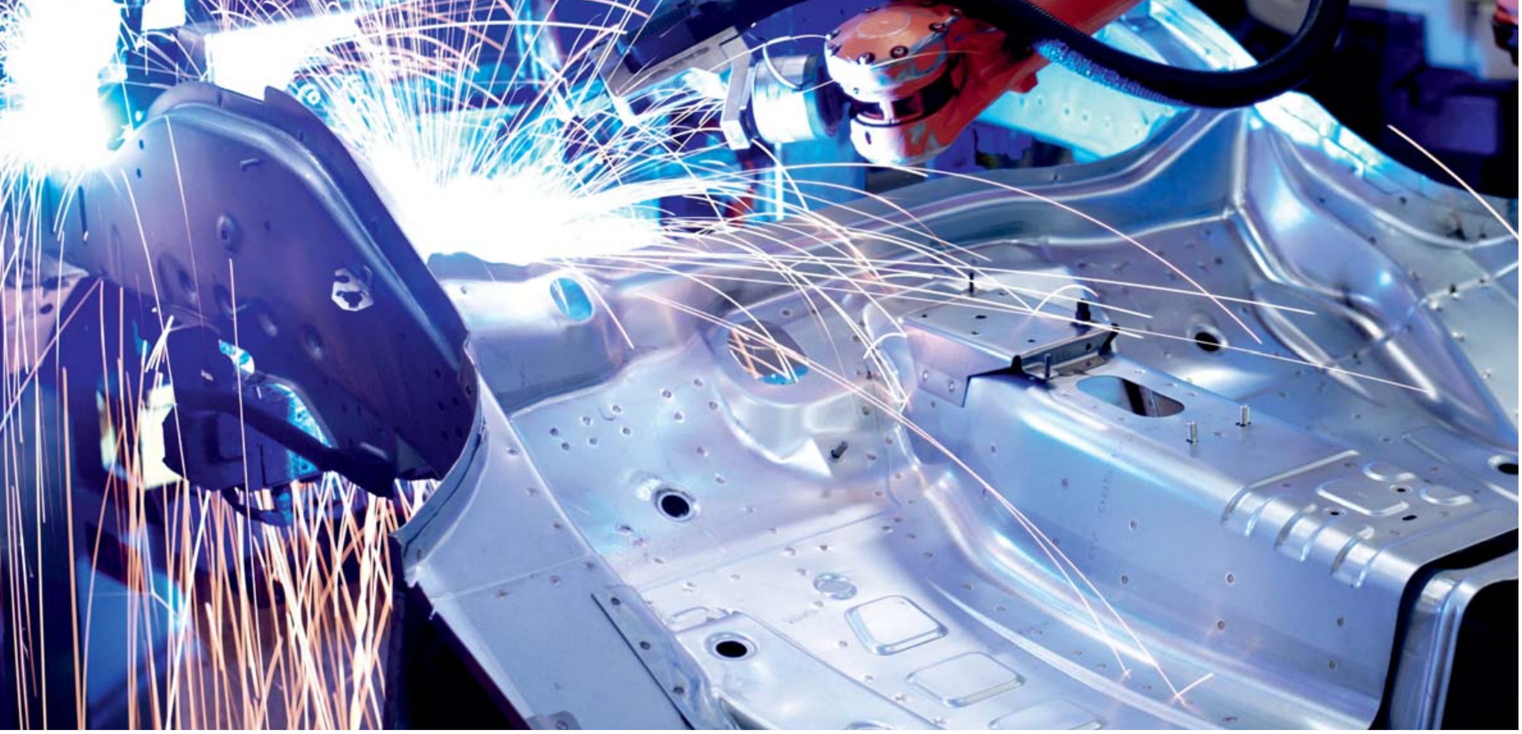

Mastering Complexity Through an Adaptable Production System

Gregor Tuecks/Jan Eilers

Diversification and resource efficiency are the current megatrends when it comes to production systems. But what does this mean for a product line that typically requires capital intense equipment? It is both opportunity and risk at the same time. The key is to design and implement the right level of adaptability in order for the production system to meet the requirements of the complexity in the product system.

Manufacturers in high wage countries are facing challenges that are not just diverse, but increasingly complex. Internal and external factors are determining an environment in the enterprise that is best characterized by diversity, dynamics, and insecurity. In order to be successful, an enterprise must be able to adapt to this environment. The complexity challenge an enterprise is facing can best be described with the following dimensions:

- Diversity within the Production System
  - Heterogeneous and individualized products
  - Diversity of the value streams
  - Heterogeneous resource requirements and constraints in resource usability
- Dynamics within the Production System
  - Shorter product life cycles and more diverse customer requirements
  - Smaller average order size and changing market demand
- Insecurity within the production system
  - Vulnerable processes and logistics chains

Areas of Tension in Complex Production Systems

All decisions related to the configuration of the production system in an enterprise are made based on the two areas of tension known as Production Planning and Production Operation. Both areas of tension are described by two contradicting sets of goals.

In the Production Planning field the goal is the optimization of the value stream using capital intense, highly specialized systems for simulation and planning (focus on planning). At the same time there is a strong desire for maximum flexibility and adaptability of the value streams in the enterprise (focus on value).

In the Production Operation area the trade off is between economies of scale and economies of scope as a result of the structure of external market requirements and internal costs. Therefore, in low wage countries the focus is normally on exploiting scale effects, while in developed areas of the world it is more on the individualization of products in order to meet more heterogeneous customer requirements.

These four dimensions together form a two-dimensional field which is often referred to as the "polylemma" of production (Fig. 1).

The key to successfully deal with the complex challenges lies in the configuration of the production system. This should be done in a way that the contrasts in the areas of tension are disambiguated as much as possible. At the same time, equilibrium between the system complexity and the level of adaptability of the production system must be established.

Fields of Activity for the Configuration of Complex Production Systems

The areas of tension mentioned above can be used to identify areas of activity for the configuration of complex production systems. These can be understood as practical approaches to implement adaptability of production systems. Of greatest interest are topics and industries that are most relevant for industrialized countries (Fig. 2).

Individualized Production System

The best way to address the demand for heterogeneous and individualized products is through the individualized production system that combines aspects of the opposing production concepts of mass manufacturing and individualized production. The goal is to allow efficient manufacturing of highly individualized products, an ability that is particularly important in developed countries. In order to resolve

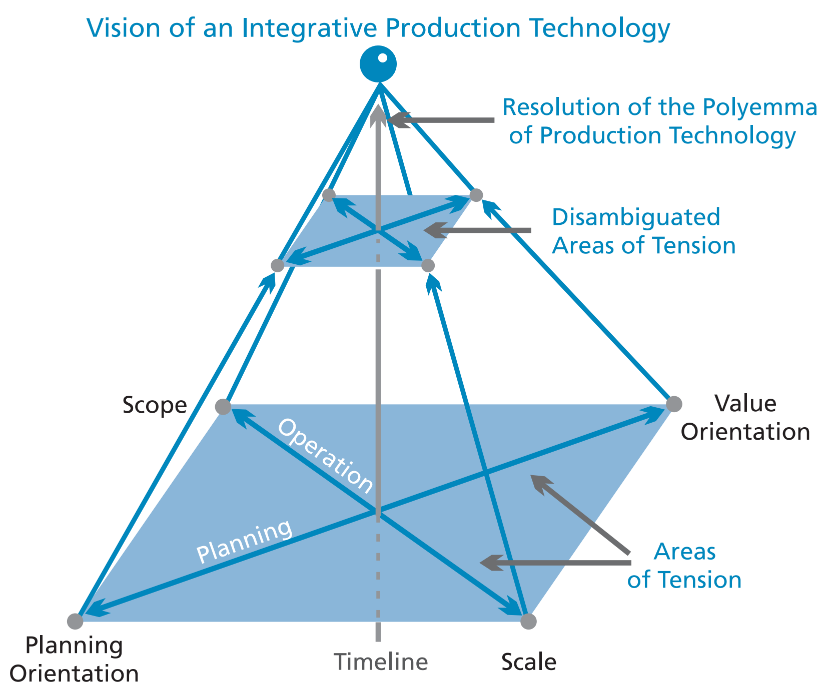

Figure 1: Polylemma of Production

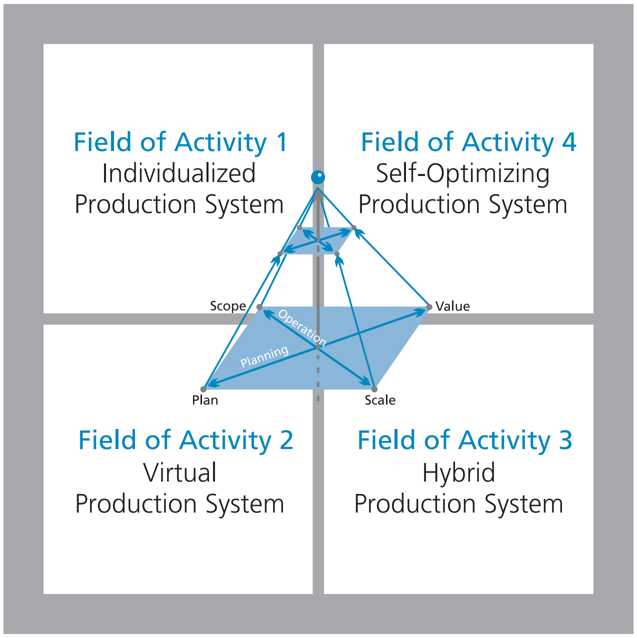

Figure 2: Fields of Activity for the Configuration of Complex Production Systems

the dilemma between economies of scope and economies of scale, the structural elements of product and production structure must be harmonized to the highest possible level.

Accordingly, individualization of the production system must consider both, the view of the customer as well as the view of the production organization. From a customer's perspective, a high level of individualization in terms of a cost vs. value ratio is of interest. From the viewpoint of the production organization however, the focus should be on standardized production processes and equipment. This helps to maintain the highest possible volume effects while still providing individualized products in large enough consumer markets.

Most recent developments in production technology such as Selective Laser Melting (SLM) are examples for how the dilemma between scale and scope will be disambiguated in the future. It allows a close relation between product structure and production process while maintaining efficient manufacturing despite small production lots. As a result, enterprises are enabled to meet individual customer requirements at reasonable development and production costs despite the increasing complexity of equipment and production processes.

Virtual Production System

The goal of the Production Planning tension field is to achieve a continuous optimization of the efficiency and quality in the production processes. This is becoming increasingly difficult when more complex production processes are used, as is normally the case in developed economies. It often can only be done using simulation technology. As simulation itself is not a value creating process, its contribution to the achievement of the goals must be continuously monitored and evaluated. In doing so, the resulting planning quality and the flawless integration in the value creation chain must be systematically improved over time.

A special focus should be on the holistic planning of the production system using cross-departmental simulation methods in order to achieve the next higher level of simulation quality. The most promising approaches combine several methodologies to an integrated simulation system. This allows for a more precise prediction of process results, as factors and effects can be simulated that cannot be considered in simpler systems. Nevertheless, the simulation methodologies used in the sub-systems must also be continuously improved.

Examples for higher level simulations are called Virtual Manufacturing Systems, which are combining a multitude of NC control units, control loops, mechanical equipment, and processes in order to predict both single effects as well as interdependent impacts.

Self-Optimizing Production System
Self-optimization of production systems is focusing on decentralization of planning activities towards local units that are directly embedded in the value creation process. A key capability of a decentralized system is to react autonomously to complex, i. e. quick and frequent changes to external factors such as work load, user interactions, errors, etc. Compared to simple control loops that are designed to control a single output variable, self-optimizing systems have the capability to adapt the production system more dynamically based on the external needs. It does this by using continuous monitoring of a multitude of external values, evaluation of situation specific target values, and an adaptation of the system characteristics in order to meet these target values.

However, preconditions for the successful implementation of a self-optimizing production system are always the precise description of highly complex production processes and the identification of all parameters that must be controlled.

Hybrid Production System
Integration of diverse manufacturing technologies to a hybrid production system allows for achieving several advantages. For example, process chains can be shortened through higher integration, e. g. resulting in a reduction of the number of setups. This not only results in reduced setup time but also in increased quality and minimized risk.

The most significant challenge when integrating processes is to avoid collisions of the individual platforms during the manufacturing sequence. A very precise synchronization of all movements is key, which means that control systems of several, normally individual platforms, must be interconnected. An example of a hybrid manufacturing center is e. g. a combination of a milling center with a handling robot and a laser welding robot to a hybrid machining center.

Conclusions and Recommendations

Configuring the production system in order to meet the requirements of the market system is key to its success. The question to be answered is: How much adaptability of the production system is required to meet these requirements? The trade-off between adaptability and system complexity must be actively managed in order to guarantee robust results and processes. This can only be achieved when using an integrated approach considering all four of the above areas of activity (Fig. 3).

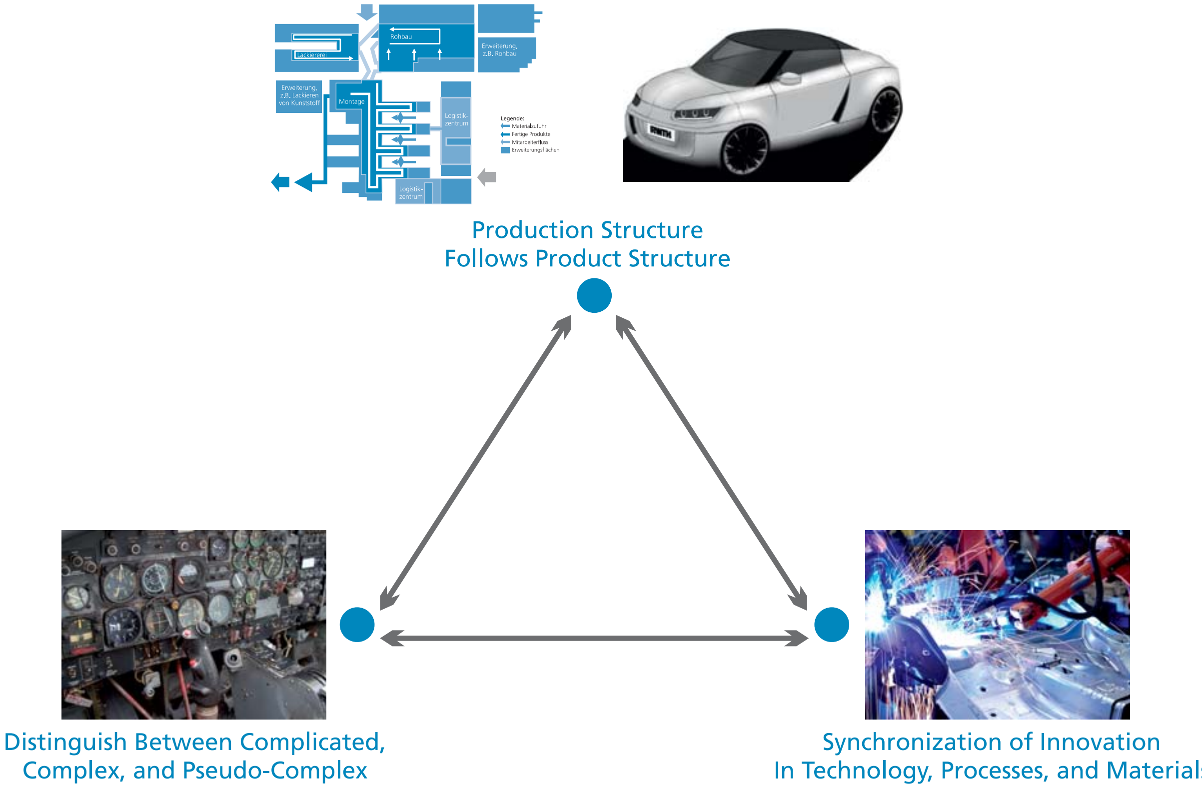

Figure 3: Intergrated Complexity Management to Resolve Areas of Tension

Therefore, the following three recommendations should be considered for the structuring of any production system:

- Production structure follows product structure
  - Create visibility of dependences and define the required degree of adaptability
- Synchronize innovations in technology, material, and processes
  - Harmonize production innovations in the context of the product design process
- Distinguish between complicated, complex, and pseudo-complex
  - Classify production problems, some things only appear to be complex but aren't

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