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*model of a factory structure,*
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# MODEL OF A FACTORY STRUCTURE UNDER CHANGEABILITY ASPECTS IN AUTOMOTIVE MANUFACTURING

The complexity in automotive manufacturing increased enormously in the last couple of years. Reasons therefore are due to a widened product portfolio, enlarged manufacturing capacities distributed over several manufacturing sites and a large number of suppliers feeding the manufacturing network around the world. The factories are under permanent change and must be planned, configured and adapted in a permanent way. Consequently, planning tasks go along with a comparable degree of complexity as the manufacturing itself and must stand the continuous change manufacturing is faced with. Therefore, a factory model representing the essential information about the products, the technological resources and their interdependencies must be built for planning purposes. In context of long-term strategic planning tasks, structural changes are in specific focus and must be considered in the model. In this paper, a model of a factory structure, which can be used for the strategic planning of a manufacturing network is proposed. The factory structure model is based on a current configuration and has the architecture to consider future change within forecasts and scenarios.

## 1. INTRODUCTION

Permanent change is the situation factories in automotive industry are faced every day. Especially in the last couple of years the challenges for manufacturing increased enormously due to a growing customization and individualization of products, an enlarged degree of product diversity and shortened product life cycles. Facing market induced challenges on the one hand and meeting efficiency objectives with the coupled pressure of permanent innovation in products and technologies on the other hand is a dilemma factories have to deal with. Permanent adaptation of manufacturing has to be the consequence.

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With the enhanced complexity of the system factory, its products and technologies planning tasks get more complex and must be conducted continuously with the adaptation and configuration of manufacturing structures. Structural changes must be prepared and planned by strategic structure planning on a long-term time horizon.

Factories in automotive industry are characterized by operating in a network of manufacturing and suppliers. Therefore, the systems of products, capacities and technological segments are distributed over many manufacturing sites around the world. In the past, production structures were mainly optimized under the influence of lean thinking and logistic criterions [12]. Since time to market and the time needed for an adaptation will be crucial for keeping the competitiveness in the globalized environment of the future other criteria will also be essential for optimization objectives. The capacitive and technological structures of manufacturing must be configured according to the market and order situation. Flexibility and changeability of manufacturing structures are key enablers for meeting the challenges coming from the global market [8]. To achieve changeability objectives in the capacitive structures of manufacturing, models of factories describing existing technological structures regarding the sub-systems of product and production must be built. They are the basis for systematic structure planning under changeability objectives.

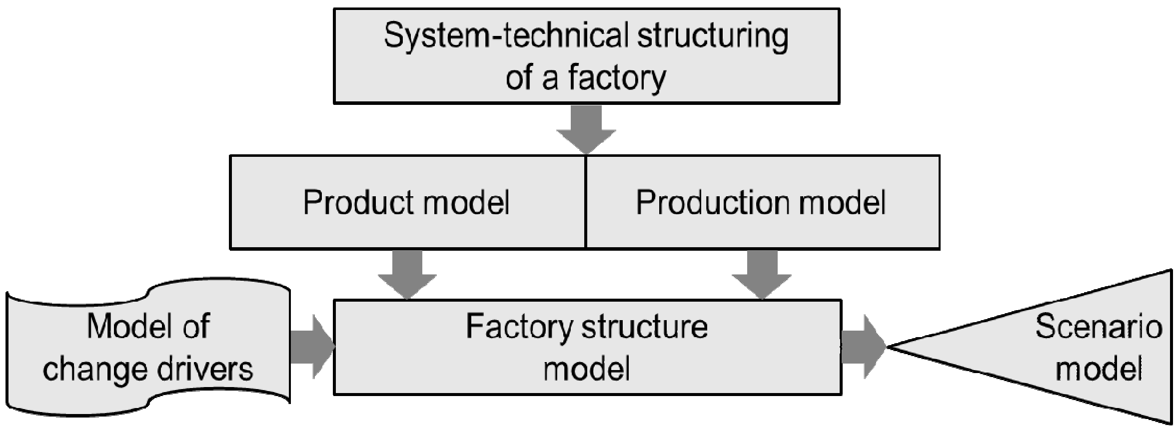


Fig. 1. Modelling a factory structure

The purpose of this paper is to describe a factory structure with its relevant elements and attributes in context of a long-term strategic planning task according to Fig. 1.

Therefore, the factory is structured with its systems, sub-systems and elements in accordance to system-technical criteria. Based on this a model of the factories´ product and production systems is described and matched to an overall factory structure model. In order to study the effects of change and the necessity to adapt in the modelled manufacturing network, the change drivers must be identified and modelled as possible input parameters and driving forces influencing the factory. Based on the model of the change drivers scenarios can be built up for planning tasks affecting the factory structure model. By giving the factory structure model dynamism in a forecasted way the dependencies and effects of change drivers regarding product and production can be described in advance and essential adaptations for optimization objectives can be planned and prepared proactively.

## 2. SYSTEM-TECHNICAL STRUCTURING OF A FACTORY

Factories in general can be regarded as socio-technical systems interacting in and with a turbulent environment. The system of the factory consists of sub-systems on several levels comprising elements which operate through complex relationships and interactions. The elements of the system factory are characterized by attributes and interlinked by complex relations and processes in material and information chain [4]. The network and dependencies of system elements and its relationships represent the structure of the system factory [10]. A basic principle of structure planning under changeability aspects is the structuring of the factory following system-technical criteria. The system factory comprises two relevant sub-systems in this context and its relationships – the system of the product and the system of production. These two partial systems of the factory represent the perspectives which are important when modelling a manufacturing network for a structure optimization. The sub-system of the product requires capabilities from the sub-system production, whereas the sub-system of production offers resources to satisfy the manufacturing demands. Regarding the system factory as product [4],[10], which has the structure of a product and must be designed, planned and built as product, correlations between the two partial-systems of the factory can be derived and used for adaptation.

Figure 2 illustrates the system factory with the representative elements in context of structure planning - on the left side, the system of product in its structuring levels and on the right side, the system of production. Based on system theory approach both partial-systems can be structured hierarchical.

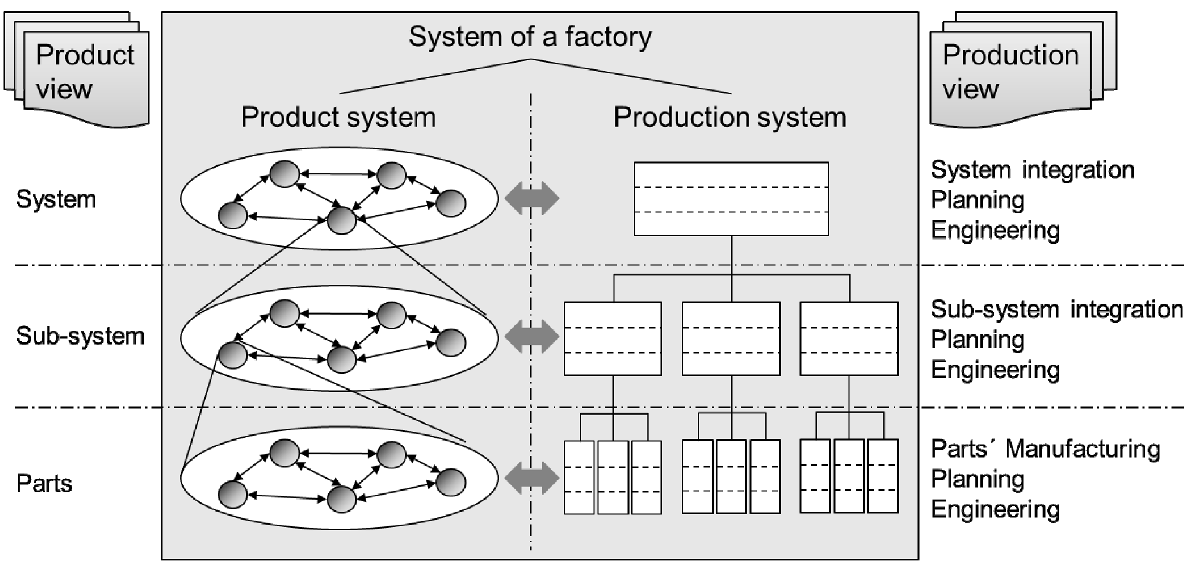


Fig. 2. System-technical structuring of a factory

Products are systems containing sub-systems and parts with elements which can be specified by attributes. On each level of the product system, the production system has its corresponding system level fulfilling the demands and requirements of the product. The overall system of the product is integrated in the system integration of the production. Therefore, capabilities are required in the system-integration itself but also in the pre-located systems of engineering and planning. On the structuring level of sub-systems, the sub-systems must be engineered, planned and integrated to be prepared for the highest level before customer delivery. On parts level of the product parts manufacturing processes are the corresponding capabilities to the demands by product parts. The steps of engineering, planning and manufacturing must be passed through on this hierarchical level. The interdependencies in the vertical levels of product and production as well as the relationships between the partial-system of the product and the partial-system of the production on the corresponding vertical level are of relevance regarding an optimization of the whole system of a factory embedded in a manufacturing and suppliers´ network.

Since the overall efficiency of the system factory depends on the efficiency of each system element and its interdependencies, a structure optimization of the factory is affordable if the overall efficiency of the system is in danger due to change. Then, an adaptation of the structure is essential and must be based on a model of the current factory structure. The measurement and criterion of structure optimization must follow the criterion of economic efficiency and can be measured by hours per vehicle in the sub-system of products and the sub-systems of production in automotive manufacturing.

## 3. FACTORY MODEL

Basis of a structure optimization is modelling existing structures and its interdependencies. Therefore, the factory model is described by the sub-models of product and production and integrated finally by matching the two sub-systems to a factory system according to the system-technical structuring proposed in chapter 2. The models are built up based on a detailed analysis conducted in an automotive manufacturing network, whose method is described in [5].The analysis is essential in order to understand and clarify the causalities of the existing systems [7] and to aggregate the models.

### 3.1. PRODUCT MODEL

Modelling the products regarding the context of structure planning of capacity and technology in a manufacturing network means to specify the qualitative and quantitative requirements in hours per vehicle on the structuring levels along the process chain illustrated in Fig. 3. The product can be structured top down from the highest structuring level of the product portfolio, following the levels of product series, systems, sub-systems, sub-systems to single parts and material. In context of factory structure planning the network-level downwards to the level of technological systems and sub-systems are relevant to be described by characteristics in the product model.

On the level of systems representative vehicles are modelled by their required capacity along the complete process chain comprising the design and engineering, planning, purchase, parts´ manufacturing, sub-system integration and system integration in the end. The system leader contains at least all characteristics of its sub-systems and is in direct relationship with the market. Basis for all product models is a standardized product structure according to the system levels shown on the left hand side of Fig. 3.

In addition to the variety of product systems in the product portfolio, the inner variety regarding the sub-systems of the products is of relevance in the model due to the effects on the required capacities coming from the configuration options of the customers. Therefore, in the model of products partial models of average, minimum and maximum equipped systems are described in the same manner of their systemic levels. In this way the whole product portfolio of the manufacturer is described in its system and sub-system variety and represents the overall requirements to be manufactured quantitatively and qualitatively.

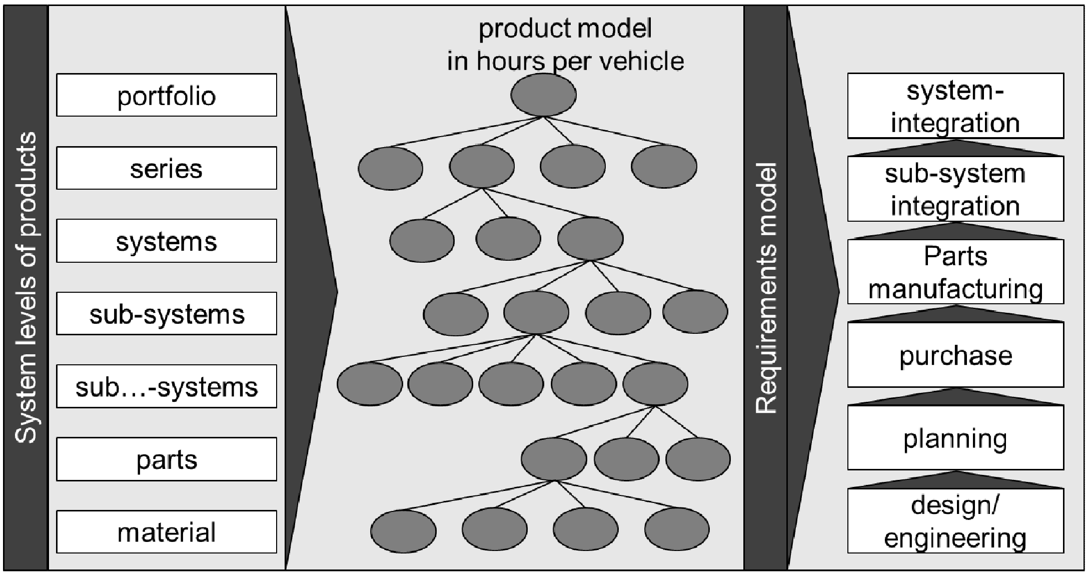


Fig. 3. Product model

3.2. PRODUCTION MODEL

The production model is structured in accordance to the structuring levels of the product structure model, based on the structuring proposed by Westkämper [11], Nyhuis [6] and Wiendahl [9]. The highest structuring level is the network, which can be interpreted from resource view as production sites linked by material, information and structural dependencies regarding capacity, location and technological restriction. Sites represent production units at different geographical locations and serve as nodes in the network of production and supply chain [8]. A site consists of technological segments illustrated in the capabilities model of a manufacturing site in Fig. 4. The levels of production can further be consequently broken down into systems, sub-systems and manufacturing processes in detail. Optimizations often focus on the operational factory level. Work in process regulations of work-systems [2], based on mathematical approaches or short-term personnel and production programme planning of assembly lines [1] are examples therefore. For strategic planning purposes on long-term horizon in contrast, especially the first three levels – the network, the manufacturing sites and the segments – must be modelled comprising the whole process chain of the networked manufacturing.

On the level of manufacturing sites the technological segments of parts, sub-system and system-integration represent the direct manufacturing functions. In addition, indirect functions like the technological segments of prototyping, tool making, logistics, maintenance, quality and testing are modelled as supporting functions in the model of production. The pre-located segments of design/engineering and planning are integrated in the characterization of the production model as well. Correlating to the product structure the technological segments are modelled by the attributes of capacity hours per vehicle and the location due to the local arrangement of the manufacturing sites.

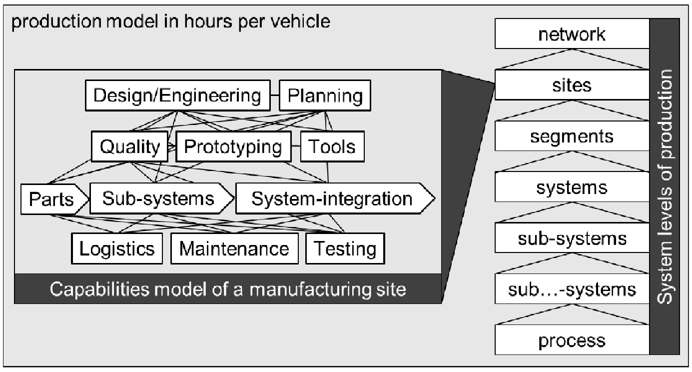


Fig. 4. Production model

The model of production structure represents the capabilities of each site of the network from the technological and capacitive point of view regarding direct and indirect segments along the complete process chain. In order to consider outsourced engineering and manufacturing tasks, a virtual site is described in addition to the manufacturing sites of the company. All parts which are bought from suppliers are modelled by the required capacity in a virtual factory, which is equal partner in the network of manufacturing sites.

### 3.3. FACTORY MODEL

The factory model is built by integrating the two partial models of product and production to an overall model representing the existing factory structure with all manufacturing tasks coming from the products, all functionalities installed in the several manufacturing sites as well as the arrangement and attribution of manufacturing tasks and product systems to manufacturing sites in the network. Whereas the product perspective on the factory represents the requirement model in capacity hours, the production view represents the capabilities model of existing capacitive and technological resources located in the different sites of the manufacturing network and its suppliers. The factory structure model in an abstract version for strategic structure planning and optimization is shown in Fig. 5. Each element in the matrix is described by capacity hours per vehicle and the partial-systems of product and production are correlated according to their system-technical levels for the whole network of products and manufacturing. In Fig. 5 the systemic levels for the product portfolio are broken down to systems´ level and the manufacturing network is broken down to the third level of segments attributed to manufacturing sites.

The model of the factory structure builds the basis for systematic planning purposes from the point of a current configuration of the manufacturing network. For reducing the reaction time to changes in product and production enhanced with the dynamic and permanent adaptation of technological and capacitive structures effects on the model can be simulated in advance and planned in a proactive way. Based on the model, the factory structure can be given dynamism by change drivers and the consequences for the manufacturing sites can be investigated. Intended is a synchronization of expected developments regarding product and production in a systematic planning process based on the factory structure model.

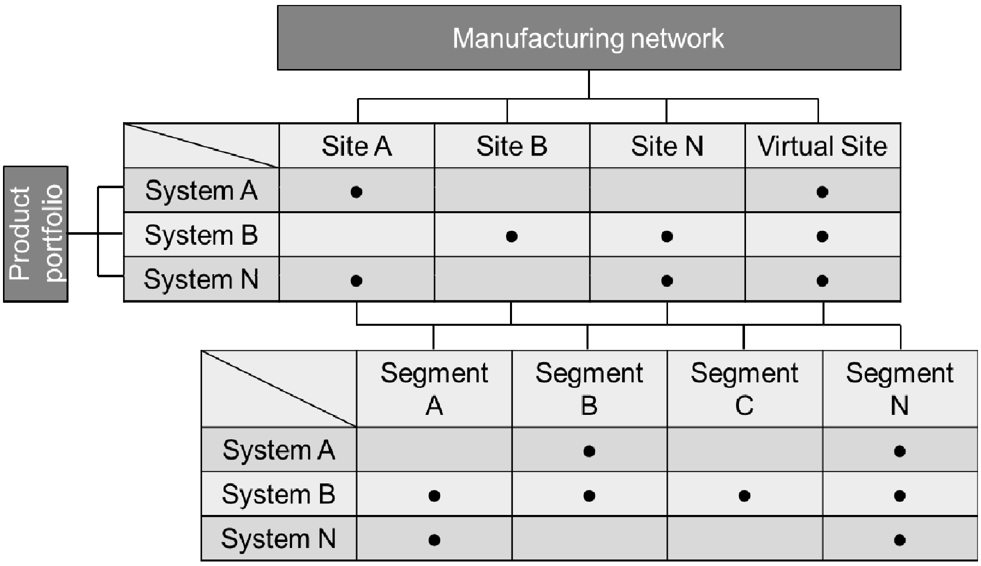


Fig. 5. Factory structure model

## 4. MODEL OF CHANGE DRIVERS

Change drivers force manufacturers to a permanent adaptation of their factory structures in order to keep the economic efficiency. The adaptation must be planned and implemented in the factories based on the preparation conducted with the help of a factory model. In context of strategic planning tasks changes with structural effects on the manufacturing network must be identified and specified as disturbing quantity on the factory structure model. The impacting factors on manufacturing can be classified in external and internal change drivers in accordance to the system border of the system “factory” illustrated in Fig. 6.

External drivers come from the market and influence the factory direct and indirect by influencing the sub-systems of product and production. Its frequency and unpredictability is challenging manufacturing enterprises [3]. The market driven changes can be modelled and summarized in a market model. In the market model, economic and financial cycles as well as social and political factors are reflected in the behaviour of the customer regarding demand and expectation. In consequence, the order situation of a manufacturer can be extremely dynamic. The volumes and customer configurations are main drivers represented in the market model. The volumes directly influence the production system by the manufacturing program, the trend of customization directly influence the products due to an enormous innovation pressure regarding the product systems.

Internal drivers comprise the change models of product and production. The sub-systems of products and production are change drivers on the one hand and enablers for change regarding the dynamic adaption of the factory structure system.

Customized and individualized products lead to an exploding number of product systems and sub-systems which must be engineered, planned and manufactured according to the described process chain. A high complexity in the products due to the system diversity and optional integrated sub-systems is the consequence. New sub-systems, e.g. the electrical drive of a vehicle have tremendous structural effects on the factories. The development and combination of material offer new possibilities in designing and dimensioning a product and production. A permanent upgrading of product systems driven by market and marketing of the enterprises shorten the life cycle of products and increase the frequency of innovation on each systemic level of the products enormously.

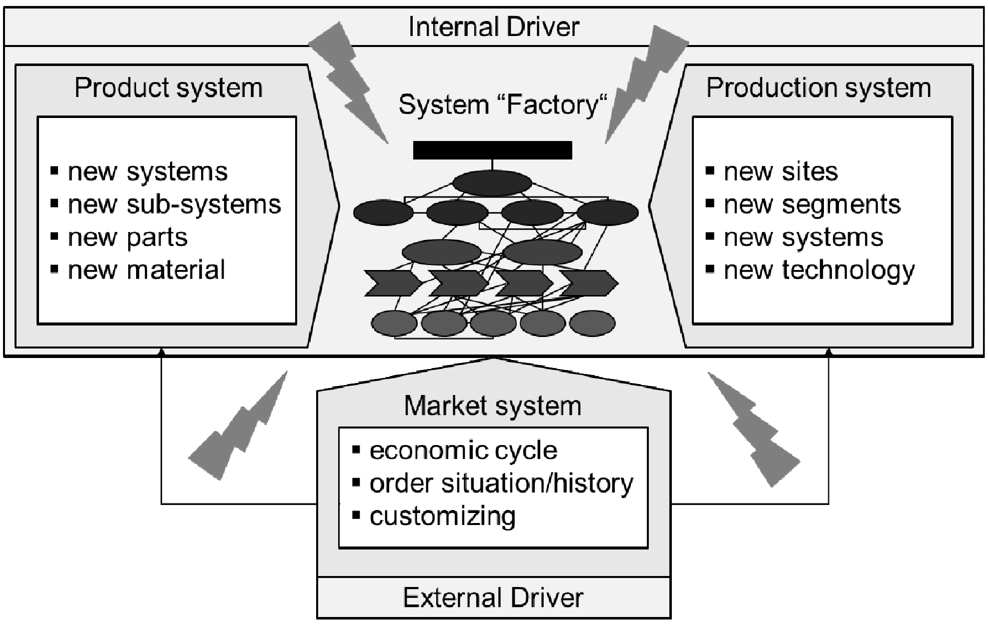


Fig. 6. Model of change drivers

The second internal driver is the production itself. According to the systemic levels new manufacturing sites offer expanded capacities and go along with a complication of production processes due to manufacturing at different sites and cooperation in networks [8]. Increasing outsourcing has the same effect and can be regarded as impact factor as well since a virtual site is integrated for investigation in the factory structure model. On the level of segments technological changes enhanced with investments in new technical concepts force manufacturing to dynamic adaptation. On segments and systems´ levels the measures of a continuous improvement regarding the organizational and technical processes is a change driver with effects on the capacitive and technological structure of a factory. Innovative manufacturing processes and production concepts influence the structure of production and enable the system factory to new technological dimensions.

Internal drivers coming from the product and production system have close internal dependencies and effects. Whereas quantitative changes in the product configuration and changes of the production volume directly influence the capacitive structure of the factory, conceptual changes in products and production can only be evaluated in a more complicated way. The attribution of systems to manufacturing sites is another change driver which must be regarded in strategic structure planning. The changes described in the change driver model require adaptive product and production structures regarding capacity and technology and must be regarded as impacting factors on the factory structure model.

## 5. SCENARIO MODEL

The model of factory structure consisting of the partial models of product and production structure build the basis for variations in context of possible scenarios. The change drivers described and modelled as market, product and production driven forces according to chapter 4 impact the model of the factory structure. In order to increase the changeability in the factory structures of product and production systems, the effects of changes on the system factory can be regarded within forecasts and scenarios as illustrated in Fig. 7.

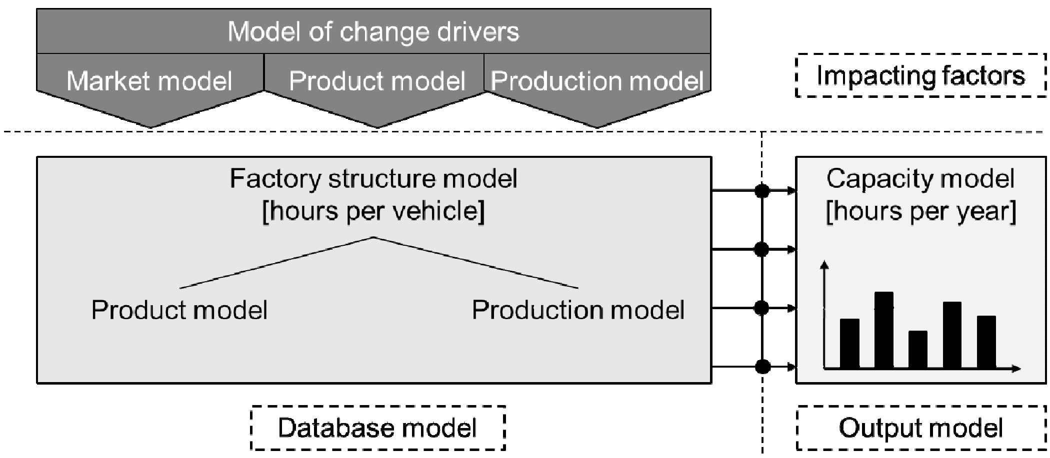


Fig. 7. Scenario model

The basis therefore is the described factory system and its sub-systems in their system-technical structure, which can be impacted and evaluated by the model of change drivers. Since the effects and necessity of adaptation are of structural importance the dependencies in the technological and capacitive structure can be described based on scenarios in the output model.

## 6. SUMMARY

For a permanent adaptation of the socio-technical system factory consisting of the sub-systems product and production a model of the existing structures is essential for strategic planning tasks. Especially due to the increased planning complexity, distributed technologies and capacities in a networked production with several manufacturing and suppliers´ sites models are important to understand the causalities and dependencies simplified by the essential information. Therefore, the relevant sub-systems of a factory with their sub-models of product and production are described according to a system-technical structuring. The actual configuration of the system factory embedded in the network of products, manufacturing sites and suppliers could be modelled and validated for the automotive industry. The model of the factory structure with its representative elements and attributes build the basis for further steps in systematic structure planning. The change drivers impacting the factory structure in the future could be classified and specified. Based on the model of change drivers an approach of a scenario model, linking the impacting factors with the factory structure model was given to investigate the driving forces on the capacitive and technological structure of the system factory.

## 7. FUTURE WORK

Future work will be done by variations of the holistic factory model of the networked manufacturing due to the impacting driving forces. Based on forecasts and possible scenarios in the automotive manufacturing network, dependencies will be described and measures for a structure optimization and adaptation for keeping the economic efficiency will be planned and prepared in a proactive way in context of systematic structure planning.

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