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CONCEPT FOR THE DEVELOPMENT OF AN INNOVATION FOCUSED SEMANTIC PRODUCT MODEL

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Abstract: *Development and production of innovative products is the core business activity of manufacturing companies. During the development process, companies have to decide, which product aspects should be innovated. The identification of the most promising product aspects for innovation needs transparency about the holicity of all product aspects that could be alternated. Due to the increasing use of databased methods within innovation management, the required product model also needs be accessible by humans as well as machines. Therefore, a concept for the development of a semantic product model to support the innovation process consisting of three steps is presented.*
Key Words: Innovation Management, Semantic Network, Ontology, Product Model, Product Development

1. INTRODUCTION

The core of the entrepreneurial activities of manufacturing companies is the demand-oriented development and production of goods. In particular, the fulfilment of heterogeneous customer needs through the change from a classic seller's market to a buyer's market requires a stronger customer focus from the market actors [1]. Chang and Taylor, for example, were able to prove that the outcome of product development can be significantly improved if customers are included in the development process [2]. However, in addition to the customer, other external dimensions of influence such as society, the environment or the market must also be taken into account during product development [3]. When innovating a product, the multidimensional product environment influences the process. According to a study by Deloitte, 43% of the participating companies see the identification of the right trends and technologies as a success factor for innovation [4]. However, 32% of the participating companies also name the identification of trends and technologies as the biggest obstacle to innovation in their own company [4].

Technological advancements as well as the volatility of customer needs cause companies to be uncertain about the external variables affecting product development [5]. To reduce this uncertainty in product innovation, it is particularly necessary to analyse and process the knowledge that already exists externally in the product environment. Enkel and Horváth have found that 80% of all innovations [...] are a recombination of already existing knowledge. Only a very small number of technological innovations or products are based on truly new knowledge and developments [6]. However, a holistic analysis of the external dimensions of influence causes a high personnel effort due to the processing of large amounts of data [7]. There are already use cases that demonstrate the potential of text mining and analysis of big data for innovation management [8]. For these applications is it manadatory to create product models that entail the entirety of all product aspects that can be the object of the innovation process as well as their interrelationships.

In particular, it must be mapped what influence the insights gained from these data and reports have on the product and the product concept. Successful innovations can be derived from analogies in which patterns from known fields are transferred to new fields [9]. For the identification of such innovation possibilities for existing products, creativity and thus the ability to think in networked systems is particularly necessary [3]. A tool for this can be the construction of a semantic network, which models the product itself on the one hand and the product environment as a network on the other. Both, machines and humans, are able modelling and structuring of semantic networks [10].

However, at the moment a method for modeling an existing product is not available, yet. This model has to represent the holicity of all product aspects that may be adressed by the innovation management in order to create transparency about all product aspects that can be innovated and their interrelationships. The concpetualization of such a method is adressed by this paper.

2. RELEVANT TERMINOLOGY AND STATE OF THE ART

The concept developed by this paper interprets and addresses products as technical systems. According to Hull a technical system in the context of requirements engineering is a collection of components (machine, software and human) which cooperate in an organized way to achieve desired results [11]. Following a definition by Gilb, a (technical) system can be described by its set of function, performance, resource and design attributes [12]. During product development, products have to follow and meet specific requirements. Requirements are the basis for every project, defining what the stakeholders - users, customers, developers, businesses - in a potential new system need from it and also what system must do in order to satisfy that need [11]. There are multiple options available to characterize requirements in the context of the systems engineering. Gilb defines five types of requirements that are used within the context of this approach [12]:

- Function requirements
- Performance requirements
- Ressource requirements
- Design constraints
- Condition constraints

As mentioned in the motivation of this paper, innovation management needs an innovation focused model of a product to monitor all componts, attributes and their interrelationships that determine the system. The Oxford dictionary defines a model as a simple description of a system, used for explaining how something works or calculating what might happen [13]. This model has to be adapted to the modelling objective [14] to being able to represent the desired aspects and structures.

Graphs are one type of model. Graphs are a natural way of modelling scenarios, data and interrelationships by using, circles, boxes and arrows [14]. One special kind of graphs are semantic networks. The term semantic network goes back to the linguist Quillian [15]. The objective of a semantic network is the representation of knowledge or information [16–18]. The stored information is not only human, but also machine readable [10]. Similar to graphs, semantic networks also consist of nodes and arcs [16,19]. Nodes (or circles, boxes, or units) represent concrete or concpetual objects and constitute the network [16]. Each node can also be assigned with characteristics that may store additional information without affecting the visual representation in the network [10]. Arcs (or arrows, or links) represent the relations between objects [16,19].

A graph is a semantic network if each edge is assigned a meaning [16]. This meaning of the edges is typically expressed in natural language [10]. According to Brachmann as well as Giarratano and Riley, it is only through the connection of the nodes and thus the terms that knowledge can be stored and retrieved in the semantic network [20,21]. Due to its proximity to natural language [19,22], knowledge in the network does not have to be stored explicitly, but can also be stored implicitly [16]. Implicit at this point means that knowledge is stored in the network without it having to be explicitly defined [22]. Instead, additional knowledge can be generated by the totality of explicit knowledge. Fig. 1 shows an example of simple semantic network with six nodes and six arcs. An example for implicit knowledge within with this network is the statement that peter drives a car that has an electric engine.

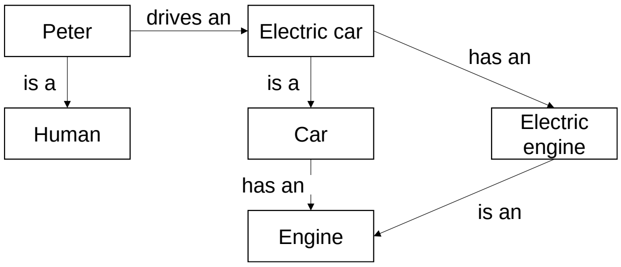

Fig. 1. *Example of a simple semantic network*

The underlying concepts of semantic networks are a thesaurus, a taxonomy and an ontology [10,16,23,24].

A thesaurus is defined as a controlled and structured vocabulary in which concepts are represented by terms organized so that relationships between concepts are made explicit, and preferred terms are accompanied by lead-in entries for synonyms or quasi-synonyms [25].

Du Preez describes taxonomies as a hierarchical classification system with only hierarchical relations between terms that lead to a tree-shaped structure without cross connections [26].

Van Rees defines an ontology as a set of well-defined concepts describing a specific domain. The concepts are defined using a subclass hierarchy, by assigning and defining properties and by defining relationships between the concepts [24].

Additionally semantic networks have two basic properties. At first, semantic networks have to be redundancy-free meaning that every object must only appear once within the network [22]. Concpets or objects having the same meaning must be merged for being included in the network [10]. Then objects within the semantic network have to be in a hierarchy, an inferential structure that exists between the objects classified in the network [16]. This hierarchy also leads to the inheritance of characteristics between nodes and concepts [16] and therefore to the ability to include implicit knowledge.

A special kind of semantic networks are fuzzy semantic networks that allow more nuances than regular semantic networks by introducing weighs to links by assigning values between 0 and 1 [19,27]. Fuzzy semantic networks also allow users to calculate the semantic distance between two objects. The semantic distance is the distance along the shortest path between two objects within the network [19,28].

There is no uniform structure of a semantic network [29], instead semantic networks are designed according to the application. In the following, three exemplary use cases of semantic networks within the context of product development are presented

Ahmed et al. [30] describe a procedure for building a semantic network to support the management of knowledge and data during product development in variable use cases. For the creation of the network, taxonomies already existing in the company (e.g. function structures, product structures or folder directories) are integrated and supplemented with further required nodes depending on the use case. A thesaurus is used to assign information to the objects in the network. The network is expanded and supplemented during its use.

Dotsika and Watkins [31] present an approach for identifying and assessing potentially disruptive technologies. Scientific publications that deal with a technology under investigation are evaluated in order to determine its distribution or reach. In addition, a keyword network is used to draw conclusions from the co-occurrence of keywords on the dependency of the addressed topics and on trends and innovations in the environment of the technologies under consideration.

Shi et al. [32] developed an approach in which the knowledge elements for product development and their dependencies are mapped from the knowledge available on the internet. Documents (e.g. scientific publications) are evaluated by means of text mining in order to extract the topics addressed by the documents. Subsequently, the recorded topics are modelled relationally in a semantic network based on their correlation when they occur. This semantic network can then be used, for example, to derive the dependency of design elements or to synthesise new technical solutions.

3. RESEARCH QUESTION AND STRUCTURE

In the analysis of existing approaches to the use of semantic networks in product development, various possible applications were discussed. In the three use cases presented, the use of semantic networks is mainly limited to the modelling and structuring of (product) knowledge. In particular, the focus is on the modelling of product data during product development or the modelling of information from external sources. However, the perspective of innovation management perspective when modelling exisitng products is still missing. Thus, it must be assumed that many elements of the resulting network are not relevant for the search for innovations or that other elements are missing. An adaptation of such an approach for this means is therefore not possible. So far, there is approach suitable for modelling existing of the product from the perspective of innovation management. However, this model is necessary in order to be able to search for innovation potentials based on current product aspects.

Based on this deficit of the currently available methods for innovation management, the following research question is formulated:

How can products be modelled in context of innovation management by using a semantic network?

Based on this research question, the objective of this paper is creating a concept for the development of an innovation focused semantic product model.

This modelling precedes the actual search for innovation potential in the product environment and serves in particular to narrow down the search field. In order to meaningfully narrow down all the information available in the product environment, the modelling of the product under consideration is the starting point for environmental scanning. Here, the product is understood as a system of various physical and non-physical product aspects that are interrelated. In the following, a concept is presented on how a semantic model of an existing product can be developed from the perspective of innovation management.

The procedure proposed here essentially corresponds to the V-model [33] for product development, which is used in particular in (model-based) systems engineering. Accordingly, after a decomposition of the problem space on the requirements side, the individual problem elements are linked with corresponding solutions, components and product aspects in order to build up a semantic network for the product description. The procedure for this requires three steps:

The first step is to build a glossary that contains the terms that are to be used in the semantic network. The glossary also defines which terms may be used synonymously. In the second step, the product under consideration is described in terms of requirements. This includes the documentation of the interrelationships of the requirements. During the third and last step, the product is hierarchically decomposed into sub-systems and components. The elements of this structure are linked to the requirement elements and in this way a product network with cross-relationships is introduced and a semantic network is created.

4. CONCEPT

These steps of the procedure concept shortly presented above are detailed in the following:

A. Development of a product glossary

The first step of the procedural concept is the definition of a glossary, which serves as a database of the terms contained in the network. By building such a glossary, several goals are achieved in the context of describing existing products. First, the glossary defines a common vocabulary for the things depicted in the network. In particular, synonyms are mapped in the glossary, which could otherwise lead to misunderstandings and contradictions when modelling the product, as communication within product development is usually insufficient [34]. Accordingly, a glossary defines an unambiguous naming of all elements contained in the network and at the same time guarantees the uniqueness and differentiation of the elements from each other. Another goal achieved by defining a glossary is an initial review of the product by building a common understanding. In most cases, companies lack a holistic overview of all the elements that define the product from the different perspectives of the company.

When building the glossary, just as with the semantic network, no new knowledge is generated, but the existing knowledge about the product is bundled in a single source of truth. For this reason, the sources of information available about the product must first be identified. In their approach, Zahay et al [35] define eight types of information that are relevant for product development: Internal information (strategy; finance, project management), external information (competition, regulations) and mixed information (customer, needs, technology). For the definition of a product glossary, two perspectives in particular are decisive and will be considered here: the internal technical perspective and the external market and customer perspective. For the analysis of the technical perspective, internal documents such as drawings, models, parts lists or product structures, but also internal contacts from product development are available as sources of information. The essential elements from the market and customer perspective can be evaluated with the help of forum entries, entries from social media or also through customer enquiries or customer interviews. The exact selection of information sources to describe the two perspectives is product- and company-specific and cannot be defined in a general way.

The information sources identified in this way must then be evaluated with regard to the definition of a glossary. In this context, a glossary can be compared to a dictionary or encyclopaedia. Accordingly, one entry is created for each term identified in the course of the information collection. The information required for the glossary per entry is the name of the entry for clear identification, an agreed definition and synonyms that could be used instead of the term in another context.

B. Semantic description of the product requirements

In the following step, the semantic modelling of the requirements for the product takes place, whereby the dependencies and interrelationships of product requirements are mapped. Five types of product requirements are distinguished according to Gilb [12]: Function requirements (FR), performance requirements (PR), resource requirements (RR), design constraints and condition constraints (DC and CC).

The identification of product-specific requirements begins with the assumptions underlying the original product development, which should be addressed by the product. If these refer to the product as a whole system or to individual subsystems, a further decomposition of the requirements can be helpful to identify requirements that address individual product components or properties. The underlying hypothesis of the work is the assumption that innovations always occur when requirements for a product are fulfilled in a new way. For this reason, the status quo of the fulfilment of these requirements must first be recorded. It follows from this that when modelling the existing product, the perspective of functions, performance, resources and materials, design and the conditions are relevant.

In the following, it is shown how a semantic network of requirements is first modelled on the basis of these five perspectives. Starting from the product or system to be modelled, the main function requirements are defined and these are further decomposed until the elementary functions relevant for the product are reached. In the process, interdependent functions and functions with their children should be linked. Fig. 2 demonstrates the functional decomposition of the system requirements.

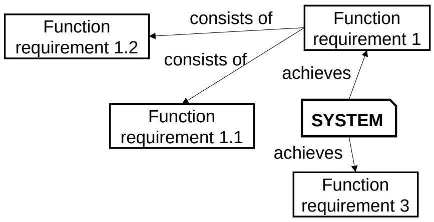

Fig. 2. *Semantic network of function requirements*

In the next step, the existing performance and resource requirements are linked to the corresponding function requirements. These can have both an improving and a limiting effect on the existing function requirements. Furthermore, it is also possible to decompose performance and resource requirements into further requirements, which are then integrated into the network. Fig. 3 demonstrates how performance and resource requirements can be added to the existing network.

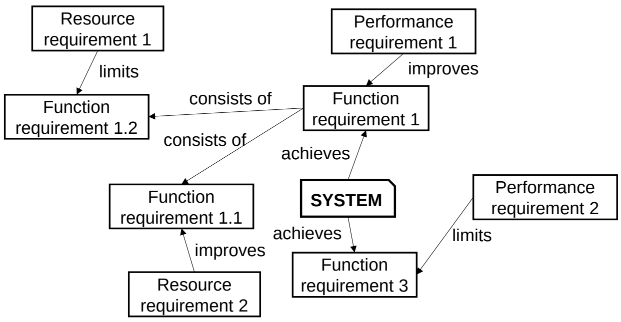

Fig. 3. *Semantic network with preformance and resource requirements*

Finally, the design and condition constraints valid for the product are inserted, which can potentially influence all the requirements contained in the network so far and must be linked accordingly. An example how design and condition constraints can be implemented in an existing network of requirements is shown in Fig. 4.

In order to embed the semantic network of product requirements thus obtained in the overall context of the company system, stakeholders and their goals can also be

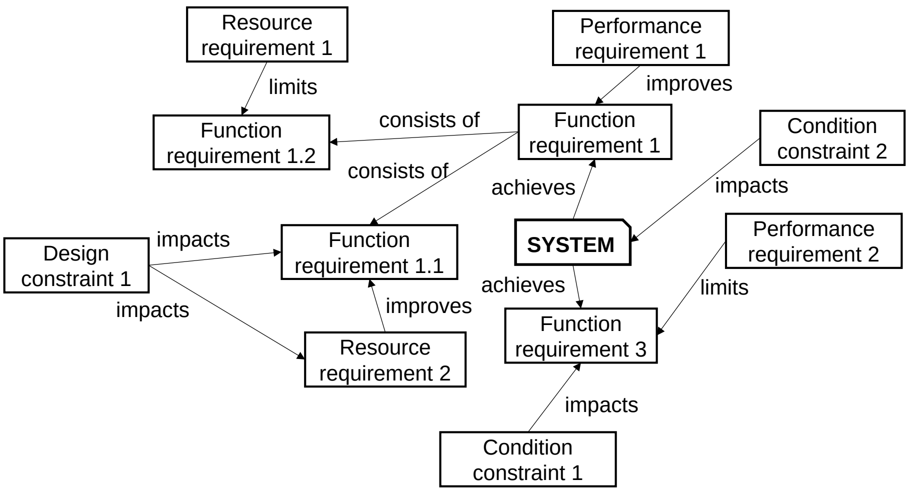

Fig. 4: *Semantic network with condition and design constraints*

taken into account when designing the network. To do this, the stakeholders relevant to product development are first identified. These stakeholders have various touch points with the product and can be either part of the company (production, quality, logistics) or external (customers, suppliers, approval). Requirements result typically from the target system of the respective stakeholders. The addition of stakeholders and their goals to the requirement network is depicted in Fig. 5. Goals that have not yet been addressed by requirements contained in the network indicate missing requirements that should be integrated into the network.

C. Semantic description of the product

Now, building on the semantic linking of the requirements directed at the product, the actual semantic modelling of the product follows. In this way, the concept follows the aforementioned V-model, according to which the decomposition and systematisation of the requirements is followed by the realisation on the product side.

The elements that make up the semantic network of the product are defined as the product (or system), sub-systems, components, design ideas, and attributes. In this understanding, sub-systems are components of the product, which in turn can be meaningfully divided. Components are therefore no longer sensibly divisible parts of the product. A technically or physically possible division of these product components is not taken into account in this framework if the integration of the resulting elements into the semantic network does not add additional information value to the model. Design ideas represent solutions that are used in the context of product development. These can be, for example, technologies, chemical reactions, physical or construction principles. Attributes are descriptive elements that refer to properties of the physical as well as non-physical components of the product. For example, shapes, materials or similar elements can be considered in the semantic network.

To build a semantic network, a hierarchical decomposition of the system is first carried out using these four product elements. First, a system is divided into the relevant sub-systems. A sub-system can consist of sub-systems or components. Furthermore, a sub-system or a component can realise a design idea or possess an attribute. A design idea can also be specified by an attribute. When defining these elements, a continuous comparison with the glossary must be made to ensure that all defined elements are included and described. After building this first hierarchy, duplicate entries are merged. Again, the built-up glossary must be taken into account in order to also merge synonyms according to their assignment. Defined links are retained during this reduction of the network and are assigned to the new representative of all nodes of a glossary entry. Fig. 6 shows the hierarchical decomposition of a generic system.

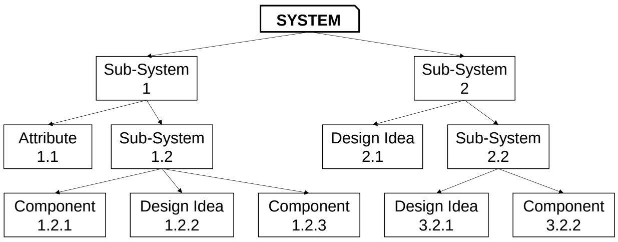

Fig. 6. *Examplary hierarchical decomposition of a system*

Finally, the further interweaving of the described nodes takes place on the basis of the dependency of the requirements. For this purpose, the relevant elements of the product description are first assigned to the requirements. Since requirements are realised by certain product elements, a linkage of the two elements follows, which indicates that the product element realises a certain requirement. This relationship forms cross-relationships within the hierarchical decomposition of the product. In Fig. 7 requirements interconnect the former hierarchical strucutre from Fig. 6 and create a semantic product model.

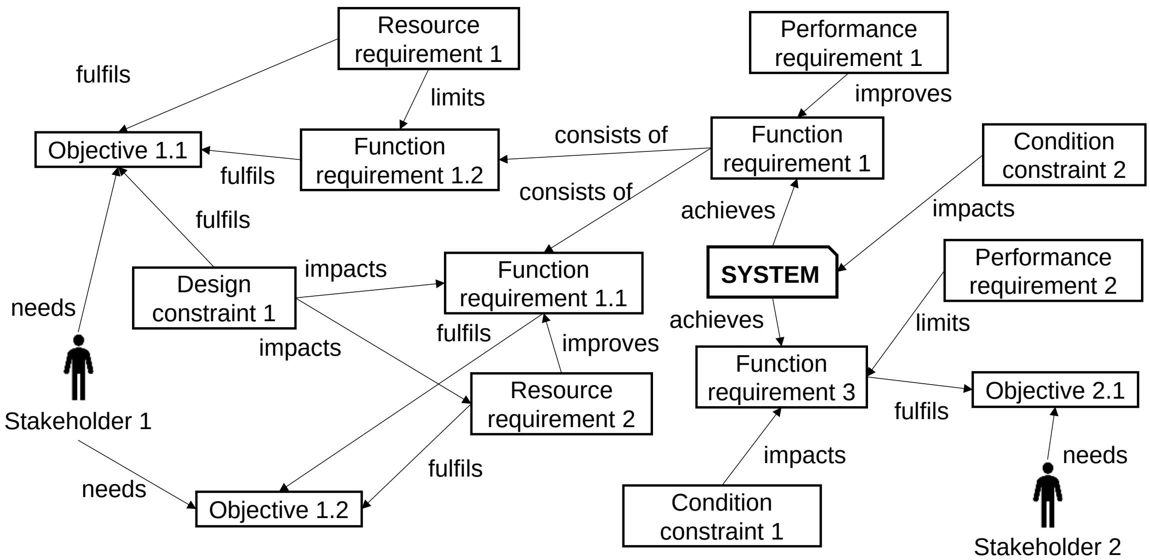

Fig. 5: *Semantic network with objectives and stakeholders*

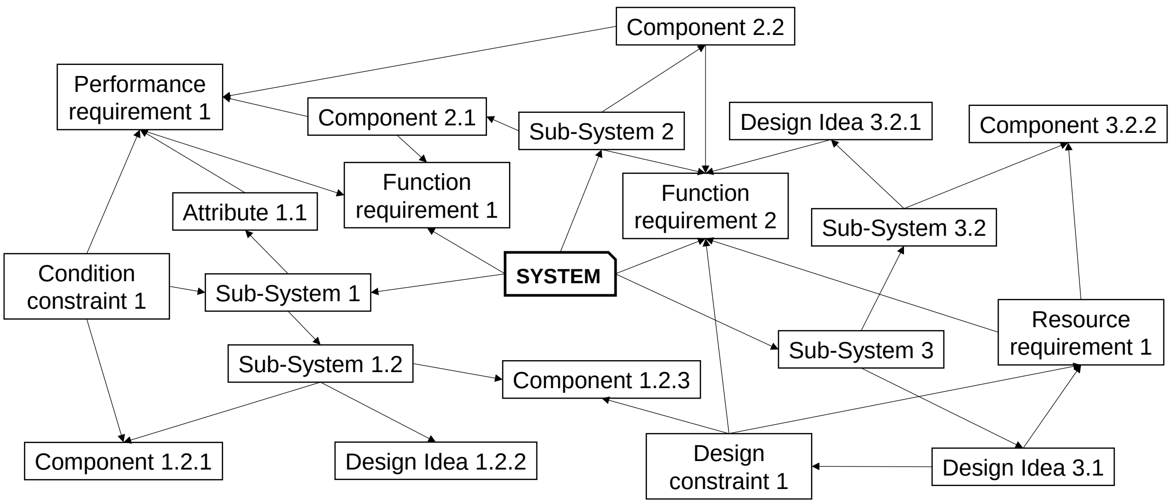

Fig. 7: *Interconnection of the hierarchical product network with the requirements*

By considering a weighting of the edges in the sense of a semantic network, it can also be taken into account that dedicated requirements are realised by several product elements. In this case, the edge weights indicate in each case what share of the overall degree of fulfilment the individual component has.

6. DISCUSSION AND CONCLUSION

The presented approach for the semantic product modelling in the context of innovation management supports companies by providing a holistic overview of the product aspects relevant to innovation management and at the same time maps their interdependencies. First, a glossary is defined that contains the elements to be considered in the network and their synonyms to maintain object identity. The subsequent procedure is based on the V-model for product development processes, which is relevant for system engineering, since the model is intended to support the generation of ideas along the entire development process. According to this model, the problem on which the product is based is first decomposed on the requirements side. The partial result is a network of requirements and their dependencies. Subsequently, the product is broken down hierarchically according to its technical structure. Not only physical components, but also non-physical elements such as design ideas, and attributes are taken into account. The selection of the elements contained in the network is based on the description on the requirements side, so that a customer-side relevance of the elements in the network can be ensured. This selection criterion thus reflects the perspective of innovation management in the procedural model.

The concept presented has been able to support the early phase of idea generation in particular in initial experimental applications. It was observed that innovation management often has only a limited view of the totality of the elements that determine the product and, when deciding for or against an innovation idea, is unable to assess the mutual dependencies within the product. On the one hand, the semantic model can help to map and visualise these dependencies. On the other hand, the semantic model can also be used to gain an understanding of the changeable product elements in order to specifically search for innovation potentials for individual elements.

However, first applications have shown that the semantic modelling of complex products can currently still require an amount of personnel effort on the part of companies. Future research should therefore focus on the question of how the creation of the semantic network can be supported by automated processes. Another field of research opens up in the evaluation of the elements already present in the product and the search for innovation potentials for these elements. Although a large amount of text data is available for search and evaluation, there is still no automated procedure for adding an external perspective to the network that has been built up.

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