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Strategic Planning of Global Changeable Production Networks

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Abstract

By focusing on core competencies and the utilization of international location advantages such as access to low-wage labor and local sales markets, global production networks are becoming increasingly complex. The key for control is a changeable production network that can change within preconceived solution spaces for the dynamic challenges. The presented article describes an approach for the strategic planning of global changeable production networks, based on future scenarios and a multi-objective optimization to identify the most favorable network configuration. The final result is a production network, which can be changed into network alternatives to control dynamics and positively utilize globalization.

Keywords: production networks; changeability; multi-objective optimization

1. Introduction

Producing companies are exposed to today's turbulent times which are characterized by great uncertainty. Dynamics which results from the change of influencing factors on global acting companies are permanently increasing. For instance, companies are faced with, amongst others, steadily increasing customer requirements, unpredictable market developments, the internationalization of markets, customized product demand and growing competition. In this context of the continuously growing complexity in the business environment it will be more difficult to forecast future developments [1] [2] [3]. Not only multinational large corporations but also small and medium-sized businesses (SMBs) have taken advantage of these different factors and represent themselves in the form of global production networks. Quite a few focus on an internationalization of production for the use of local advantages of location – single steps of the value-added process are carried out at globally distributed locations. In addition, the proportion of purchased parts is increased significantly by concentrating on core competencies. Complex mechanisms of action result within these internal and external production networks as a consequence of more and more networking. Furthermore, the partly short-term changes of internal and external influencing factors require adaptability of the global production network to avoid negative effects of the continuous change. Thus, producing companies need an approach for the sustainable use of global advantages of location which are provided for in the course of globalization. Existing approaches are delivering courses for the strategic planning of global production networks [4] [5]. However, a method to determine the need for change and to evaluate the cost effectiveness of changeable network structures has not existed up to now. Without the clear identification of the benefits of changeable structures a global acting company will not decide on the preparation for future needs for change. Therefore, in the framework concept "Research for Tomorrow's Production" of the Federal Ministry of Education and Research (BMBF) the approach presented in this contribution was developed in the collaborative research project "Planning and Optimization of Changeable Global Production Networks" (POWer.net) [6].

The aim of the approach is the description of a systematic course of action by means of which companies are able to carry out the strategic planning of

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a changeable production network under consideration of undetermined prognoses. The general approach is reflected by Figure 1.

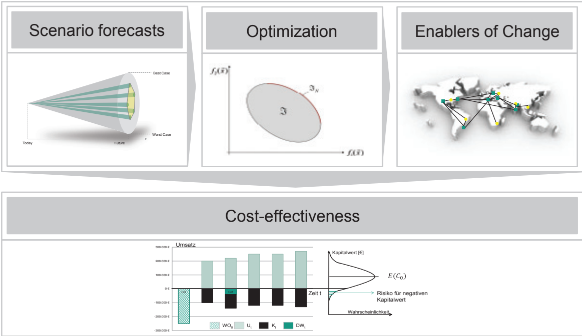

Fig. 1. General approach

The scenarios provide a basis for the determination of the company-specific need for change (paragraph 3). For every scenario the optimal structure of the production network will be determined by a multi-criteria optimization which is explained in paragraph 4. Advantageous configurations of the production network at discrete points of time within the planning horizon of a scenario are the result of this multi-criteria optimization. Paragraph 5 presents the course of action for the identification of the enablers of change for the respective scenarios. Subsequently, in paragraph 6 the cost-effectiveness for enablers of change is assessed. Concluding, the results achieved are summarized and an outlook on further research activities which are advanced within the collaborative research project POWer.net is presented.

2. Changeability

Due to the challenges described at the beginning it will become more and more important for companies to be able to adapt themselves to the given surrounding and environmental conditions. Therefore, a collective understanding of the term changeability is a fundamental requirement. Wiendahl divides changeability into five classes on the basis of the levels of output and market performance, whereby superordinate classes comprise the subordinate ones. The lowest production level is a single machine or workstation. If another workpiece is to be machined it is necessary to change over. The lowest level of changeability is hence the ability to change over. The next highest level contains manufacturing respectively assembly cells. If the group is to be expanded or reduced by one means of production, Wiendahl talks about reconfigurability. The combination of several cells leads to the formation of production segments in which sub products are manufactured. Flexibility describes the ability of these areas to adapt production to other variants. Beyond that, there exist other various definitions of the term flexibility which considered further in this contribution [8] [9]. The term transformability describes now the ability to change the whole factory in its structure. Moreover, when looking at the changeability of the whole production network and of the complete product portfolio one gets to the highest level, agility. By means of agility, changes which can have impacts on the location structure and the whole product portfolio are summarized [10] [7].

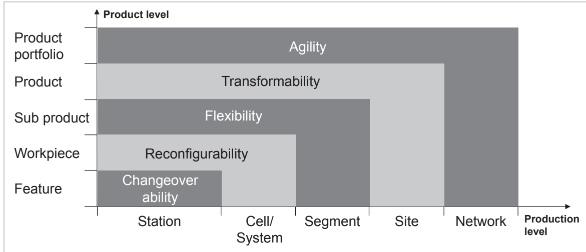

Fig. 2. Classes of Factory Changeability by Wiendahl [10]

This paper presents an approach for the strategic planning of a changeable production network. Consequently, production network is put at the center of consideration. In contrast to the definition of Wiendahl only one product group and not the whole product portfolio will be considered in the following approach. Thus, change does not only refer to factory objects but also to the complete structural characteristics of the production network.

It is still necessary to ask why flexibility is used as a form of adaptability. In the case of small changes the flexibility which exists in the production system is sufficient to reestablish the state of equilibrium. If bigger changes occur the so-called corridor of flexibility is exceeded to establish the state of equilibrium. The flexibility made available is not able to compensate changes. The system has to change, as illustrated in Figure 3 [11].

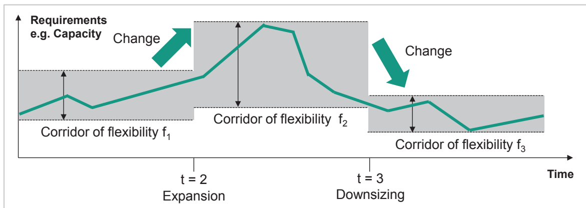

Fig. 3. Flexibility vs. Changeability by Nyhuis [1]

If flexibility of a production system is so high that all changes can be compensated without structural adjustments the feature of changeability is not needed any more. From an economic point of view this involves huge costs and is for this reason unprofitable [1]. Thus, it is the objective of companies to identify possible solutions for needs for change which seem to be reasonable from an economic point of view. It is at exactly this point where changeability starts at. First approaches for the evaluation of changeability and its economic efficiency are provided by [7], [12], [13] and [14].

In connection with the term changeability also the term driver of change is used. In this approach drivers of change are used in connection with global production networks. Similar to the definition of Wiendahl they are defined as external and internal influencing factors the dynamics and complexity of which can initiate processes of change in the production network in order to restore the optimal allocation of all used resources. For this reason, drivers of change are in a simplified way understood as triggers which effect a change of network structure.

3. Scenarios

In paragraph 1 diverse influencing factors were already described to which companies are exposed in today's turbulent time. Within this context of a growing complexity and dynamic of the business environment the future is not subjected any more to a great uncertainty but it is rather undetermined. Given the situation, the use of the scenario planning method would appear to be promising. This technique serves as an instrument for the generation of possible images of the future, so-called scenarios, which are based on a coherent combination of possible developments of single influencing factors [15].

First, the development potential of the field of observation, the scenario field, is described by means of drivers of change. These drivers of change are collected company specific by a team of experts. Further activities reduce the amount of drivers of change. As a result, the key drivers for the projection of the future are available. At this point, scenario prognostic adds with the formulation of assumptions of the future, which describe several possibilities of development for one key driver within a defined planning horizon. The description of future developments of key drivers is a basis for the following step. Only these images of the future are generated which consider combinations of possibilities of development being consistent within themselves and thus coherent (see figure 4). This selection is made with the help of a consistency assessment for each pair of projection [15]. A multitude of consistent projection bundles have to be clustered in order to reduce the number of representative scenarios. Thus, the final scenarios are determined, generally between 2 and 5, which describe the images of the future in a qualitative manner. As to the developed optimization model presented in paragraph 4, the future scenarios have to be made useable. For this, input parameters are defined for the optimization model to take account of the key drivers. Stochastic events like changes of local content requirements are depicted e.g., as auxiliary conditions (see paragraph 4).

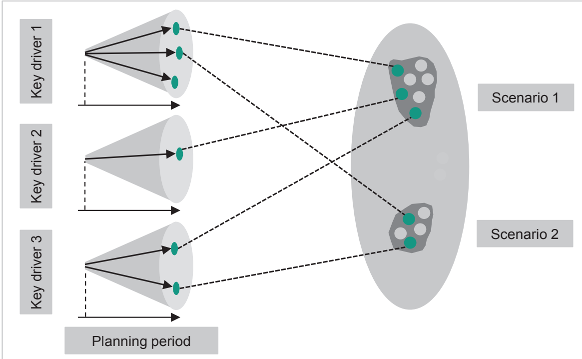

Fig. 4. Scenario forecasts for global production networks [15]

The trend and volatility of input parameters which are subject to dynamic changes like e.g., material price or labor costs developments are assigned and modeled as stochastic process by a probability function. By means of a Monte Carlo method random numbers are simulated for the current value of the parameter respectively for the consistently developing parameter combinations at discrete points of time in the course of planning. These random numbers represent the development of the consistent influencing factors in a defined scenario. Thus, all input parameters are available to determine within the optimization at discrete points of time in the planning horizon the most advantageous production network.

4. Optimization

Multi-criteria discrete and combinatorial optimization problems include in general network problems in operations research. They are regarded as multi-criteria variant of the mixed-integer optimization with a finite solution space, the so-called combinatorial optimization. In the following paragraph a stochastic and mixed-integer MODM approach ("multi-objective decision making") for the identification of optimized network configurations of a global production network is introduced. The multi-criteria optimization problem (MOP) is resolved after the transformation into a mono-criteria substitute function using hybrid scalar methods [16]. The developed model is implemented using ILOG OPTIMIZATION STUDIO® by IBM. In this context, solver CPLEX is used to solve mathematical optimization problems. This is where a "branch and bound" method takes effect to provide an integer optimal solution.

The formulated MOP will be solved within the established scenarios at the particular discrete times of planning (see paragraph 3). At each time of planning random numbers are generated on the basis of the modeled stochastic input parameters and the production network is optimized. A total optimal company-specific configuration of the production network at the different times of planning is the result of a solution space which is defined implicitly via auxiliary conditions. This configuration relies, under consideration of the strategic focus of the decision maker, on quantitative and qualitative target variables. On the basis of the business situation and strategy individual target systems are generated by criteria weighting, reference points and aspiration levels. With the help of these target systems the assessment of different configurations is carried out within the solution space. The model set-up is detailed below.

The following paragraph serves for the description of a detailed modeling of a production network in terms of mixed-integer optimization. Using binary, integer and not integer parameters and decision variables, the value added process as well as the network elements of the focal company, especially locations but also suppliers and customers are modeled formally. At first, a value-added process is formulated for each of the considered products. The value-added steps represent the production process which is proceeded. Different materials, intermediate products or components can be integrated with the steps as input. They are provided by the pre-stages of value added or suppliers and correspondingly modeled. Besides the value added process the structure of the network is modeled. It comprises all nodes like external partners, especially suppliers and customers as well as internal locations. Each supplier has a specific capacity for the allocation of each good and offers it at a fixed price. If a material is not in the supplier's portfolio he receives a capacity of zero for this one. For the time being, the focused company is not obliged to buy material from a particular supplier. It just has to meet its needs via the modeled suppliers arbitrarily. In an analog way the possibility of outsourcing is established. Suppliers offer intermediate products at fixed prices under consideration of their specific capacity. A further external partner is described by the customers. Each customer looks for a quantity of a product at a price. This demand is to satisfy within the model. Thus, for each customer a demand and price vector for the description of the real demand are generated. If for one product a big number of customers exists it is generally useful to unite the regional demand of a market to one customer group to reduce complexity. The nodes of the production network of the focal company, concretely the internal locations, are defined with the help their capacities and the technologies which are localized there. Both already active and potential locations which are still not active are addressed. Furthermore, various technologies are available in the context of the optimization model to demonstrate different capacities, scale effects and cost differences in production. The decision for the localization of a technology at a location is represented by another binary decision variable. To come up to reality in which not every technology is available at each location – especially on the basis of employees' qualifications certain combinations are excluded – the suitability of technologies for the accomplishment of value-added steps is linked with the defined value-added process and the locations. During an optimization run a decision is made on the most advantageous technology for the accomplishment of value added activities at the intended location. If none of the technologies is advantageous a transport process is required and the value added is continued at an alternative location. Further parameters like geographic conditions of the network or cost items the characteristics of which depend also partly on the here defined decision variables are not further detailed to keep this contribution clear and comprehendible. The already mentioned transportation relations and production volumes are described within the level of flow of goods. At each location one value-added step of the product can be processed on a technology which is available there. In doing so, an integer decision variable indicates how many quantity units of the level of the product are produced on this technology at the location. In the network, transport connections are indicated as arrows between the nodes. In general, different transport modes are available which differ in transportation costs and speed.

Thus, a configuration of a production network is composed of a multitude of decision variables and therefore contains information about active and non-active locations of the network with their practiced strategic roles, technologies installed at the locations, production volumes of several products on the technologies of the locations and transport volume of materials, intermediate and final goods depending on the mode of suppliers, locations and subcontractors to locations and customers.

The formulated model aims at the consideration of monetary as well as other quantitative and qualitative criteria. In order to integrate the latter into the optimization approach metrics which allow for the assessment these were developed. To a certain extent, qualitative criteria are quantified, i.e. transformed into quantitative sizes what indeed does not change the original character of the target variable. This is necessary to compare results of criteria of different kinds with each other and to provide for a holistic assessment. For this purpose, utility functions of which each is set up with the modeling of the corresponding criterion are developed. To remain in the field of linear optimization always linear utility functions on the interval are included [0,1]. A total of seven criteria are formulated: costs, delivery time, flexibility, quality, coordination, market proximity and the criteria other location factors which summarizes criteria like political stability, infrastructure and expert qualification. In the following, three criteria are explained qualitatively in an exemplary way. The criteria cost covers several for this approach relevant monetary factors like production costs, transport costs or overhead for administration, management, purchasing and development. In most cases, the main focus is on labor costs because of internationally different wage levels. Not to be neglected are also expenses for material, energy and capital commitments. For now, investment costs are not taken into consideration. These are included in the final evaluation in paragraph 6. The period of time from the incoming order to the receipt of goods at the customer is to be conceived as delivery time. In this context, it is to be assumed that production is based on make-to-order i.e., several inputs for the production of the good are still not made available respectively delivered at receipt of order. The responsiveness or rather flexibility of the network is to be understood as volume flexibility. In order to determine it an approach was developed which detects the ability of the network to shift production volumes from one location to other locations in the form of a production-shift rate.

By means of linear inequality and linear equality constraints the feasible solution space of network configurations is determined. The following constraints are considered as regards content: Flows of material and intermediate as well as finished products, outsourcing, capacity limitations, minimum activity of an active location, suitability of technology, product and location, local content requirements and optional strategic requirements which are to be modeled in a company-specific way.

The previously defined MOP is now, by means of a hybrid approach, transformed from the field of scalar methods into a mono-criteria substitute problem in order to allow for the application of the branch and bound algorithm for the determination of the total optimal configuration. The hybrid approach consists of reference point and ε method and follows a variant according to Zeleny [17]. First of all, the needed factors for optimization are determined. Such factors include for example the weighting of target variables, the reference point in the criteria space and the aspiration levels for the limitation of the feasible solution space. The weighting of the target variables is carried out with the help of a comparison of pairs. The implementation of this method leads to a defined target hierarchy which comprises all considered criteria. With the help of the reference point the decision maker determines a target variable at which the reference point assumes an optimal characteristic value which is considered in a mono-criteria manner for each target value. In simple terms, the reference point is an ideal point. In the multi-criteria decision problem which is used here it is reflected in the ideal characteristic of each target variable. At this, a relatively simple method lends itself to the determination of the characteristics of the reference point: For the identification of the utility of a target variable the limiting values for the corresponding metrics were determined already in the course of modeling. Since the characteristic of metric for the determination of a target variable is respectively imaged in the criteria space [0,1] by a linear and monotone utility function it is obvious to assume a value of 1 as an optimal characteristic with respect to a criterion. This value is reached for a target variable whenever the metric assumes the value of the corresponding limiting value. As a result, the reference point coordinates will be set on value of 1. In general, an aspiration level for each target criterion has to be defined via the decision maker. Aspiration levels serve also for the limitation of the feasible solution space and therefore for the improvement of runtime. Already during the development of the metrics limiting values for selected criteria were introduced. From the decision maker‘s point of view these limiting values represent the worst case and are consequently assumed as aspiration level. For all other criteria the decision maker is free to limit the solution space further.

In the result the optimization of the mono-criteria substitute problem provides for each combination of randomly generated input parameters at discrete points of time within the planning time of the scenarios a total optimal configuration of the global production network. This configuration shows the following elements:

For each location it determines the total optimal standard configuration regarding its strategic role and its technology configuration concerning localized technology.

For each product it determines the total optimal production volumes of the intermediate and finished products on the technologies at the production sites. Further, it stores the total optimal procurement quantities of material and intermediate products of suppliers which are transported in the transport mode and processed to products. It also informs about the optimal transport volumes of intermediate products of the product between the locations and of the focused company as well as the distribution quantities of the finished product from location to customer.

In addition to the optimal configuration the present characteristic values of the target variable metrics are displayed to avoid, if indicated, a loss of information by the use of scalar methods and in order to create transparency in decision making.

5. Enablers of Change

The required need for change results from the comparison of the identified best solution at the next time of planning t+1 with the optimal network structure at the preceding time of planning within a scenario. Possible changes appear in the internal locations, the localized technologies and generated products, suppliers for needed materials and components as well as customers who demand products. The changes can be identified for all discrete times of planning and for all scenarios. The change from one network alternative to another network alternative (= change) is to be effected at low effort. Therefore enablers of change will be selected to support quick and low costing transformations.

6. Cost Effectiveness

The cost-efficiency analysis to prepare early for possible scenarios is described in the following paragraph. When changing from one network configuration to the next one direct investments like initial, facility, replacement or additional investments incur. These can be numbered precisely for the changed objects like technologies, locations, suppliers, customers and transportation relations. If required, relevant variables are estimated. Furthermore, costs for the integration of the enablers of change for changed objects are necessary. Thus, direct implementation costs incur for changeover, disestablishment and establishment of process capability. Other cost types are indirect implementation costs like e.g., production downtimes, extra work or inventory costs.

7. Evaluation and Summary

The approach presented in this article enables companies and the responsible decision makers to adapt to the changing framework conditions of a globalized economy in a better and more efficient way as today. The described influencing factors which companies are subject to lead as a whole to a pressure for change. This pressure for change is based on the interconnectedness of many influencing factors so that an extrapolation alone for the influencing factors is not sufficient any more. The undetermined future has to be described with the help of scenarios and the need for change to be identified and assessed. The presented overall methodology provides the companies firstly the possibility to identify the need for change on the basis of a multi-criteria optimization. Secondly, it shows a course of action for the derivation and assessment of business strategies regarding future developments. The presented multi-criteria optimization delivers a recent method to handle company-specific monetary, other quantitative and qualitative target criteria within an automatic generation of an optimal network structure. This leads to a sustainable strategic positioning in the field of competition in the long term. Right now, the method delivers company specific needs for change for future scenarios. The concrete method for the cost-effectiveness assessment of changeable network structures is an integral part of further research works and is detailed further within the collaborative research project POWer.net.

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