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CHANGE DRIVERS AND ADAPTATION OF AUTOMOTIVE MANUFACTURING

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ЗМІНА ВИКЛИКІВ І АДАПТАЦІЯ АВТОМОБІЛЬНОГО ВИРОБНИЦТВА

Зміни спонукують виробників до безперервної адаптації своїх підприємств. Заводським підрозділам, які в стані пристосуватися й організуватися відповідально викликам нестабільного зовнішнього середовища, важливо захищати конкурентоспроможність. Зміни викликів, обумовлені ринковою конкуренцією товарів і виробників, і їхній вплив на технологічні сегменти й продуктивні можливості заводу, становлять особливий інтерес для завдань довгострокового стратегічного планування. У цій статті представлений метод планування й оптимізації для систематичного структурного планування. Він передбачає синхронізацію удосконалень продукції й самого виробництва для одержання оптимальної економічної ефективності.
Ключові слова: виробництво, пристосовність, структура підприємства.

Изменения побуждают производителей к непрерывной адаптации своих предприятий. Заводским подразделениям, которые в состоянии приспособиться и организоваться соответственно вызовам нестабильной внешней среды, важно защищать конкурентоспособность. Изменения вызовов, обусловленные рыночной конкуренцией товаров и производителей, и их влияние на технологические сегменты и производительные возможности завода, представляют особый интерес для задач долгосрочного стратегического планирования. В этой статье представлен метод планирования и оптимизации для систематического структурного планирования. Он предусматривает синхронизацию усовершенствований продукции и самого производства для получения оптимальной экономической эффективности.
Ключевые слова: производство, приспособляемость, структура предприятия.

Change forces manufacturers to a permanent adaptation of their factories. Therefore, factory structures, which are able to be adapted and configured according to the challenges of the turbulent environment, are essential to preserve the competitive ability. Change drivers, coming from the markets, products and production, and their effects on the technological segments and capacities of a factory are of specific interest regarding long-term strategic planning tasks. In this paper, a planning and optimization method for systematic structure planning is presented. It is intended to synchronize the developments in product and production for operating at the optimum of economic efficiency.
Keywords: Manufacturing, Flexibility, Factory Structure.

1 INTRODUCTION

Systemic changes characterize the industrial environment, manufacturers have to deal with. In automotive manufacturing the complexity increased enormously in the last couple of years. This can be traced back to a widened product program, distributed manufacturing capacities in a production network and per-

manent changes regarding the technical and technological systems of the factories. For the upcoming years fundamental changes in the product and production systems are to be expected. Manufacturers are forced to adapt permanently to these changes in order to keep their economic efficiency. Changeability and flexibility aspects regarding factory structures will be key enablers for meeting the challenges coming from the global market [1] and for keeping the global competitiveness. Based on a definition of terms, a systematic planning method is suggested in this paper. It has the objective to increase the changeability potential within the capacities and resources of the factories on a long-term strategic basis.

2 FUNDAMENTALS OF FACTORY STRUCTURE PLANNING

2.1 Definition of terms

Factories are regarded as socio-technical systems consisting of elements, which operate through complex relationships and interactions. The elements of the system factory are characterized by attributes and interlinked by manifold relations and processes in material and information chain [2]. The network and dependencies of system elements and its relationships represent the structure of the system factory [3].

In context of factory structure planning under changeability aspects, the relevant elements to be described are the products and the production. The hierarchy of the products follows the system-technical levels starting from the product portfolio, the vehicle series, models/systems, components, sub-components, parts and material. The production is vertically structured from resource view by the manufacturing network, sites, segments, systems, cells, stations and processes [2, 3]. The product and production view on a factory are regarded in the method on network level down to the fourth level. In this paper, a ‘factory structure’ is defined by the products, resources, capacities, technologies, processes, in-/outsourced value added and the relations in an automotive manufacturing network. The term ‘structure’ is interchangeably used to the definition of ‘factory structure’.

2.2 Concept of the planning method

The planning and optimization method for systematic structure planning proposed in this paper follows the steps illustrated in Figure 1.

The first step of the method is a characterization of the existing factory structure based on a detailed analysis of the products and production. Relevant change drivers are identified and classified according to system-technical criteria. They are considered and synchronized in their time line of implementation by introducing a technology roadmap. The effects on the factories coming from the impact of change are specified in the next step. Finally, the results and relations of the first four steps are integrated in a factory variation tool. By the tool,

a variation of the factory structure is simulated and essential adaptations are forecasted. Hence, change processes are systemized in a strategic way.

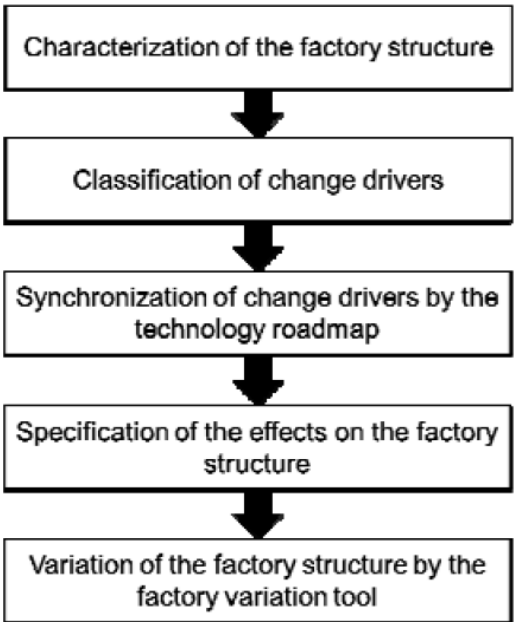

Figure 1 – Method for factory structure planning

3 CHARACTERIZATION OF THE FACTORY STRUCTURE

The basis of an optimization is describing the existing factory structure with its relations by an analysis in order to understand and clarify the causalities of the existing systems [4]. A detailed analysis of an automotive manufacturing network comprising the complete product portfolio is accomplished according to the method of structure analysis [5]. The products are analyzed by efforts in hours per vehicle on the levels of the product portfolio, vehicle series, models/systems, components and subcomponents. The efforts, required by the products, are measured along the complete process chain comprising the product design, engineering, planning and manufacturing. The production is described on the level of the network, the manufacturing sites and the segments of parts, components manufacturing and assembly. In addition to the direct manufacturing functionalities, the analysis is extended to the indirect segments of logistics, maintenance, quality and testing. All data were collected in hours per vehicle. Value added, which is produced at the suppliers sites, is attributed as a node to a virtual manufacturing site [5].

Matching the two views, namely the analysis models of product and production, the factory structure is characterized according to Figure 2 in its current configuration. It contains the description of the factory elements in hours per vehicle. The competences regarding the products, the engineering and the technological segments are attributed to manufacturing sites. Hence, the model of

factory structure represents all functionalities of the manufacturing sites, its localization on the layout and the correlating manufacturing requirements coming from the attributed products. The arrangement of this network is a strategic planning task [1]. Any adaptation and optimization is based on this characterization in the planning method.

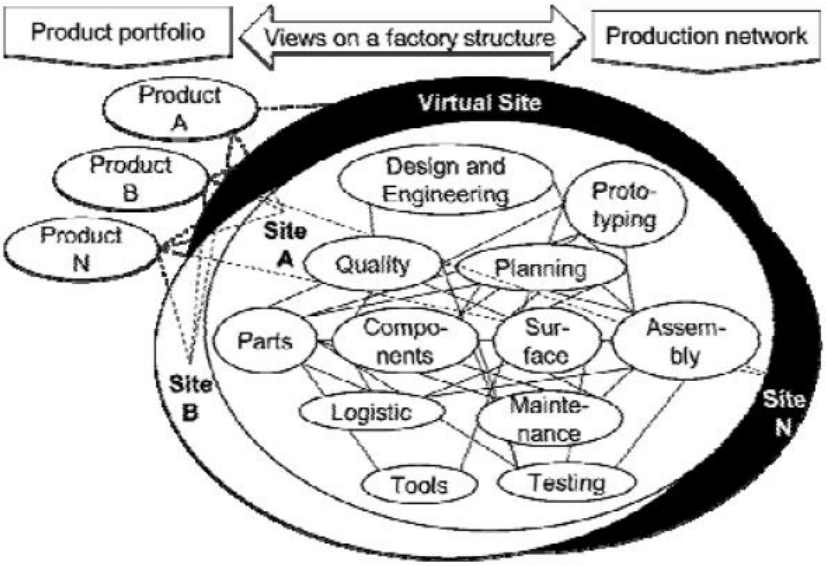

Figure 2 – Characterization of the factory structure

4 SYSTEM-ORIENTED CLASSIFICATION OF CHANGE DRIVERS

The environment of manufacturing can be described as turbulent and dynamic. Since the effects of this dynamism on factories are tremendous, the sources of change affecting the structure of a factory must be identified and classified in a systematic way. This helps to receive transparency regarding cause and effect within the complicated manufacturing processes in a networked production.

Related to the system border of a factory, change drivers are categorized into external and internal drivers. External drivers cannot be influenced by the manufacturer, whereas internal drivers are designed by the manufacturer itself driven by the influences of the environment. The main drivers of change impacting a manufacturing network are illustrated in Figure 3. They are classified into market, product and production driven impacts. Each main driver of change has sub-drivers, which are attributed to the levels of the products and production. The systemic level of the impacting drivers gives hints about the degree and profoundness of change. It is an indication for the necessity of a factory structure adaptation.

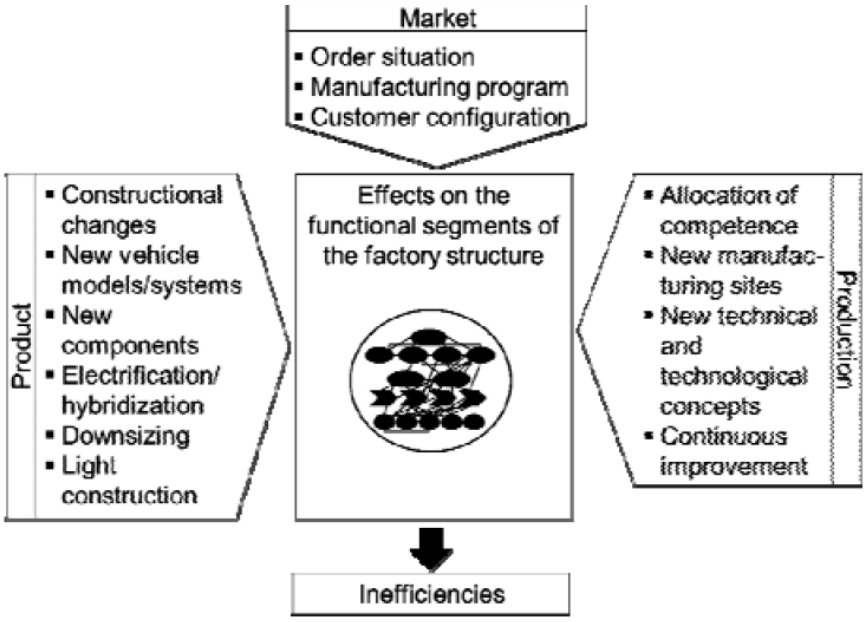

Figure 3 – Classification of change drivers

4.1 Market driven changes

Market driven changes come from the environment outside the system factory and can hardly be forecasted. The unpredictability of the market is one of the main challenges facing manufacturing enterprises at present [6]. Except by marketing strategies of the enterprises the influence on these factors is limited. Therefore, it has highest priority in factory structure planning to adapt permanently to the changes coming from outside the system. Volume related parameters have strong effects on the capacities, e.g. the requirements in hours per year regarding personal and technological resources of the manufacturing network.

The volatility [1] of the market is reflected in the order situation coming from the customer. It impacts the first level of a factory - the whole network of product and production. On the system level of specific vehicle models/systems, the manufacturing program represents the requirements due to the outer vehicle variety with respect to volume and product mix. On components level of the products, the customer configuration leads to an inner variety of the vehicles due to the choice of additional features and the motor gear combinations, for instance. This inner variety has tremendous effects on the capacity requirements of the assembly.

4.2 Product driven changes

Products are permanently under change [1]. The annual frequency of constructional changes is enormous - in the design and engineering phase before launching and during the series production in automotive manufacturing. New vehicle models and systems have the highest degree of change required along the complete product engineering and manufacturing process. Due to the permanent enlargement of the product program, ramp-ups will be the daily situation

manufacturers are faced. On components level the developments of hybrid and electrified systems will lead to changes within the product and therefore within the production. The trend of downsized motor and gear combinations will lead to a shift of the volumes to be produced. On materials level light construction using new materials and material combinations has effects on the products and on the required manufacturing technologies in the production.

4.3 Production driven changes

On the network level of the manufacturer, the decision about the allocation of products and technological competences to the several manufacturing sites is of fundamental strategic importance. Therefore, it is an essential driver on the factory structure in a changeability context. New manufacturing sites offer further capacities, which must be integrated in the existing network. New technical and technological concepts are aligned with capital intensive investments. They modify the capacities and technologies of the production segments in a manufacturing site. A continuous improvement of the production resources, processes and workflows increase the efficiency and change the required capacities in manufacturing. The benefit of these improvements can be seen by analyzing learning and experience curves of the technological segments. Therefore, the effects of the permanent improvements are modelled by learning curves and are considered in the method for strategic factory structure planning.

4.4 Necessity of adaptation

In consequence of the described changes, there are inefficiencies in the factory structure to be observed. The efficiency of the system depends on the efficiency of each system element of the factory and its relations. If the overall efficiency is in danger, an adaptation of the factory is affordable in the strategic context of this paper. Therefore, the measurement and criterion of factory structure optimization must follow the criterion of economic efficiency.

5 SYNCHRONIZATION OF CHANGE DRIVERS BY THE TECHNOLOGY ROADMAP

Based on the classification and description of expected changes in the future manufacturing environment, it is important to consider the time schedule, when changes are to be expected in the factories. Therefore, a technology roadmap is developed to synchronize the product program, new product technologies and new production technologies [7]. By the technology roadmap, capacities, technologies, resources and investments are planned in a systematic way. Based on this approach, a technology roadmap is suggested and built up according to Figure 4. Correlating to the classification of change drivers, the technology roadmap contains the three main sections of market, product and production in-

duced changes. The sub-structure of these three main drivers corresponds to the vertical system levels of change described in chapter 4. In context of strategic structure planning the proposed level of detail regarding the products and production seems to be adequate. Optimizations on a more detailed level of the factory structure are not treated in this paper.

The planning horizon of a long-term strategic planning with the focus on factory structure optimization and adaptation comprises ten years in this methodology. This time span is practically manageable in the automotive industry regarding common planning processes and the correlated uncertainty. Therefore, the time horizon, regarded and implemented in the suggested technology roadmap, comprises the next ten years of expected market, product and production developments in automotive manufacturing.

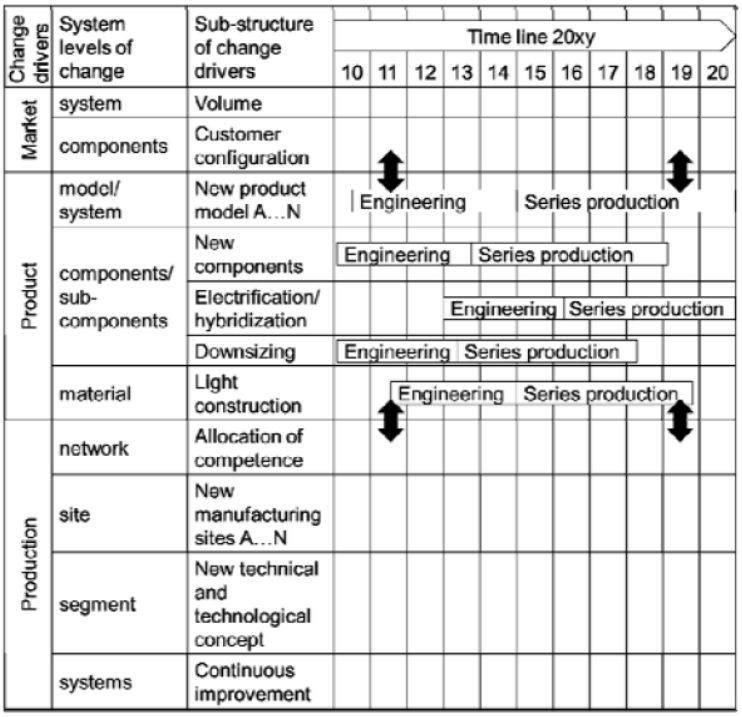

Figure 4 – Synchronization of change drivers by the technology roadmap.

Systemic changes with effects on the functional segments of the factory structure, which are planned for the defined time span of ten years, are specified in the technology roadmap. Two points in time are marked in the technology roadmap: first, the implementation readiness and start of series production; second, the time span required for design, engineering and planning. These prelocated functions along the system development process, which prepare and support the maturity for ramp-ups, are denoted as engineering phase in the technology roadmap according to the convenient schedules.

The order behavior of the customer is reflected in the order situation of the manufacturer. A variation of the manufacturing program affects the volumes per years to be produced by the manufacturer. The forecasted volume history per year based on a long-term sales and operation planning on the level of specific vehicle models is integrated in the technology roadmap by quantity. In this history, the life cycles of vehicle systems are noticed. On components´ level the customer configurations of ordered models regarding trim-lines, engine and additional features are considered in the technology roadmap. The distribution of maximum, basic and minimum configurations is derived by the history of built vehicles in the past and an adequate market analysis. Both sub-drivers, the volume and the configuration, are quantitative factors and have a direct effect on the personal and technical capacities of the manufacturing and suppliers´ network.

Conceptual changes are outlined in the sections of product and production driven changes in accordance to the levels of product and production.

Constructional changes of the products are noticed on all system levels of a vehicle: new models must be integrated in the product program and components are permanently changed and implemented in the systems. New materials on parts and components level change the vehicle systems and require adequate technologies.

All of these developments are in strong correlation with the developments of the production. The competence allocation of product and technological segments are of strategic importance. Changes in the arrangement on network level of product and production are outlined in the technology roadmap. On the second system level, new manufacturing sites offering additional competences and capacities must be regarded in a networked production. New technical concepts and technologies offer new capabilities to fulfil the manufacturing requirements coming from the constructional changes of the products. They are associated with investments in the production segments. Continuous improvements of the production systems increase the performance and quality of manufacturing. It is modelled by learning curves and is taken into consideration for the strategic planning method. The interdependencies between market driven changes, developments in the products and consequences for the production become obvious.

The technology roadmap as described and suggested in Figure 4 is a strategic planning tool, where the development lines of the three main change drivers market, product and production are illustrated according to their systemic levels. The correlations and dependencies are visualized and concentrations of changes are noticed with respect to the year of implementation. Based on this tool measures are derived for meeting the implementation schedules in advance and synergetic effects are obtained by a holistic perspective. A consequent migration and transfer regarding the dependencies outlined between the driver lines of market, product and production helps to synchronize the developments in product and production. In consequence, a dynamic and permanent adaptation of

the technologies, capacities and resources is possible due to a systematization of the change processes.

6 EFFECTS ON THE FACTORY STRUCTURE

The technology roadmap contains all developments described in their characteristics with respect to the time schedule of implementation. The next step of the method is now to link these changes with the factory structure characterized by detailed analysis according to chapter 3. The capacitive and technological effects of the change drivers on the functional segments of the factory structure shown in Figure 2 are of specific relevance in context of a structure optimization.

Therefore, an effect matrix is suggested in order to support this step of the methodology in factory structure planning shown in Figure 5.

Change drivers	Vertical system levels of change	Sub-structure of change drivers	System levels along process chain: Engineering: Design/Engineering	Tool Making	Prototyping	Planning	Series production: Purchase	Parts	Components	Surface treating	Assembly	Indirect function: Testing	Quality	Logistics	Maintenance
Market	system	Volume					●	○	●	●	●	●	○	●	○
	components	Customer configuration					○		○		●	○	●	●	
Product	model/ system	New product model A…N	●	●	●	●	●	●	●	●	●	●	●	●	●
	components/ sub-components	New components	●	●	●	●	●	●	●	●	●	●	●	●	○
		Electrification/ hybridization	●	●	●	●	●	●	●		●	●	●	●	
		Downsizing	●		●	●	●				○				
	material	Light construction	●	●	●	●	●	●	●	○			●		
Production	network	Allocation of competence	●	●	●	●	●	●	●	●	●	●	●	●	●
	site	New manufacturing sites A…N	●	●	●	●	●	●	●	●	●	●	●	●	●
	segment	New technical and technological concept						●	●	●	●	●	●	●	●
	systems	Continuous improvement						●	●	●	●				

● strong effect
○ weak effect

Figure 5 – Effects on the functional segments of the factory structure

The input drivers of change are described in their vertical levels on one dimension of the matrix. In the second dimension the functional segments of the factories along the process chain of system engineering and manufacturing are outlined. For each driver line of change the effects on the specific functional elements in the factory structure are described in a qualitative way. In addition, assumptions for the next step of the planning method are defined. The effects of the change drivers on the capacities of the factory are shown. This comprises the engineering phase, the direct functions of the series production and the indirect functionalities supporting the value adding manufacturing segments. The effects of the main drivers of change are described qualitatively in the matrix shown in Figure 5 by a classification in strong effect, weak effect and no effect on the capacities.

Market driven changes mainly influence the series production. The variation of the volume affects all functions starting from the parts manufacturing, components assembly, surface treating to the final assembly of the vehicle model. The variation of the customer configuration primarily affects the assembly. Hence, there are only capacitive effects on the final process before customer delivery. This is affirmed and verified based on an analysis conducted in an automotive manufacturing network.

Constructional changes of the products usually affect the complete process chain on network level of product and production with specific characteristics in the several functional segments. For a detailed estimation of the effects, the change drivers must be clarified in a more detailed way. For this specification, further fundamental studies regarding the dependencies in capacity and technology are essential to give a verified statement.

Changes in the production occur on all system levels. A main purpose regarding strategic structure planning is the allocation of competences to specific manufacturing sites in the networked production. The competence allocation compass the attribution of products to one or more manufacturing sites and the attribution of technological segments to specific manufacturing sites. The configuration coming from this attribution defines the role of a manufacturing site within the network. It decides about the way of processes and about the local occurrence of effects regarding changes driven by the markets, products and production. Due to this importance, the arrangement of the network has to be specifically in focus of strategic structure optimization. Additionally, enormous effects are expected regarding the integration of new manufacturing sites in the production network. The effects concern the complete process chain. Investments in technical concepts and technologies only affect specific technological segments and must be investigated in a more detailed analysis to estimate and

evaluate the effects on the factory structure. Effects coming from a continuous improvement and rationalization are observed and evaluated in all direct segments of the series production. By the effect matrix, the change drivers are linked with the characteristic of the factory structure. Hence, the dynamism of the turbulent manufacturing environment is described in quality.

7 VARIATION OF THE FACTORY STRUCTURE

To transfer the qualitative valuation and the assumptions made in the effect matrix to a quantified valuation, a variation tool is developed and implemented in the method for structure planning. The variation tool basically comprises a tableau for input data with the relevant change drivers, a database model of the factory structure and an output field containing the capacity distribution from the perspective of the products and the perspective of production. The link between input and output data is carried out by a calculation algorithm, where the assumptions made in the effect matrix are described. The output capacities are visualized on a user interface of the software environment. The main principle of the factory variation tool is shown in Figure 6.

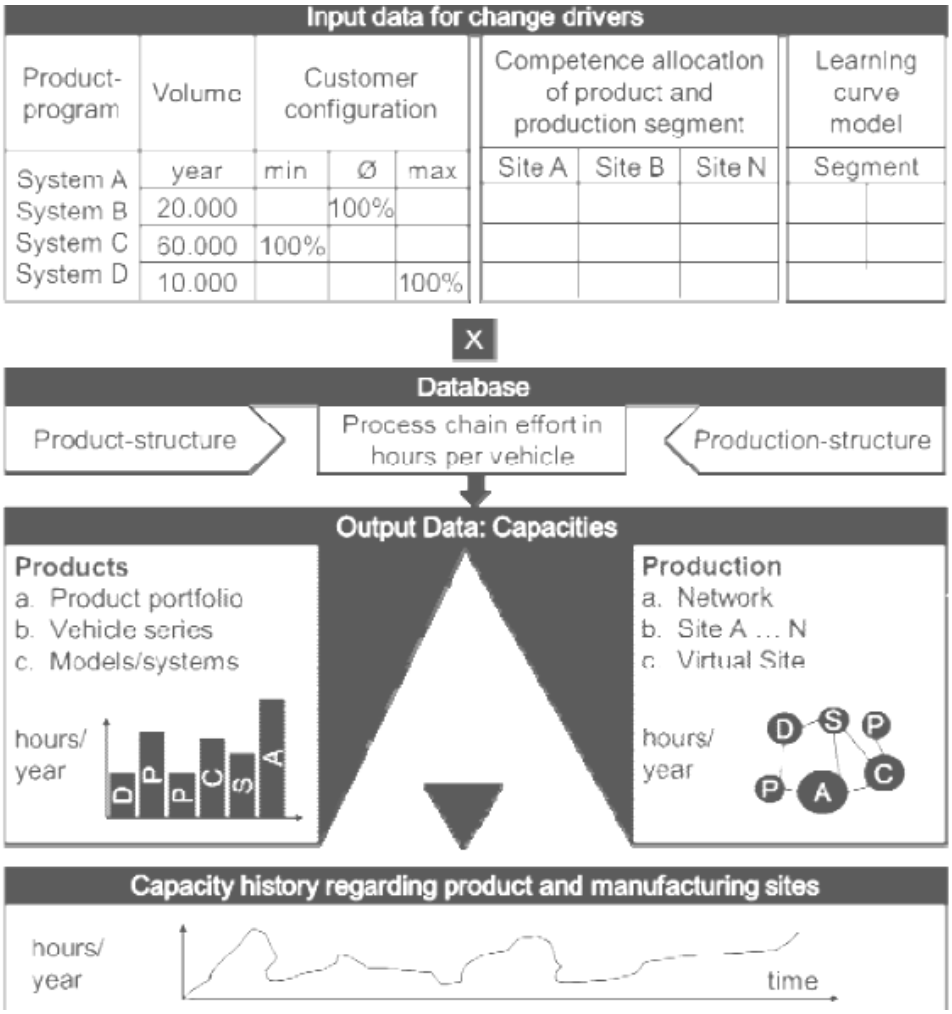

Figure 6 – Factory variation tool

7.1 Database

The database of the variation tool is represented by the data model characterizing the factory structure described in chapter 3. The data hierarchy of the tool is derived by the levels of the factory model, which comprises the two submodels of the products and production. The factory structure model in hours per vehicle builds the basis for any variation coming from the change drivers. The database of the products contains average quantities of reference vehicle models in their system levels analyzed over a representative time range. The capacity hours per vehicle coming from the different vehicle models represent the outer variety to be produced in the manufacturing network. In addition to the fluctuations on systems´ level due to the models, the product model comprises quantities of vehicles with maximum and minimum equipment based on the customers´ configuration. This represents the so called inner variety of the vehicle model/system in the database. On the one hand, the database from the product perspective gives values and information about the direct manufacturing functions, namely the operation time in series production. On the other hand, it contains efforts which are required in the pre-located functional segments before series production, namely the design and engineering, planning, prototyping and tool making. These efforts depend on the overall volume to be manufactured during the life cycle of the vehicle models/systems. They are transferred to hours per vehicle by the division of the overall life cycle volume.

The production model completes the database due to data from production view. It contains the additional required time of the indirect manufacturing functions, namely logistics, quality, testing, maintenance and support. In addition, the allocation of capacities to the manufacturing sites is considered from this point of view and integrated in the database.

The integration of the two databases of product and production to one basic data, containing the overall process chain effort in hours per vehicle, results from a calculation mode implemented in the functionalities of the tool. This builds the basis for any variation conducted in the algorithm.

7.2 Input data for variation

In the input data tableau market, product and production driven changes are integrated. They are relevant to be investigated and evaluated in structure planning with respect to the performance and economic efficiency of the manufacturing network in a quantitative way. They are varied in possible scenarios. The implemented drivers are studied separately or in their combinations of defined scenarios considering the effects on the capacities of the networked production. The

assumptions made in the effect matrix are assigned to the several driver lines and integrated by terms and conditions in the calculation mode. Fixed and variable parameters are defined when combining input data and database.

One of the main change drivers comes from the order situation of the markets and lead to a variability of the manufacturing program in quantity. Changing the volume on the level of vehicle systems, effects on the capacities at the different manufacturing sites are simulated and analyzed for a various number of scenarios. The direct and the indirect functional segments in the series production including the purchase, which is modelled by a virtual manufacturing site of the suppliers, extremely depend on the volume. Therefore, these functional segments are set variable following this driver line. In contrast, the prelocated segments engineering, prototyping, tool making and planning are set as fixed quantity in the calculation mode due to the volume independency.

In addition to the fluctuations of the required capacity hours per vehicle coming from the various models, the inner variability of a vehicle due to the ordered customer configuration is a further important driver of the market. Its effect on the required capacities is integrated in the input data as well. Based on the overall volume the percentage rate of the three trim-lines minimum, average and maximum is varied and the effects are calculated. In the database the quantities coming from the design and engineering efforts as well as the required planning hours remain constant when only varying the vehicle configuration in the data input. In the effect matrix, it is also assumed that the fluctuations regarding the required operating hours only occur in the assembly of the vehicle.

Therefore, any other functional segments are set as fixed parameters for this driver line. Regarding the conceptual changes coming from the products, new systems can be integrated in the product program by adding hours per vehicle along the whole process chain to the database of the factory structure model. Any constructional change and innovation of the products must be evaluated in a further study. Their effects can be integrated by a manual modification of the current database.

The allocation of competence to the manufacturing sites in the regarded network is another driver sourced in the production. On a percentage basis of the manufacturing program products, manufacturing tasks on segment level and the pre-located functions are assigned to specific manufacturing sites. Effects are shown by the distribution of required capacities in the manufacturing sites.

In addition, the manufacturing network can be extended by adding new manufacturing sites to the model. In order to regard measures conducted in con-

text of continuous improvements and rationalizations, industrial learning effects on segments level are integrated in the driver lines of production by a mathematical description. In accordance to the assumptions made in the effect matrix, the learning rates are only applied to the direct manufacturing functions in series production, since effects on other functional segments were not analyzed and verified. Industrial learning effects are regarded in the simulation, optionally.

The input data of the tool comprises the main change drivers, whose effects are calculated by quantity. Basically, it is assumed that the technologies in products and production remain constant during the calculation mode. The architecture of the tool is designed in an open way with the opportunity to integrate conceptual change drivers with respect to products and production manually in the process chain effort of the variation tool. Therefore, further studies will be necessary.

7.3 Output data

The data output are the capacities of the manufacturing network in hours per year obtained by a calculation mode integrated in the tool. The effects of market, product and production driven changes on the capacities of the factory are simulated, analyzed and visualized.

The visualization is carried out for the product perspective on the levels of the product portfolio, vehicle series and specific vehicle systems. From the perspective of the production, the results are reported on the network, manufacturing site and segment level. According to the time span of ten years regarded for structure planning in this method, the year based capacity history is prepared for a summarized reporting. On basis of the chosen parameters and scenarios, the results are reported for the product and production view on the manufacturing network. Comparing the results of the scenarios with the restrictions of the current factory configuration, it is derived, when and where an adaptation of the networked production is essential.

8 SUMMARY

In this paper, a method for systematic structure planning and optimization was presented. The method was developed to systemize change processes in automotive manufacturing. Based on a detailed characterization of the existing factory structure on network level, change drivers were identified and classified according to systemtechnical criteria. Furthermore, the necessity for an adaptation of factory structures according to the criterion of economic efficiency was outlined. In order to consider the time schedule of expected market, product and

production driven changes in the automotive industry, a technology roadmap was established for the time span of ten years.

The link between the change drivers and the characterization model of the factory structure was made by the development of an effect matrix, where the impacts of changes on the functional segments of the factory were described in quality. Based on these steps, a variation tool for giving the factory structure dynamism by change drivers was designed and implemented in an adequate software environment. In the tool, market, product and production driven changes were integrated for describing and evaluating the effects of driving forces on the capacities of the factory. The factory variation tool builds the framework for the quantitative variations of the factory model due to change drivers in systematic structure planning.

9 FUTURE WORK

In the next steps scenarios of possible future changes will be built on basis of the conditions in automotive manufacturing. They will be implemented and calculated in the factory variation tool for describing the effects on the capacities, technologies and resources. Future work will be done by expanding the considerations of change drivers. The effects coming from the variation of technical and technological concepts in products and production, the description of the dependencies and the impacts on the factory structure will be in focus of further research in structure planning and optimization.

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