3rd Conference on Production Systems and Logistics

Software-based Identification Of Adaptation Needs In Global Production Networks

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Abstract

Internal and external influencing factors force companies to adapt their production networks to changing conditions, which entails a high level of complexity. To be competitive in the future, manufacturing companies have to minimize the required adaptation time between the occurrence of a change and the implementation of an adaptation. While some approaches deal with modelling and evaluating network configuration, there is a lack in identifying the need for adaptation. In practice, the creation of scenarios is often based on the experience and knowledge of the network designer. This paper presents an approach to systematically link perceived key figure changes to possible adaptation alternatives in network configuration. For this purpose, the relevant objects for network adaptations are first defined and adaptation alternatives are systematically described. Subsequently, these are combined with a set of key figures to derive suitable adaptation alternatives depending on their development. The approach is further implemented in a software-based prototype that enables the automated generation of adaptation alternatives in response to perceived changes and provides the user with a listing of possible alternatives prioritized by their utility. The validation with company data demonstrates that by earlier and automated identification of possible configuration adaptations, the adaptation time to changes can be reduced and the generated scenarios are less dependent on the individual experience of the user.

Keywords

Global Production Networks; Network Design; Network Configuration; Adaptation; Optimization Model

1. Introduction

The majority of manufacturing companies of all sizes and industries operate globally in the form of global production networks [1]. These production networks are often historically grown and exposed to a multitude of influencing factors [2]. These internal and external influencing factors are dynamic and require adaptations in the design of the global production network, which is a complex challenge for companies [3]. However, in the face of increasing competitive pressure and dynamics, the ability to adapt to changes is a necessary prerequisite for companies to remain successful in the future [2]. The capability and ability of the footprint to regain a stable state after changes or disruptions is termed network resilience [2]. To improve resilience in global production networks, faster detection of adaptation needs and responsive countermeasures are required [4]. The time required to adapt to a change is divided into three parts and called hysteresis [5]. The first latency period between the occurrence of change until the change is perceived, followed by the latency period until a need for change is identified, and finally the planning latency until the adaptation is implemented [6]. To shorten the adaptation time, the network planner has to be able to react faster in the second part of hysteresis and choose the appropriate adaptation alternative despite the mentioned

DOI: https://doi.org/10.15488/12169

complexity. Therefore this paper focuses on decreasing the time between the perception and identification of a need for change, which can be achieved by the creation of transparency and standardization [7]. The use of company data offers the possibility to record key figures and to present their changes transparently [8,9]. A systematization of adaptation alternatives further supports the selection of a possible response to change [9]. Previous research of the authors systematizes adaptation needs and describes concrete adaptation cases, which now need to be linked to the key figures [10]. In order to provide the network planner with decision support, interactive tools are useful to make the complexity of the planning task manageable [11]. Accordingly, this paper aims at reducing the design complexity of global production networks from a network perspective by combining identified changes and possible network reactions. For this purpose, an indicator-based systematic method is presented to reduce hysteresis by linking the adaptation cases with quantified influencing factors to identify the appropriate response to changes. The approach is further implemented in a software-based prototype that enables the automated generation of adaptation alternatives in response to perceived changes. Prioritization of the adaptation alternatives supports the user in the selection of network adaptations to be considered in more detail.

2. State of the art

In this context, research approaches regarding structural adaptations of network configuration and adaptation time in network design should be considered in particular. The most current and relevant approaches are presented in the following. WIEZORREK presents an approach for integrating a continuous decision process. Within the framework of permanent monitoring, this process records relevant influencing factors and thus addresses the early identification of the need for adaptation [12]. SCHUH ET AL. provide a reference process for the continuous design of global production networks. The process uses the performance of the production network as a decision basis for identifying the need for adaptation [13]. An approach based on Big data techniques for optimization of network design is presented by GÖLZER ET AL. Within the approach generic planning cases for planning, executing, and validating adjustments are proposed [14]. NEUNER provides a reference framework for the configuration of global production networks considering uncertainty. In the process, uninfluenceable factors are determined and structured according to target variables. These serve as the basis for the evaluation of the configuration alternatives [15]. Some authors use key figures to determine necessary adjustments or to evaluate global production networks. RITTSTIEG examines the factors influencing the performance of production sites. These are quantified by a comprehensive system of key figures [16]. The performance of the production network, as well as environmentally induced adaptation needs, are considered by SAGER. He describes an approach for configuring global production networks by using the concept of selective key figures. Both strategic and operational metrics are used to compare possible adaptation needs in the network configuration [17]. Few authors attempt to handle the complexity of the planning task by implementing interactive software. The solutions developed by SCHUH ET AL. and MOURTZIS ET AL. focus on identifying optimal network configurations based on decisions about the allocation of resources and tasks in the production network, but do not deal in detail with adaptation alternatives to changing influencing factors [18,19]. In summary, approaches to adapting network design as well as the elaboration of key figures can be found in the literature. However, a detailed consideration of the derivation of adaptation needs based on identified changes to shorten the adaptation time is lacking.

3. Conception of the approach

Based on an already existing method for systematizing adaptation cases, chapter 3.1 presents how identified key figure changes can be linked to the adaptation cases. Subsequently, chapter 3.2 prepares the integration into a software tool by creating a data model and introducing the object of the strategic unit. Finally, in chapter 3.3 an optimization model is presented to prioritize the adaptation alternatives.

3.1 Systematized derivation of adaptation alternatives

Within preliminary work, the authors developed an approach to systematize adaptation cases for the design of global production networks. The approach describes each possible design case in the network configuration and allows to structure decisions for a generic production network. A production network is represented by the superposition of several node-edge models, each representing the subnetworks of the product families. Accordingly, the edge of a subnetwork can be understood as the flow of a product between locations in the production network. This flow is referred to as the production chain and can be changed specifically in an adaptation reaction. In addition to the production chain, other network objects are modelled that are relevant for the adaptation. These are the locations of the company with their resources and the manufacturing processes. The adaptation alternatives of the entire production chain result from combinations of the adaptation possibilities for the described object types of the production network. For this purpose, the individual adaptation options for each object type are first defined and bundled in a configuration framework. For example, the production chain has four adaptation options *No Change*, *Ramp-Up*, *Adaptation* and *Ramp-Down*. By linking the adaptation options of each object type, 160 combinations of potential adaptations are obtained for the production chain. Due to internal dependencies and contradictions, these are further reduced to 61. Each of these adaptation cases can be identified by a code resulting from a concatenation of the individual codes. For example, the code 1132 means the modification of a resource and emergence of a new production process without the change of production chain or location (see Figure 1). [10]

Object types	**Adaptation reactions (AR)**				
Production chain (PC)	PC-1 No adaption	PC-2 Ramp-up	PC-3 Adaption	PC-4 Ramp-down	
Location (L)	L-1 No adaption	L-2 Opening	L-3 Increase in size	L-4 Decrease in size	L-5 Closure
Resource (R)	R-1 No adaption	R-2 Commissioning	R-3 Modification	R-4 Decommissioning	
Manufacturing process (MP)	MP-1 Known	MP-2 New			

Figure 1: Adaptation reactions in the configuration of global production networks [10]

In order to identify the appropriate adaptation reaction to internal and external influencing factors, the systematized adaptation alternatives described above have to be linked to change drivers. RITTSTIEG and other authors have developed extensive collections of relevant key figures. For the method and the implemented prototype, 15 key figures were selected that were considered to be generally relevant. However, the method works equally with other key figures, which should be selected on a company-specific basis. The linking of the selected key figures is done by analyzing for each adaptation case to what extent it is suitable to counteract deterioration of the key figures. The evaluation is carried out by company experts. Figure 2 shows the section of a general example and represents the interrelations as a table. For adaptation case 1121 it is deduced that it could potentially be used to counteract deteriorations in capacity utilization, area utilization, volume flexibility, or route flexibility. This potential is determined for all adaptation cases. Thus, starting from the deterioration of a key figure, all potentially suitable adaptation cases are captured.

	PC	**L**	**R**	**MP**	**Quality rate**	**Transport time** *internal*	**Capacity utilization** *bottleneck*	**Capacity utilization** *overcap.*	**Area utilization** *bottleneck*	**Area utilization** *overcap.*	**Employee productivity**	**Production costs**	**Material costs**	**Volume flexibility**	**Machine flexibility**	**Transport volume flexibility**	**Route flexibility**	**Transport time** *supplier*	**Transport time** *market*
1	1	1	1	2	1	0	1	0	0	0	1	1	0	1	1	0	0	0	0
2	1	1	2	1	0	0	1	0	0	1	0	0	0	1	0	0	1	0	0
3	1	1	2	2	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
.	.	.	.	.															
61	4	5	4	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0

PC: Production chain **L**: Location **R**: Resource **MP**: Manufacturing process (1) interrelation (0) no interrelation

Figure 2: Linking the key figures with the adaptation cases (example)

Combined, the individual adaptation cases result in an adaptation alternative for the entire production network. However, this approach still has application-related gaps that need to be closed. In a production network, there are numerous network objects that are all interdependent. Key figure changes can occur simultaneously in several objects. Therefore, in the following a consideration of a multitude of key figures is enabled and adaptation alternatives are generated in an object related way. In addition, interdependencies between production chains have to be taken into account by determining the adaptation reactions of the entire production network simultaneously instead of considering the individual production chains successively.

3.2 Division of the production network into strategic units

In order to provide the network planner with software-based decision support, a data model has to be set up that contains the object types for defining adaptation cases. In addition, the model of the production network is extended by the suppliers and the sales market to take external key figures into account. Further, transport routes are integrated into the network that link two locations with each other as well as suppliers and sales markets with a location. The resulting data model is implemented as a class diagram based on the Unified Modeling Language (UML) and visualized in Figure 3.

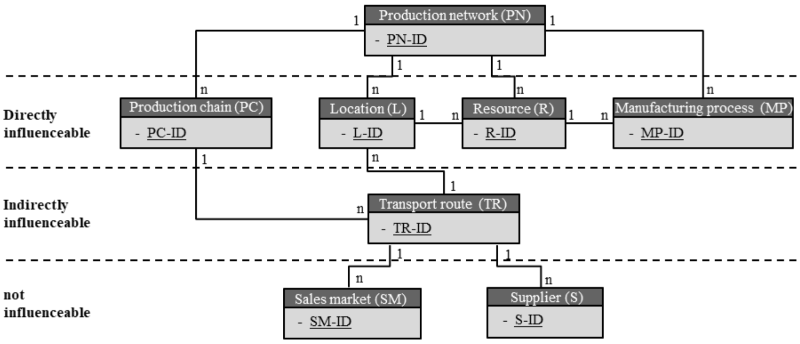


Figure 3: UML data model for configuring global production networks

For an assignment of design measures in the production network, a distinction is made in the data model regarding the influenceability of the network objects. While the influenceable objects also serve as the output of an adaptation reaction, the non-influenceable objects are only seen as input, i.e. they can only be used to identify a need for action. The network objects that are addressed by the adaptation cases, i.e. the production chains, locations, resources and manufacturing processes, are classified as directly influenceable. On the other hand, the sales market and the suppliers cannot be influenced. These are defined as exogenous in the model. In between are the transport routes, which connect the locations internally with each other as well as locations with suppliers or customers. Since sites and production can be influenced, the transport routes can also be addressed indirectly through design measures. However, due to the dependency on the exogenous objects of the network, their adaptation possibilities are limited. The selection and distribution of suitable adaptation measures in the production network is based on the reference process for the continuous design of production networks according to SCHUH ET AL. [13]. In the reference process, a network configuration for the entire production network is determined on a tactical level by decomposing the network into the individual value streams. For these value streams, possible scenarios are developed and evaluated, checked for dependencies, and finally selected. In this work, the production network is grouped into strategic units, each containing a value stream and the network objects relevant to the value stream. The strategic units contain all strategic decisions of relevant objects, which are used for identification as well as for the implementation of an adaptation. By decomposing the production network into such units, several of the generic adaptation cases can be assigned to the production network at the same time, in that each strategic unit receives exactly one adaptation case if action is required within the strategic unit. Thus, the adaptation of the network is no longer dependent on the successive consideration of individual production chains, but all production chains can be considered simultaneously. In addition, several network objects of the same class can be addressed within a production chain. For example, adaptation alternatives can be identified that react simultaneously to key figure changes from two different locations and select suitable adaptation cases in each case. The structure of a strategic unit is shown in Figure 4.

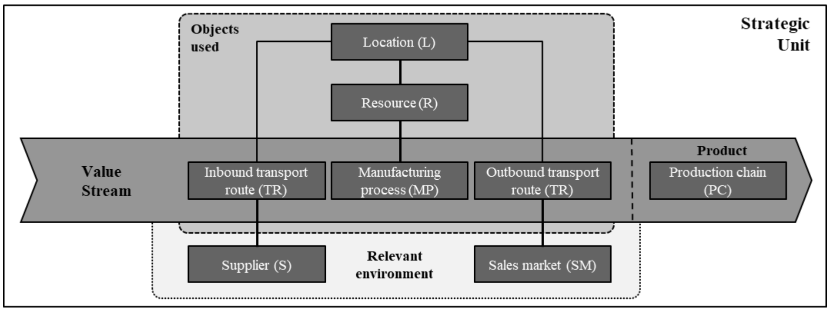


Figure 4: Model of a strategic unit

At the center of each strategic unit is the value stream, which always relates to a specific product and is therefore part of a production chain. The value stream begins with the inbound transport route, which delivers the product to the respective location. This transport route starts either at a supplier or at a company-internal location. At the core of the value stream is the manufacturing process used. As a value-adding element, the manufacturing process requires a suitable resource for its execution, which is located at a site. The output of the value stream is the outbound transport route, which leads either to another location (and thus to another strategic unit) or to the sales market. Each of the network objects mentioned occurs exactly once in a strategic unit, so that there are at least as many strategic units as there are manufacturing processes in the company. If a manufacturing process is linked to several transport routes at the input or output, the number of strategic units is even higher. Each strategic unit can be assigned to one of the 61 generic adaptation cases by addressing the network objects that can be directly influenced. The need for action is determined based on the key figure changes that occur in the network objects of the strategic units. Thus, there is a strategic dependency within each strategic unit, as the objects influence or constrain each other in the choice of an adaptation action. Outside the strategic unit, other primarily structural interdependencies have to be considered. For example, the same network objects may occur in several units, i.e. a site could have two resources, each has two manufacturing processes. In this case, four strategic units would be created, so that the site as well as the resources would occur various times. Therefore, when designing all strategic units, it is necessary to ensure that the actions of the network objects are unique.

3.3 Optimization model

3.3.1 Structure of an optimization model

The method presented in this paper aims to identify adaptation needs at an early stage by automatically generating adaptation alternatives to changes in key figures. A decision problem arises about which adaptation cases are assigned to which strategic units, so that the action requirements are met in the best possible way considering the restrictions in the network. Decision problems can be solved with qualitative, quantitative and combined methods. In contrast to qualitative methods, quantitative ones are based on objectively measurable criteria and serve as a rule for the optimization of a target value by parameter variation [20]. The presented decision problem in this paper considers objectively measurable ratio changes. To enable an automatic identification of adaptation alternatives subjectivity is to be avoided and a quantitative evaluation method is appropriate. For mapping the decision problem a mathematical optimization model is chosen to deal with the optimization of functions under constraints. An optimization model is a formal representation of a decision problem that contains, in its simplest form, at least one set of alternatives and an objective function evaluating them. The model is developed to be able to determine optimal proposed solutions using appropriate procedures. In its basic structure, an optimization model consists of an objective function to be optimized, a variable vector describing the alternative courses of action, and a restriction system consisting of several constraints that restrict the solution space and define the range of values of the decision variables [21]. An important special case of mathematical optimization are linear optimization models. A linear optimization model exists if the variables are not multiplied by each other and no variables are found in exponents. If it is possible to put a mathematical optimization model into this linear form, enormous advantages arise, since fundamental efficient methods for linear models have been developed. This enables to communicate the mapped problems as well as problem instances to standard software known as solvers, which solve the problem instance optimally. These solvers have increased their performance enormously in recent years, allowing them to solve increasingly complex problems more efficiently [22]. For this reason, a linear optimization model is chosen. By adding secondary conditions to the model, the solution space of the problem is narrowed down and restrictions from the structure of the production network considered [22]. In the following, the optimization model is described in detail.

Objective function:

$$max \quad N(x) = \sum_{i \in S} \sum_{j \in P} n_{ij} x_{ij} \tag{1}$$

Secondary conditions:

$$\sum_{j \in P} x_{ij} = 1 \; \forall \; i \in S \tag{2}$$

$$n_{ij} = \sum_{k \in K'} r_k * e_{jk} * z_{ik} \quad \forall \; i \in S, j \in P \tag{3}$$

$$x_{ij} \in \{0,1\} \quad \forall \; i \in S, j \in P \tag{4}$$

$$x_{ij} + x_{lm} \; \leq 1 \quad \forall \; (i,j,l,m) \in K \tag{5}$$

$$x_{ij} = 0 \quad \forall \; (i,j) \in R \tag{6}$$

Table 1: Overview of the elements of the optimization model

Category	Symbol	Description
Index	*i,l*	Index of a strategic unit
	j,m	Index of a generic adaptation case
	k	Index of a key figure change
Decision variable	*x*	Binary variable indicating the assignment of an adaptation case to a strategic unit
	e	Binary variable for assigning an adaptation case to a key figure change
	z	Binary variable for assigning a key figure change to a strategic unit
Coefficient	*n*	Matrix of the utility values of the adaptation cases for each strategic unit
Objective function value	*N*	Total utility value of the adaptation alternative for the production network
Set	*S*	Set of strategic units in the production network
	P	Set of 61 generic adaptation cases
	K'	Set of all key figures
	K	Conflicts between two assignments resulting from the structure of the network
	R	Restrictions that arise from individual specifications of the user

3.3.2 Definition of the objective function

The objective of the method is to generate the best possible adaptation alternatives for the production network, which is captured in the optimization model by the objective function (1). The first constraint (2) specifies that only one adaptation case $j \in P$ can be assigned to each strategic unit $i \in S$. This condition is needed so that reasonable solutions can be determined. Overall, the adaptation cases are to be assigned to the strategic units in such a way that the total utility value of all assignments is maximized. To achieve this, the first step is to calculate the individual utility values for all combinations of potential assignments. These individual utility values serve as parameter *n* for calculating the total utility value of an adaptation alternative. A utility analysis is used to calculate the individual utility values. In practice, this is a frequently applied procedure for the evaluation of alternative actions [20]. In this process, the alternatives are ordered according to the preferences of the decision maker concerning a multidimensional target system [23]. In the context of the method, the action alternatives are the adaptation cases of the production network. The target system results from the multidimensional key figure system. The utility of an adaptation case is calculated by how many key figure changes (considering their relevance) can be addressed. Formula (3) represents the individual benefits of each adaptation case for each strategic unit. K' is the set of all key figures and r_k is the relevance of the development of a key figure $k \in K'$, which can be calculated via the relative deviation of the key figure development. The binary variable e_{jk} indicates whether an adaptation case $j \in P$ is suitable for addressing a key figure change *k*. This information can be derived from the table in Figure 2. The individual utility values *n* have to be calculated for each strategic unit, since the key figure changes are assigned to the objects of the production network and several strategic units do not exclusively contain the same objects. Therefore, the action required per strategic unit may vary. In order to take this into account, the utility analysis is complemented by the additional binary variable z_{ik}, which indicates whether the key figure change *k* occurs within the strategic unit $i \in S$. For the implementation of the method in a software demonstrator, the strategic unit is included as a network object in a database so that the relationship to the other objects can be retrieved and used to automatically determine z_{ik}. For individual strategic units, the calculation of individual utility values can be performed using a table (see Figure 5).

Suitability e_{jk}		**Key figures** $k \in K'$															**Individual utility values** n_{ij}
		QR	**TT (I)**	**CU (B)**	**CU (O)**	**AU (B)**	**AU (O)**	**EP**	**PC**	**MC**	**VF**	**MF**	**TVF**	**RF**	**TT (S)**	**TT (M)**	
Adaptation cases $j \in P$	**1**	1	0	1	0	0	0	1	1	0	1	1	0	0	0	0	0.2
	2	0	0	1	0	0	1	0	0	0	1	0	0	1	0	0	0.9
	3	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0.9
	.																
	61	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	1.0
Relevance r_k		0.5	0.7	0	0	0	0	0.3	0	0.4	0	0	0	0.9	0	0	
Assignment z_{ik}		0	1	0	0	0	0	1	0	1	0	0	0	1	0	0	

Figure 5: Exemplary calculation of the individual utility values for a strategic unit

In this example, the utility value of adaptation case 61 for the considered strategic unit with code number 1 is calculated as followed:

$$n_{1,61} = \sum_{k \in K'} r_k * e_{61,k} * z_{1,k} = (0.7 * 1 * 1) + (0.3 * 1 * 1) = 1.0 \qquad (7)$$

Thus, adaptation case 61 has the highest individual utility value of the adaptation cases considered in the example. The individual utility values are calculated for each strategic unit and serve as coefficients for the objective function (1) of the linear optimization model. The total utility value *N* is the sum of the individual utility values of all selected adaptation cases. The decision variable x_{ij} serves for the assignment of an adaptation case $j \in P$ to a strategic unit $i \in S$. x_{ij} is a binary variable that takes the value one if an assignment takes place and zero if not. This binarity is expressed in the optimization model by constraint (4). The task of the solver is to determine a value for all assignments so that the objective function is maximized. Constraints (5) and (6) represent restrictions of the network and are explained in the following subchapter.

3.3.3 Restrictions from the network configuration

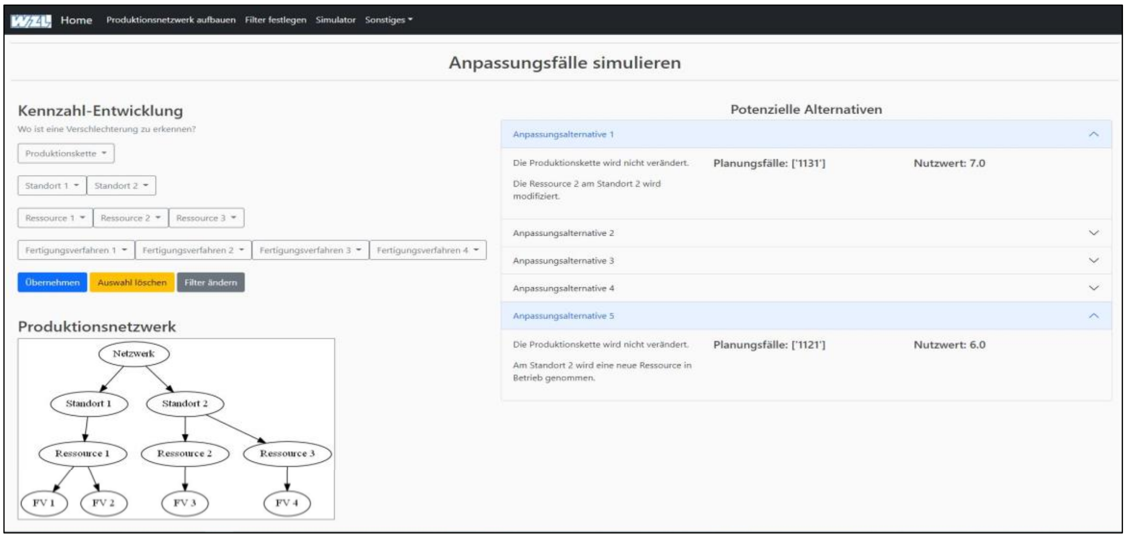
If there are no interdependencies between strategic units, the objective function could easily be optimized by selecting all adaptation cases with maximum individual utility values. In reality, the selected adaptation cases may contradict each other and thus not be feasible. For example, one adaptation case might involve the decommissioning of a resource, while another adaptation case involves only a modification for the same resource. Therefore, structural interdependencies between the strategic units of the production network have to be considered when selecting adaptation cases. These interdependencies are accounted for by constraint (5) in the optimization model. The constraint specifies that two assignments (each between a strategic unit and an adaptation case) cannot both be selected if this constellation is stored in the conflict list *K*. The conflict list *K* is a list of interdependencies between the strategic units of the production network. The conflict list depends on the structure of the production network and the composition of the strategic unit. Therefore it has to be created individually for each production network in advance. In this method, the conflict list is created with the help of an algorithm. All possible assignments are reviewed and checked for dependencies between the strategic units. The basis is the contradictions in the generic actions of the individual network objects. If there is a contradiction, the two actions under consideration cannot be performed within the same object. In preliminary work of the authors, the actions were defined as unique and not overlapping [10]. Therefore, a uniform adaptation reaction has to be selected for a single object. However, there is the exceptional case that an adaptation reaction creates a new network object. Then it is possible to perform any action on the first object as well as to create the new object. For example, a new resource could be put into operation while the old resource is modified. This also applies to the opening of a site and the development of a new manufacturing process. The described constraints are used to consider the structure of the production network. With regard to the application of this methodology, however, it should be possible to generate additional constraints that incorporate strategic guidelines from the company. Thus, guidelines from the network strategy can be considered. For example, location decisions can be dependent on a superordinate strategy, such as the development of a new sales market. In addition, the solution space of the problem can be further restricted by following the guidelines, so that the decision is facilitated. In this optimization model, the user-specific restrictions form the constraints (6), which are not further detailed here.

3.3.4 Iterative solution of the optimization problem and prioritization of the alternatives

After all required coefficients and quantities have been determined, the optimization problem can be set up and solved. Since the optimization model contains a binary decision variable, an integer optimization problem has to be solved. Manual selection of an algorithm is not necessary, since a standard solver (*Coin-or-branch and cut*) is used in the software implementation, which automatically determines a suitable algorithm. Since the adaptation alternatives as results of the method should only serve as decision support for the network planning, the specification of a single adaptation option is not purposeful. Rather, several alternatives for the production network should be generated and listed according to their utility value. This results in a clear solution space of potential alternatives, which are further checked for feasibility and reasonableness. For this purpose, the optimization problem is solved iteratively. In each subsequent iteration the solution of the previous iteration is forbidden. Thus, each iteration provides an additional adaptation alternative for the production network, whose utility is smaller or equal to the utility in the previous iteration. Thus, starting from the second iteration, a new constraint must be included in the optimization model that excludes all previous solutions.

4. Application

The described method was transferred into a software demonstrator, which is structured in the form of a web application and can be operated via any internet browser (see Figure 6). The software demonstrator allows the user to simulate various situations to identify individually tailored adaptation alternatives for a production network. The result is a prioritized list of adaptation options, which the user should then evaluate based on various criteria (effort, cost, risk, etc.) in order to finally adapt the production network. The decision is facilitated by the application, as the solution space is reduced by systematizing the adaptation cases and prioritizing the network alternatives. The software demonstrator was applied and validated at a household appliance manufacturer. The company's network consists of several global locations and has grown historically. There is high potential by adapting to changes such as growing unit numbers in new markets. A key figure system for monitoring the production network consisting of 15 key figures was used for the validation. The key figures were examined for changes using historical data. Five key figures were identified that had changed in different optimization directions. By creating a table to determine the dependencies between the 61 adaptation cases and the key figures, the software demonstrator could be fed with the corresponding data. The resulting list of prioritized adaptation alternatives was validated by a network planner. 5 of the 8 highest prioritized alternatives were classified as realistic adaptation alternatives and could be investigated in a next step with respect to the criteria mentioned above.



Anpassungsfälle simulieren

Kennzahl-Entwicklung

Wo ist eine Verschlechterung zu erkennen?

Produktionsnetzwerk

Potenzielle Alternativen

Anpassungsalternative 1

Die Produktionskette wird nicht verändert.

Die Ressource 2 am Standort 2 wird modifiziert.

Planungsfälle: ['1131']

Nutzwert: 7.0

Anpassungsalternative 2

Anpassungsalternative 3

Anpassungsalternative 4

Anpassungsalternative 5

Die Produktionskette wird nicht verändert.

Am Standort 2 wird eine neue Ressource in Betrieb genommen.

Planungsfälle: ['1121']

Nutzwert: 6.0

Figure 6: Excerpt of the software tool (anonymized example)

5. Conclusion

The paper presents a methodology and its transfer into a software tool for the identification and prioritization of possible adaptation alternatives in global production networks. This provides decision support to the network planner by narrowing the solution space and suggesting possible adaptation alternatives in an early and automated way. There is currently a need for research in the processing of the data from the systems, which enables the automated calculation of the key figures used. In addition, possibilities for further evaluation of the prioritized adaptation alternatives should be investigated. Factors such as effort, cost, strategic importance, sustainability, and risk of the identified alternatives should be considered to assess the alternatives for feasibility and reasonableness. Further development of the method focuses on reducing the high degree of subjectivity in linking the metrics to the adaptation cases. This could potentially be countered by a feedback learning system, using appropriate machine learning algorithms to adjust the values of the table used to produce more meaningful results.

Acknowledgements

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC-2023 Internet of Production – 390621612.

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