Changeability in Structure Planning of Automotive Manufacturing

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Abstract

Manufacturing is faced by change, which force manufacturers to permanent adaptation of their factories. For handling the manifold dynamic change drivers and the complexity of the planning objective factory, a systematic planning system is essential. Therefore, in this paper an innovative planning method for the long-term adaptation and optimization of manufacturing network structures is proposed taking into account the technological developments of the products and the production resources. With the new planning method structure optimizations in a networked production will be prepared and planned in strategic scenarios to increase the changeability of the factories with their capacitive and technological resources.

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1. Introduction

Manufacturing operates in a turbulent environment. Faced by the volatility and challenges of the markets, automotive manufacturers widened their product and technology portfolio and enlarged their manufacturing capacities of their manufacturing network. For keeping the competitiveness in the global environment, manufacturers are forced to permanent adaptation of their factories. The configuration of the manufacturing network regarding the attribution of manufacturing tasks, capacities, technologies and resources to manufacturing sites and the long-term adaptation of the structures is a complex strategic planning task. Therefore, in this paper an innovative planning system for the long-term and systematic adaptation of factory structures is proposed taking into account the three main change drivers, the markets, the technological developments of the products and the innovations of the production resources. By the application of the new planning method, the changeability of the factory structures will be increased.

2. Fundamentals for the strategic planning of factory structures

2.1. Definition of a factory structure

Factories are regarded as socio-technical systems consisting of elements, which operate through complex relations like processes in material and information chain [1]. The network and dependencies of the internal system elements and its relationships represent the structure of the system factory [2].

The system factory consists of the two relevant subsystems of the products and the production, which build the term of a factory structure [3]. Based on systems theory approach, a ‘factory structure’ is defined by the products, the resources, the technologies, the capacities, the characteristics of the manufacturing sites with the location of the resources, the processes, the in- and outsourced value added and the relations in between the manufacturing network [3]. The method for strategic structure adaptations focus on the first three system lev-
els of the product and production structure starting on the network levels according to the generic model of structure adaptations in chapter 2.2.

2.2. Generic model for strategic structure adaptations

The optimization and adaptation of manufacturing structures takes place in strategic production planning on the levels of the networks down to the sites and segments [4; 5]. The configuration and reconfiguration of a manufacturing network is a strategic planning task [6], activated by the developments and conditions of a turbulent environment and needs to be geared to the available resources and competences in manufacturing [7].

In this context the frame of reference for the strategic planning of changeability in networked production follows the generic model illustrated in Fig. 1 based on the viable system model [8; 9]. Viability means in a broader sense the ability to adapt to changing circumstances and to advance oneself in the future by learning from experiences in the past. Hence, this model is transferred to the adaptation of factory structures impacted by change.

![Generic model for structure adaptations](image)

The model consists of the environment outside the system factory with the change drivers and general conditions, which impact the levels of the system factory in differing intensity. Strong interdependencies with the environment and in between exist on the lowest level of the factory structure in the processes. Taking the interactions of the processes into account, they are to be planned and controlled as a system for fulfilling the short-term objectives. Due to the strong dependencies and restrictions, the system on level two can be changed and adapted within a pre-defined and limited scope of action, the flexibility corridor. On the level of the segments, the focus is on the middle-term tactical planning, taking into account the long-term guidelines from level four and the real conditions of the operational business. Level three operates as the intermediator of the upper and lower levels for the internal balance of the system factory. On the top levels of a factory structure, the networks and sites are to be planned in a strategic planning horizon with the change of existing limitations, restrictions and general conditions, as well as the configuration and reconfiguration of the manufacturing network with a maximum scope of action and degree of freedom – the changeability of factories. The method is focused on the top levels taking into account the level of the segments.

2.3. State of the art in structure planning

The state of the art in structure planning was investigated under three aspects, which are of importance for factory adaptations, and summarized in [3]:

1. Approaches for increasing the structural changeability in context of change enablers [11; 6; 12], technical [13; 14; 15; 16; 1] and organizational manufacturing concepts [17; 18; 19]
2. Approaches for structuring factories like the production segmentation [17]
3. Approaches of factory planning

The analysis of the state of the art resulted, that there was no adequate method for changing and adapting whole factories and their network. Therefore, a planning system with this focus was to be developed.

3. Conception of the planning system

The planning and optimization method for systematic structure planning proposed in this paper follows the steps illustrated in Fig. 2.

![Planning system for structure adaptations](image)

The first step of the method is the characterization and modeling of the existing factory structures based on a detailed analysis of the products and production. In the second step, the relevant change drivers, which are planned within the existing strategies of the market, the
product and production are analyzed in their prospective developments of the future.

In planning phase three, the factory structures are impacted by the change drivers. Based on the variation of the factory structure, alternative concepts, which fulfill the requirement for increasing the changeability, are developed in planning phase four. Based on the evaluation of the concepts, an optimal solution for certain conditions at a specific point in time is to be chosen [3].

4. Detailing of the planning system

4.1. Characterization of the existing factory structures

The basis of an optimization is an analysis in order to understand the causality of the existing systems [20], according to the method of structure analysis [21;3].

4.1.1. Analysis of the product and production structure

The analysis of the products and their variability was accomplished for a standardized product structure, which is illustrated at the example of a vehicle (Fig. 3).

Matching the two analysis models in [tpu], the factory structure was characterized in its current configuration.

4.1.2. Time variable development of factory structures

The structures are subject to the time variable developments. Continuous improvements lead to increased performance and efficiency in manufacturing, which can be described and forecasted by the learning curve concept according to Wright [23]. Learning effects can be traced back to investments in equipment, rationalizations of workflows, constructive optimizations of the products and stabilizations of the processes [3].

The learning curve analysis was conducted for all product and technology segments like shown in Fig. 4. The analysis shows the potential, which can be reached by the learning effects in manufacturing and it is the basis to forecast the required resources in the future under the influence of continuous improvements.

Discontinuous changes do not follow the steady progression of the learning curve and need to be considered separately.
4.2. Analysis of the discontinuous change drivers

Discontinuous change drivers have tremendous and radical effects on the structures of the networked factories. For synchronizing the developments of the markets and product program, new product technologies and new production technologies, the technology roadmap was built up according to Fig. 5 based on [24;25].

For this time span, the change drivers were scheduled in the technology roadmap by their time of implementation into the series production, their time duration in the series production and the period required for the engineering. A consequent migration and transfer regarding the dependencies outlined between the driver lines of market, product and production synchronize the developments of manufacturing and systemize the permanent adaptation of technologies, capacities and resources.  

4.3. Variation of the factory structures

For the variation of the factory structures, a variation tool – the FactoryVariationPlanner – was developed and implemented in the method for structure planning according to the approach of [22]. The variation tool basically comprises a tableau for input data with the relevant change drivers, a database model of the factory structure comprising the product and production structures and an output field containing the capacity distribution of the factory structure. The link between input and output data is carried out by a calculation algorithm. The output capacities are visualized on a user interface of the software environment. The main principle of the factory variation tool is shown in Fig. 6 and detailed described in [3].

By a variation of the implemented drivers in defined scenarios, the capacities of the manufacturing network in the sum of hours per year based on the [tpu] are obtained by a calculation mode integrated in the tool. The effects of market, product and production driven changes on the capacities of the factory structure are simulated, described and visualized. In the example of Fig. 6, the effects of a driver variation are illustrated for one manufacturing site in capacity nodes of the technological segments at a specific point in time. From the variation of the factory structure, the pressure for adaptation in the current factory structure configuration is derived. The results of the variation scenarios show, when and where an adaptation of the networked production is essential.

Fig. 5: Synchronization of discontinuous change drivers by the technology roadmap

The technology roadmap contains in the vertical dimension the three main sections of market, product and production induced changes described in [3]. The horizontal dimension comprises the planning horizon of a long-term strategic planning of factory structure optimizations with ten years. This time span results from the fact, that changes with structural effects on the factories exceptionally can be realized with the introduction of new products. Assuming a product life cycle in automotive industry of seven years and ca. three years for engineering the new product according to the product development process, ten years are adequate for the strategic planning and adaptation. Therefore, the time horizon, regarded and implemented in the suggested technology roadmap, comprises the next ten years of expected market, product and production developments.

Fig. 6. Variation of the factory structures
4.4. Development of alternative structure concepts

Due to the change pressure, which results from the impacting factors and the correlated inefficiencies within the factory structures, alternative structure concepts were developed according to Fig. 7.

![Partial model of the technological segments](image)

Fig. 7. Development of changeable structure models

The alternative model basically has two main objectives: the highest possible degree of changeability and a maximum of productivity. In this area of conflict, the optimum between these two objectives is to be derived.

With this mission, six general strategic approaches for the advanced development of the factory structures on the level of the networks and sites were derived for increasing their structural changeability [3].

All of these strategic approaches were evaluated with respect to their effects on the strategic objectives of the enterprise and on the change drivers by a method, which is based on Quality Function Deployment (QFD).

In a second step, on the system level lower, partial models of the technological segments of the manufacturing sites were built for describing their specific characteristics and to outline their limitations of changeability. Then, conceptions for increasing the changeability in the specific technological segments were developed.

Finally, these partial models were merged to structure scenarios comprising the product portfolio, the technological segments, the internal manufacturing sites and the external virtual factory of the suppliers [3].

4.5. Selection of the optimal structure solution

For the selection of the optimal structure concept, an evaluation process was developed for comparing the alternative scenario under the conditions of the environment and the internal circumstances and priorities of the enterprises following the steps shown in Fig. 8.

The basis for the evaluation was the definition of impartial criteria, whose degree of fulfillments gives the resilient foundation for any decision, which is made on the future development of the factory structure. The analysis and the modeling of this planning system was made in the quantitative measurement of [tpu], which reflect the economic efficiency of manufacturing. In this manner the criteria for the optimal concepts were the averaged tpu Ø per life cycle volume of the products, the sum of the capacitive efforts based on tpu and the capacitive displacements based on tpu in comparison to a specific instant of time.

In the second step, impacting scenarios were created by the change drivers. The turbulence of the market was modeled by the variation of the quantity structures by random variables. The preferences of the customers regarding the configuration of the equipment and features of the products were varied between maximum and minimum equipped products. The impacts of the products and production were spread out into continuous and discontinuous drivers. The effects coming from continuous improvements were considered by the learning curve models, whose learning rates are variable depending on the efficiency progression of the technological segments. The conceptual changes of the products and production have to be analyzed in further feasibility-studies to quantify their effects on the [tpu] and thus for the required resource and capacity adaptations.

![Evaluation criteria in quantity](image)

**Evaluation criteria in quantity:**
- Ø tpu
- Capacities based on tpu
- Capacitive displacements based on tpu in reference to an instant of time

**Impacting-scenarios of the change drivers:**
- Market: Variation of the quantity structures by random variables and equipments
- Product und production:
  - Continuous improvements by learning effects
  - Conceptual changes by feasibility-studies

Simulation of system-scenarios in the planning tool FactoryVariationPlanner

Fig. 8. Evaluation of the alternative concepts
In the third step the impacting scenarios were combined with the structure scenarios and systematically simulated in the planning tool FactoryVariationPlanner. In this way all of the alternatives were evaluated quantitatively and due to the transparency of the effects of change drivers, the results conduct as basis for the decision of the optimal concept.

5. Conclusion

In this paper, a planning method for the strategic structure development of networked factories was presented. With the suggested procedure the factory structures are planned, configured and optimized according to the required adaption pressure coming from the impacts of the main change drivers in customized series manufacturing: the developments of the markets, the products and the production. The planning system was applied and verified in an automotive manufacturing network.

Future work can be done based on the assumptions and propositions of the planning system for systematic structure adaptations regarding a systematic investment planning based on the schedules of the technology roadmap, a systematic human resource planning for the resource adaptation and a research and development planning for production technologies facing the technological drivers and challenges of future manufacturing.

The content of this paper was presented in [3; 27].

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