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# Ontology for Future-robust Product Portfolio Evolution: A Basis for the Development of Models and Methods

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**Abstract**

The future-robust evolution of product portfolios is a key challenge for manufacturing companies. It requires the integration of strategic product planning and the understanding that products are developed in generations based on references following the SGE – System Generation Engineering theory. There is, though, a lack of consistent terminology that unites these topics and makes their concepts consistent. Their terms are used differently across industries, institutions, and companies. The resulting miscommunication leads to a loss of efficiency. Hence, a structured, interrelated terminology is needed. The paper contributes an ontology that delivers a unifying basis for the development of models and methods.



*Keywords:* Product evolution; Product Generation Engineering; Strategic Product Planning; Product Portfolio; Product Portfolio Management; Product Programme; Corporate Foresight; Ontology;

## 1. Introduction

The development of products is becoming increasingly complex [1]. Faster development cycles and broad product portfolios with strongly networked products across several disciplines are forcing this circumstance [2]. Against this background, the further development of complex and networked product portfolios is a challenge [3]. To meet this challenge, new methods and processes for product planning and development are needed [1].

A basis for the development of methods and processes is a uniform understanding of relevant content through a common use of language. Miscommunication in the development of new methods can lead to delays, errors, or the failure of the project [4]. Consistent communication is therefore a central building block for the successful development of methods [4–6]. A common basis for developing approaches is needed. For this purpose, the conceptualizations and relationships of relevant artifacts are examined and consolidated within an ontology. It is developed based on strategic product planning theory according to GAUSEMEIER as well as the SGE - System Generation Engineering model according to ALBERS [7, 8]. The resulting ontology provides a basis for efficient information exchange and prevents misunderstandings [9]. The paper at hand provides the basic building block for the development of new methods and approaches for the future-robust development of product portfolios.

## 2. Theoretical Background

In the context of the state of the art, existing understandings and models are considered. Following JONAS and KRAUSE a product portfolio can be understood respectively JONAS, GEBHARD, and KRAUSE as the collection of all market offerings

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of a company. This includes trading goods and products the company produces itself. The latter can be further structured according to product lines, product families, product variants, and subsystems [10, 11]. MEYER et al. define challenges in the future-robust evolution of product portfolios based on an interview study. Accordingly, it is necessary to systematically integrate planning and development processes so that companies can realize a product portfolio with several networked product lines across several product generations [12]. Various approaches already deal with the topic of the future-robust evolution of product portfolios: SÖLLNER, for example, considers the planning and monitoring of a future-robust product portfolio [13]. DÜLME, has developed an approach for the future-oriented consolidation of product programs rich in variants [14]. KÜHN established an approach for systematic planning of product releases [15]. The KaSPro - Karlsruhe School for Product Development provide a reference product model which has already been tested for the specification and modelling of complex products in the automotive context [16, 17]. MARTHALER's method for future-oriented product development represents a systematic approach to deriving cross-generational systems of objectives for future product generations through strategic foresight [18]. Furthermore, there are already initial approaches to specifying product functions across product portfolios [19]. The approaches mentioned are successful in their areas, but do not take into account the main tasks of further development on individual levels of a product portfolio and the relations and effects of changes between different levels of the portfolio. Furthermore, the parallel evolution in generations with different lifetimes within a portfolio is not yet sufficiently addressed [12] .

Against this background, two models respectively theories are considered in the following which enable the description of development processes in generation, regarding existing elements, and can outline the planning of market offerings over different time horizons. These are the SGE - System-Generation-Engineering model according to ALBERS and the reference model of strategic planning and integrative development of market offerings according to GAUSEMEIER.

### *2.1. Modell of SGE- System-Generation-Engineering*

The model of SGE – System-Generation-Engineering according to ALBERS provides an approach that enables the description of fundamental phenomena in the evolution of new products and systems. The model of SGE is based on two hypotheses [8], [20]:

- Every development is based on a reference system. The reference system for the development of a new system generation is composed of elements of already existing or planned socio-technical systems. It represents the basis of the new product generation [21].
- A new system generation is developed based on the reference system through a combination of three types of variation: principle variation (PV), attribute variation (AV) and carryover variation (CV) [22].

### *2.2. Reference model of strategic planning and integrative development of market offerings*

The reference model of strategic planning and integrative development of market offerings describes the process of creating a new complex market offerings (products and services) from the first idea to the start of production respectively market entry [7]. It is composed of four main task areas of strategic product planning (SPP), product development, service development, and production system development [7]. Strategic product planning represents the first main task in the product development process. The main task considers the identification of future success potentials, the discovery of promising product ideas and business planning [7]. The results are the products to be developed by the company [23] and the corresponding lists of requirements [24].

## 3. Research methodology

This paper aims at an informal, domain-specific and task-oriented ontology for the elaboration of methods and processes for the further development of the product portfolio. The present work follows GRUBER'S understanding that an ontology is an explicit, formal specification of the conceptualization of a delimited domain of discourse for a defined purpose agreed upon by a group of actors [25]. Further, the conceptualization represents a set of informal rules used by a person to delineate and abstract the relevant elements and relations of the realm of reality [26]. The ontology should represent a basic building block by establishing a common understanding of the structure and meaning of information between different stakeholders by defining correlations and elements [27].

The procedure used for the ontology development is based on the procedure for the development of ontologies in the engineering design context according to AHMED et al. [28]. The procedure is illustrated in Figure 1. Figure 2 shows resulting exemplary artifacts for each step.

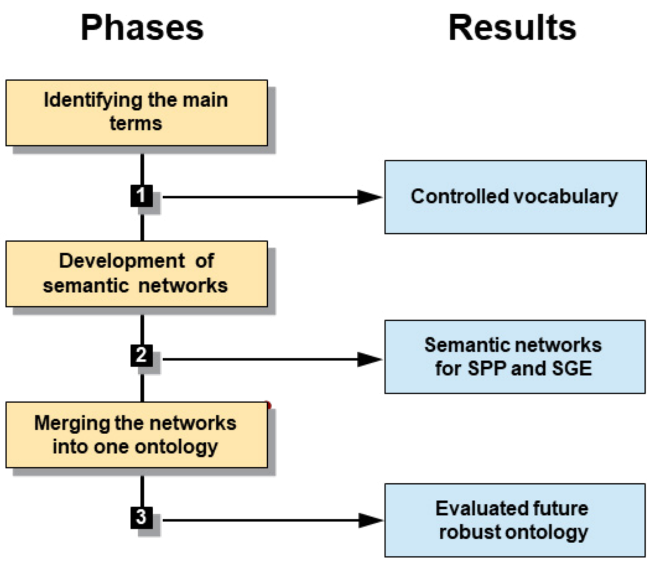


Fig. 1. Procedure for developing the ontology AHMED et al. [28]

**Phase 1:** In the first step, the identification of the relevant vocabulary in the respective domains of strategic product planning and the SGE - System-Generation-Engineering was conducted. A frequency analysis and the word pair analysis performed of the prior work in strategic product planning (SPP) and SGE using a data mining approach revealed the main terms used in the SPP and SGE approaches. Using the Data Mining results, over 1500 terms were considered in the creation of an initial vocabulary. However, the numerous results of data mining still contain terms which are not relevant for the research subject. In total, 140 relevant terms were chosen for the controlled vocabulary. Once the vocabulary has been defined and ordered, and language defects have been removed, the vocabulary is considered to be controlled. Synonyms such as car and vehicle in the automotive context, are combined [29].

**Phase 2:** However, the developed controlled vocabulary does not make any statement about relationships between the terms. Using initial approaches in the form of taxonomies, a hierarchical structuring of the terms could be shown. This could be supplemented with associative relationships to form a thesaurus. The various partial results from this phase are illustrated schematically in Figure 2. Accordingly, terms with the same meaning as vehicle and car were combined. The development of **semantic networks for the two domains** is an extension of the thesaurus: They place conceptualizations in reciprocal relationships; point out variants and set competing concepts. Figure 2 shows a semantic network with two different variants of gearwheels used for the transmission and the steering.

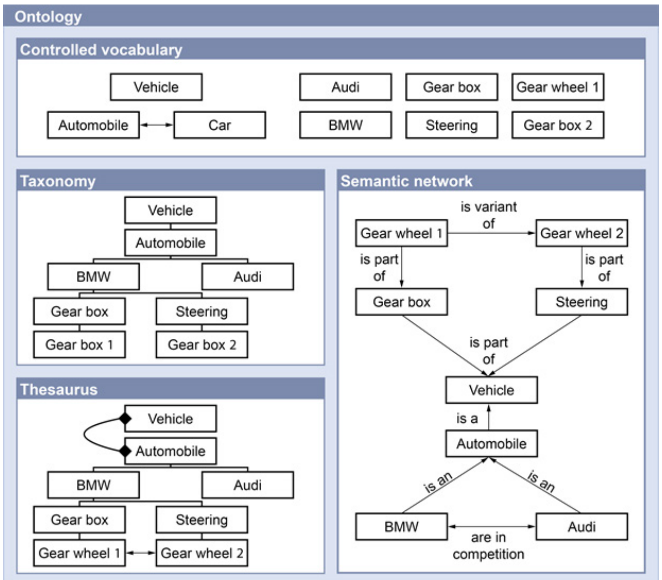


Fig. 2. Partial artefacts on the way to a unified ontology demonstrated for a case from the automotive industry [29]

**Phase 3**: Following the goal of developing a uniform basis, the semantic networks developed are combined into an **initial uniform ontology.** Thereby, the interfaces and contradictions of the semantic networks are focused on and brought together. After refinement and discussion of the interfaces, a **common ontology** could be developed in the last step [29]. The result is a uniform language for the future-robust further development of product portfolios for the development of methods, processes and models. This counteracts the sometimes heterogeneous use of terminology and creates a uniform understanding of language, which is essential for efficient communication between all stakeholders involved in future-robust product portfolio development [30].

## 4. Results

Following the research methodology shown in chapter 3, the corresponding results are presented below. Chapter 4.1 outlines the controlled vocabulary. Based on this vocabulary, the semantic networks is presented in chapter 4.2 and the consolidated ontology is introduced in chapter 4.3.

### 4.1. Controlled vocabulary

Key terms of the controlled vocabulary on the part of the SGE were for example: *Generation, Objectives, Requirements* and *Subsystems.* On the part of the SPP, terms such as *Strategic Early Detection, Technology Planning* and *Product Programmes* were added. Several terms such as I*nnovation, Strategic development* and the *Early phase* already emerged as common elements in the vocabulary of SPP and SGE. In the further course, these terms represent the interface for the creation of a cross-domain ontology for the future-robust further evolution of product portfolios based on the two semantic networks.

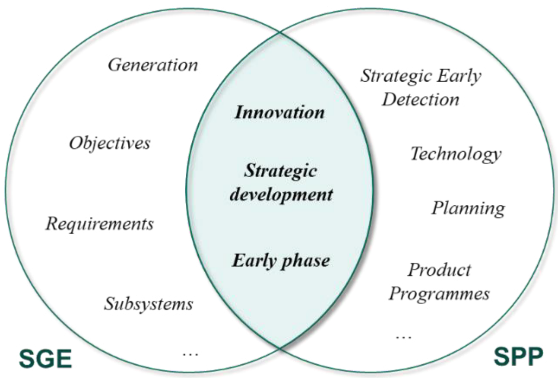


Fig. 3 Venn diagram for the partial results of the data mining approach with the single sets SGE and SPP

### 4.2. Semantic Networks for SPP and SGE

The semantic network for the SPP and the PGE is based on the controlled vocabulary. The semantic network of the SPP was structured and interrelated based on the terms from the controlled vocabulary about the main tasks of the SPP. Figure 4 shows examples of the sub-elements of the product program and the product ideas. The common elements in Figure 4 and 5 are shown in red. The elements from the SGE are highlighted in green and the elements of the SPP are depicted in blue.

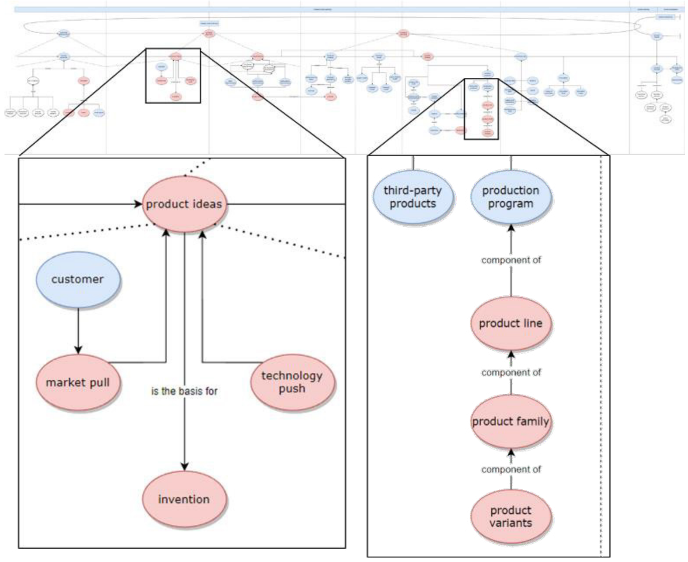


Fig. 4. Semantic network for strategic product planning according to GAUSEMEIER [7]

The center of the SGE semantic network is based at its core on ALBERS' understanding of an innovation [31]. Figure 5 shows a section of the elements of the innovation equation according to ALBERS [31]. Based on the innovation equation, the semantic connections are extended in the direction of iPeM - integrated product development model [32] and the model of SGE. As a interim result, two consistent semantic networks for the area of SPP and the area of SGE are available.

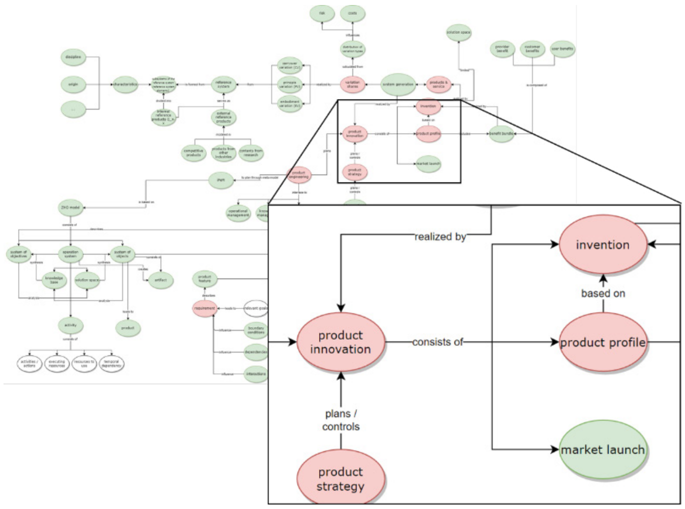


Fig. 5. Semantic network for the model of SGE according to ALBERS [8]

However, future robust portfolio evolution requires a uniform ontology that creates a consistent conceptual world beyond the two semantic networks as well as relationships between their concepts. This also includes the discussion of the elements of an ontology in the context of the language used in companies. For this purpose, the merging is carried out analyzing the language used in practice utilizing the data from the interview study *Future-proof further development of product portfolios: insights and need for action from practice* according to MEYER et al. [12].

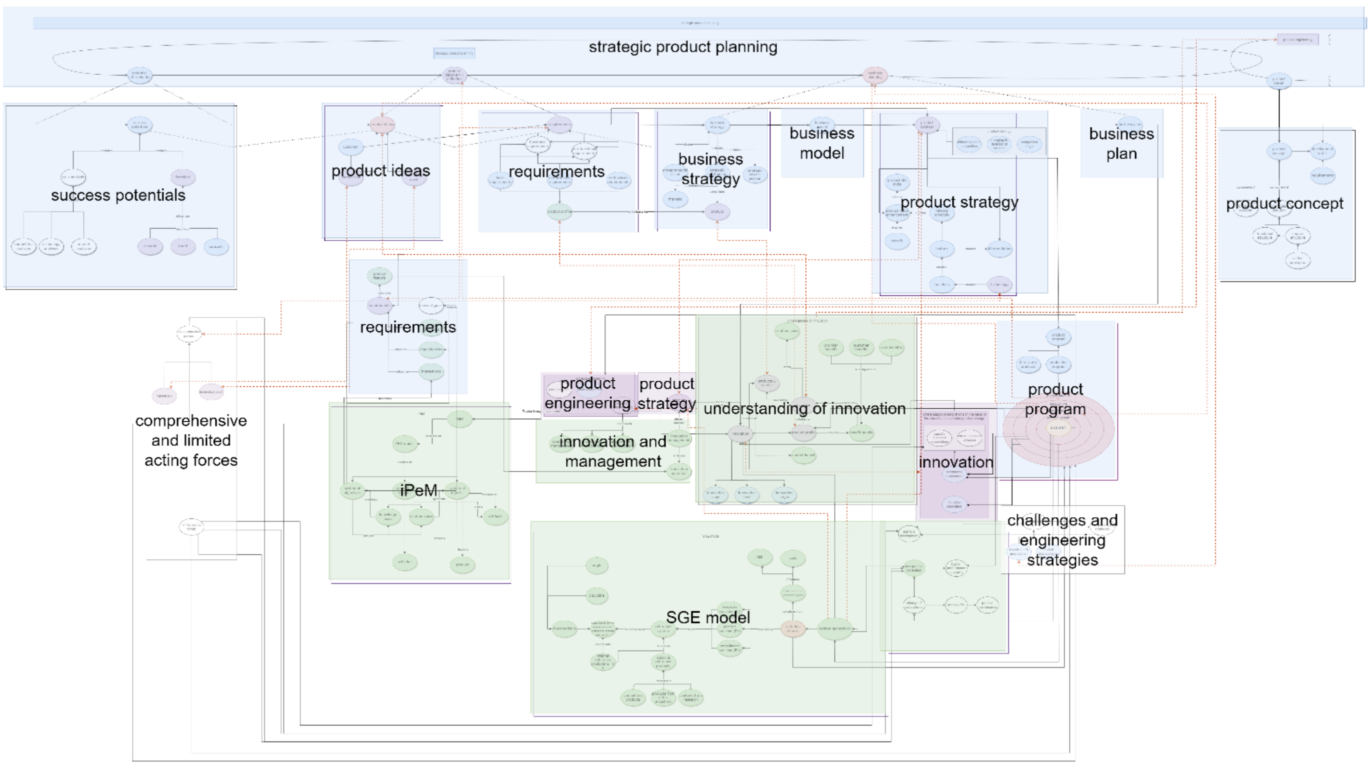


Fig. 6. The ontology for future robust product portfolio development. The illustration shows the different areas of the common ontology due to the large number of elements and connections. (Green background elements from the SGE, blue background elements from the SPP and white supplemented elements.)

### *4.3. Common future robust ontology*

A key challenge is the scope of elements and connections spanned by the two semantic networks. In the context of merging the semantic networks, the focus had to be placed on essential elements. Furthermore, this paper focuses on the central interfaces between the SPP and the SGE. An example of this is the understanding of innovation, which, according to the understanding of the SGE is composed of product profile, invention and market launch [31]. This is complemented by the division into different forms of innovation, which GAUSEMEIER discusses based on CHRISTENSEN and BULLINGER'S view [7, 33, 34]. The final overarching ontology for the future-robust further development of product portfolios is shown schematically in Figure 6. The ontology can be broken down into different areas using different activities and elements of the original models. These areas are closely linked to each other via distinct relations. Due to the complexity and large number of elements, a fractal view is chosen for the presentation and the headings of the individual areas are highlighted.

## 5. Discussion

The analysis of the two initial vocabularies reveals that the interface of the two ontologies in particular emerges as a central starting point for miscommunication, which could be eliminated by the presented ontology. On closer examination, the interfaces cannot only be traced back to the use of the same words. Especially challenging is the identification of different terms which refer to the same or similar elements. These terms can only be identified with a deeper discussion of understanding. Three central sticking points will be discussed in the following.

(I) The comparison of product profile and development order: The reference model of strategic product planning according to GAUSEMEIER sees the development order as an artifact in product creation that serves as a handover document between strategic product planning and product development [35]. KaSPro - Karlsruhe School for Product Development also holds a similar artifact called the product profile [31]. In the comparison of the product profile and the development order, it becomes clear that they cannot be used synonymously, but that both represent artifacts within the framework of product development that build on each other [36].

The product profile according to ALBERS is to be used earlier in the product development process than the development order. The product profile can serve as an increment between product discovery and business planning. In addition to the title of the product portfolio, the focus is on the various benefits differentiated according to provider, user, and customer use, the development order does not explicitly show these. The product profile also refers to references and a planned validation concept. The development order, on the other hand, focuses on the temporal operationalization of the planned product; a schedule, life cycle costs and planned steps of the development process are shown. The development order thus represents the transition to the product concept as an increment.

(II) The use of the same terms with different understandings shows up centrally with the term innovation. GAUSEMEIER discusses different forms of innovation at the degree of product change into basic and follow-up innovation as well as further into disruptive innovations [7]. These can be subdivided according to CHRISTENSEN into radical and incremental innovations. As well as further subdivision according to BULLINGER into breakthrough innovation, top innovation, must innovation or incremental innovation is possible [7, 33, 34]. In the understanding according to ALBERS no differentiation is made between the various forms of innovation. Here, an innovation consists of a product profile, an invention, and a successful market launch. [31]. The various forms of innovation can be traced back to the basic elements of an innovation in the understanding of the future-robust development of product portfolios, so that the basic equation according to ALBERS must be fulfilled for every form of innovation.

(III) Another point is the use of the terms "component" and "subsystem". For a company, the smallest element in the portfolio is the component. For its suppliers, components of the OEM in turn represent individual product variants, which are handled as systems and are further subdivided into subsystems [12]. These are taken up in the company-internal linguistic usage again as components. Several companies will contribute to the system "product" on different levels. "Components" of the OEM in turn represent a "product" as a system in supplier companies. The objective of the approaches to be developed includes transferability for different companies. This has to be considered already in the underlying ontology. Therefore, the term "subsystem" is used in the context of the ontology. This choice of term is transferable to different companies.

## 6. Conclusion and Outlook

In the paper at hand, semantic networks for the subareas SPP and PGE (chapter 4.2) were developed via a controlled vocabulary (chapter 4.1) and transferred into a common ontology (chapter 4.3). Three central points were identified during the merging process and transferred into a common consideration via a discussion: (I) Alignment of product profile and development order; both represent increments in the product development process. The product profile represents an earlier increment with focus on the demand situation compared to the development order, which operationalizes the result of the SPP for the product development. (II) Innovation understanding; The innovation promise can be derived on a common basis, which is composed of invention, product profile and market launch. (III) Product program level subsystem; a uniform cross-company designation for the lowest level of a product portfolio was found (subsystem). Looking at the whole, the considered approaches could be transferred into a common language usage. The elaborated ontology provides a basis for the development of new models and methods for future robust product portfolio development. The present ontology represents only a first basis without any claim to completeness. The present work focuses on the fundamentals of SGE and SPP other theories may not be sufficiently considered in the ontology. Depending on the topic, the existing ontology has to be further developed in the corresponding direction. The ontology needs to be continuously validated and extended.

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