling of knowhow, and maintenance of the models. The main problem remains the nonrecurring creation of simulation modules and the need to create a problem-specific overall model.

Two simulation methods can be used to speed up the planning process. The first method generates company- and industry-specific modules that can be put together to create individual simulation models. This is achieved by simply changing the parameters without having to build a completely new planning model. The modules can be continuously created until the user no longer needs to adapt the individual modules but merely has to modify the parameters of the overall model (see Figure 13).

The model of a production system developed by the Fraunhofer Institute shows that two basic building blocks suffice to create a structured model of 10 different types and 25 pieces of machinery. Within two weeks, 25 variations of the production system could be analyzed in collaboration with the production system staff.

The second method enhances the creation of simulation models by allowing distributed models to be built that interact through a common platform or protocol. Thus, various problem-specific tools can be put into action so that there is no need to apply a single tool for all problems. Moreover, the modeling effort and maintenance costs are shared by all participants. Accordingly, every semiautonomous corporate unit and partner in the corporate network can maintain and adapt its own model. On the other hand, because a common platform ensures that the models are consistent and executable, corporate management doesn't lose control over the overall model. The introduction of HLA communication standards for an increasing number of simulation systems fulfills the principal system requirements for networked simulation.

4.3. Participative Planning in the Factory of the Future

The participative planning method is used to reduce the number of interfaces that arise when a complex planning task is solved—that is, one that involves many planning partners and their individual knowhow. It also improves information flow at the interfaces, allows planning processes to be carried out simultaneously, and prevents double work in the form of repeated data input and data transfer. Participative planning is based on the theory that cooperation considerably increases efficiency in finding solutions for complex problems.

The basic principle of participative planning is not new. It was used in factory and layout planning long before the introduction of computer assistance. Previously, team meetings used paper or metal

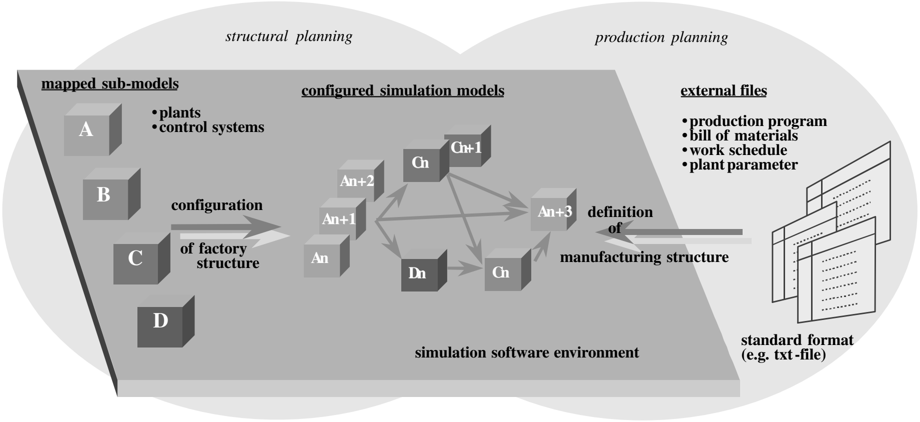


Figure 13 Modeling with Predefined Building Blocks.

components to represent machinery or production areas. These items could be fastened or glued to the factory's layout plan. This procedure has remained more or less the same in participative planning, the only difference being that interactive factory planning uses virtual elements that exist solely in the computer model and do not need to be glued or pinned. These objects not only possess proper geometrical characteristics but also include additional information concerning object values.

The basic tool of participative planning, the interactive planning table, is based on an idea from the Institute for Hygiene and Applied Physiology and the Institute for Design and Construction at the ETH Zurich. A projector is used to project a 2D image of the planning area via a mirror onto an ordinary table. Simultaneously, a 3D model of the planning area is presented on the wall. The same mirror returns the picture on the table to a camera mounted beside the projector. Thus, feedback on the changes performed on the table is made available. The interactive mechanism of the planning table works by means of metal building bricks with reflective upper surfaces that make it possible for the camera to register the movements of the bricks. Two main forms of interaction exist. One uses one of two brick sizes and the other, the classical way, uses a mouse and keyboard (see Figure 14).

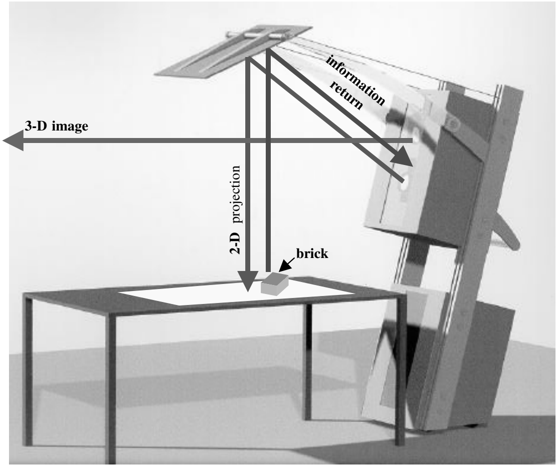
The interactive planning method leads to a significant reduction of planning time while maintaining planning quality. Accordingly, this planning model especially applies to planning cases in which the highest possible planning quality is imperative due to low profit margins and high investment costs, when several partners with different knowhow levels participate in the planning and the planning takes place under high time pressure. Given the increased speed of change, this will apply to an increasing number of planning cases.

4.4. The Integrated Evaluation Tool for Companies

Many enterprises argue that decisions must affect the revenue figures more quickly and in turn influence the corporate profit situation and business value. Hardly any company data are more controversial than the accounting figures. The main criticism of these figures is that for the most part, they are based on past results. Moreover, because the results are aggregated and based on many different accounting parameters, it is not possible to derive clear-cut measures in due time. This means there is too much time between the occurrence and recognition of weak spots in the corporate revenue figures.

However, an integrated evaluation tool has to include accounting figures, which form the basis for corporate decision making and also determine the key data that allow changes to be registered before they take effect in accounting. The balanced scorecard (Kaplan and Norton 1996), a method developed for practical use by Kaplan, provides an easy-to-understand method that enables accounting figures to be combined with other process data (see Figure 15).

The balanced scorecard identifies vital figures for answering the following questions:



2-D projection
Abeamer is used to project an image of the planning area on to an ordinary table.

3-D projection
In addition, a three-dimensional view of the planning area will be projected on the wall.

Image return
The picture reflected on the table is returned via a camera mounted beside the beamer.

Figure 14 The Technology Behind the Factory Planning Table.

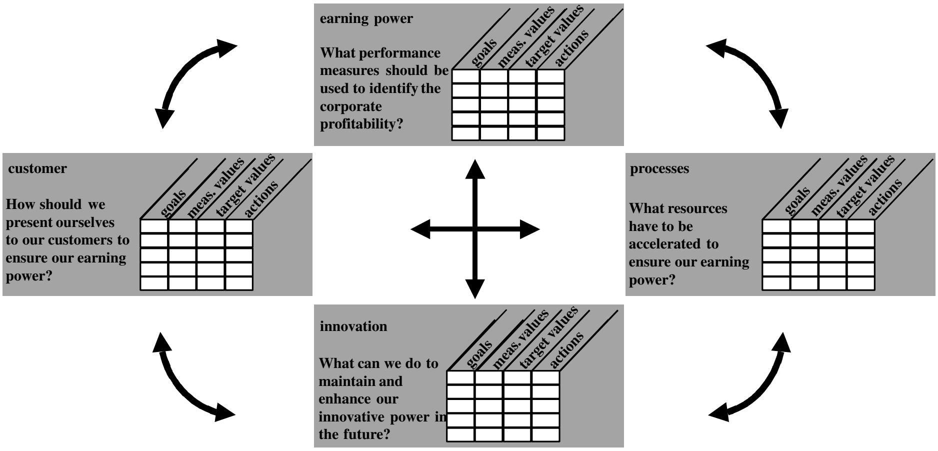


Figure 15 The Principal Structure of the Balanced Scorecard.

- How does the current profit situation of the company compare to the market situation?
- How is the company's market attractiveness rated by its customers?
- What is the current situation in the company's value-adding processes?
- What improvements can be made in corporate processes and products, and what is the innovative power of the company?

This tool helps a company recognize changes in the corporate situation at an early stage and initiate appropriate actions due to the depth and variety of the questions and their differing time horizon. The balanced scorecard thus serves as an early warning system for a company so that it can actively respond to market changes. The tool also allows the current profit and market situation of the company to be taken into consideration. Thus, the balanced scorecard helps the company avoid the short-range view of the profit situation and expand it to include vital aspects of corporate management.

5. CONCLUSION

Based on Peter Drucker's now generally recognized thesis that only the uncertain is certain in the future markets of manufacturing enterprises (Drucker 1992), it appears safe to forecast that manufacturing structures will change fundamentally. In this context, the transformability of future manufacturing structures will become an important feature, enabling quick and proactive response to changing market demands.

In the scenario of transformable manufacturing structures, the focus will no longer be on the "computer-directed factory without man" of the 1980s but on the accomplishment of factory structures that employ of the latest technology. Human beings, with their unique power for associative and creative thinking, will then take a crucial part in guaranteeing the continuous adaptation of factory structures.

Implementing transformability requires the application of new manufacturing structures in factories and enterprises. These structures are distinguished by their capacity for external networking and increased internal responsibility. Combining these new structures with new design and operation methods will lead to factories exceeding the productivity of current factory structures by quantum leaps. However, this vision will only become reality if both strategies—new structures and methods—are allowed to back up each other, not regarded as isolated elements.

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