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Effect-oriented Description of Variant rich Products

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Abstract

Due to changing market situation the variety of products and parts increases constantly. Regarding the increase of the products and parts variety the code-based description of variant rich products and their interdependencies comes to its limitations. The complexity for describing variant-rich products in the technical product documentation can hardly be managed anymore. The effect-oriented description is a promising approach for an efficient and understandable description of variant-rich products and parts. In this case the product variety is described regarding to its partonomy and taxonomy in a general ontology. The interdependencies between parts are expressed explicitly with regard to the effects and properties between the parts. In a research project at the DaimlerChrysler AG it could be shown, that based on the effect-oriented description the efforts and the complexity in the technical product documentation can be reduced significantly.

Keywords: technical product description, product variety, ontology

1 Introduction and objectives

The business of an OEM changed significantly in the last years. Heterogeneity of the customer's requests, uncertain, strongly varying demand as well as shortened product and process technology cycles mark a new competitive situation. Enterprises react to this situation with the differentiation of their material and immaterial products and services. As a consequence the increase of selectable equipment properties for a product can be constituted, as it can be observed exemplarily in the automotive industry [2]. The constant increase of selectable customer options causes substantial problems to ensure the consistent description of the product variety and the interdependencies between different parts in the variant-rich mass production. The increasing product variety causes an enormous complexity and substantial efforts in the technical product documentation. Based on the definition of the general product life cycle the technical documentation is a part of the product design process [1]. The results of this development are for example inconsistencies in the bill of material which can have direct effects on the production process, product quality and production cost [3].

The objective of this paper is to introduce a methodology for a simplified and efficient description of variant-rich products and the interdependencies between their parts. Based on this methodology the efforts to describe the product variety and the interdependencies between parts should be minimised. Furthermore the described interdependencies should be understood easily. Therefore the methodology should include an understandable form to represent information about the product variety and the described interdependencies. A promising approach is the effect-oriented description of products and the interdependencies between parts, which is introduced below.

2 Current approach in the documentation of variant rich products

In the industrial practice the description of variant-rich parts and their interdependencies uses codes. Codes represent the properties and functions of parts. Technical, geometrical and sales restrictions between the parts are described by so called production rules, which are based on Boolean algebra [4], [5]. Substantial elements of these production rules are codes of the parts functionalities as well as Boolean operators (Figure 1).

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Figure 1: Production rules based on Boolean algebra

The technical description of the product is coupled to the variety of the parts. The more parts variants have been developed, the more codes are needed to describe the parts variety and the more Boolean expressions have to be formulated to describe the restrictions between the parts consistently. The number of Boolean expressions behaves therefore proportional to the variety of parts. For a consistent description of all product variants a multitude of Boolean expressions have to be provided and maintained. The efforts in the technical product documentation rise considerably.

Furthermore the described interdependencies are hardly interpretable because of the coded restriction causes (Figure 1). Due to the difficult semantic the description and the maintenance of these Boolean expressions can not be done without sufficient training of the employees. Boolean expressions can often be understood and maintained only by the person, who wrote them.

Besides this for the description of the interdependencies the properties of parts have to be considered. Analyse in the automotive industry show that the complexity of the description of the interdependencies can be just hardly managed, if more than three properties have to be considered. However for 40% of the positions in the bill of material at least four properties have to be considered [4], [5].

3 Methodology for modelling complex systems

Regarding the theories of systems the description of variant-rich products and the interdependencies between parts characterises the modelling of a complex system. The parts and components represent the elements of the system. The interdependencies between the parts characterise the relations of the system. Therefore the complexity of the system depends on the variety of the parts as well as on the variety of the interdependencies between the parts.

Using this background a methodology for an efficient modelling of complex systems has to be identified. The methodology should fulfil the following requirements:

The methodology for modelling a complex system should be able to define products and parts as technical objects clearly [5], [6]. The properties of the parts should be represented as attributes of technical objects [5]. Furthermore the methodology should be able to illustrate the variety of the objects and their attributes in a simple, clear, understandable and complete way [5], [7]. A classification of the objects by their attributes and a hierarchical description of the system should be supported [5], [8]. It is necessary to describe and to illustrate the and variety of the interdependencies between parts completely, transparent and understandable [5], [8]. The methodology should ensure a simple alteration of the described parts and interdependencies. The efforts to maintain modelled system should be as small as possible [5], [8].

Regarding the specified requirements it is helpful to describe complex technical systems by using ontologies. Ontologies have been developed in the Artificial Intelligence to facilitate knowledge sharing and reuse. Ontology-based modelling characterises an object-oriented approach for modelling complex systems in a formal and generally accepted way. Complex systems can be described considering of their partonomy and taxonomy. The description of the partonomy contains the representation of relations between the elements of the system. By describing the partonomy it is possible to define the structure of the system. The description of the taxonomy includes the documentation of the generic relations of the system. By describing the taxonomy it is possible to classify the objects by their attributes in a general hierarchy of the product. The attributes and the relations between the objects can be inherited along the product hierarchy [14], [15].

Therefore the methodology for an effect-oriented description of parts and their interdependencies is based on an object-oriented approach for modelling complex technical systems by using ontologies.

4 Effect-oriented description of parts and their interdependencies

The starting point for the effect-oriented description of variant-rich products is the definition of the components and parts as technical objects (chapter 4.1). In chapter 4.2 these technical objects are defined in a general ontology. In chapter 4.3 the interdependencies between the parts are described. The effects between the parts are characterised in an explicit and general way.

4.1 Definition of parts as technical objects

For an effect-oriented description all components and parts of the product are defined as technical objects. Technical objects characterise individual, clearly identifiable, material parts with clear physical boundaries [8].

The physical boundaries of the parts are characterised by their geometries. At these boundaries parts can have interactions with their environments. The environment represents any physical surrounding of parts. For example other parts in an assembly can be the environment of a part. So at the boundaries of the parts there can be some exchange of energy, materials or information. The exchange of energy can be identified by the exchange of mechanical, electrical, thermal or optical energy. The exchange of material is based on the properties of the parts. For example the surface properties of parts can cause the exchange of material. The exchange of information marks the exchange of signals between parts. Signals are the physical form of information. Especially electronic parts have some exchange of signals with other electronic parts [11].

Parts and components can be identified by the description of their attributes in detail. The attributes of parts mark their inherent and distinctive properties. In practice often attributes are represented by the object parameters [8]. The attributes of parts can be distinguished in the categories of technical, commercial attributes as well as attributes for the disposition [12] (e.g. Figure 2).

Technical attributes contain technological attributes, e.g. material or weight. The exchange of energy, material or signals at the boundaries of parts with their environments is based on their technological properties. Therefore technological attributes of parts have to be considered for the description of the interdependencies between parts.

Additionally technical properties can be concretised by geometric attributes. Geometric attributes can include both the dimensions of parts and components as well as the representation of the parts in 2 and/or 3-D-Modell. Geometrical attributes characterise the boundaries of parts. Therefore geometric attributes are also relevant for the description of interdependencies between parts.

Furthermore technical attributes can be concretised by organisational attributes of components. Organisational attributes are for example the codes, names or id-numbers of parts. Organisational attributes serve mainly to identify and classify of technical objects.

Disposition attributes consider aspects for the planning and controlling of the production process. They include for example information about stock locations. Commercial attributes contain sales-specific aspects, like prices or information about the market. Organisational, dispositive and commercial attributes do not cause any kind of exchange between technical objects with their environment. Nor do they include the description of the boundaries of parts. Therefore they are not relevant for the description of interdependencies between parts.

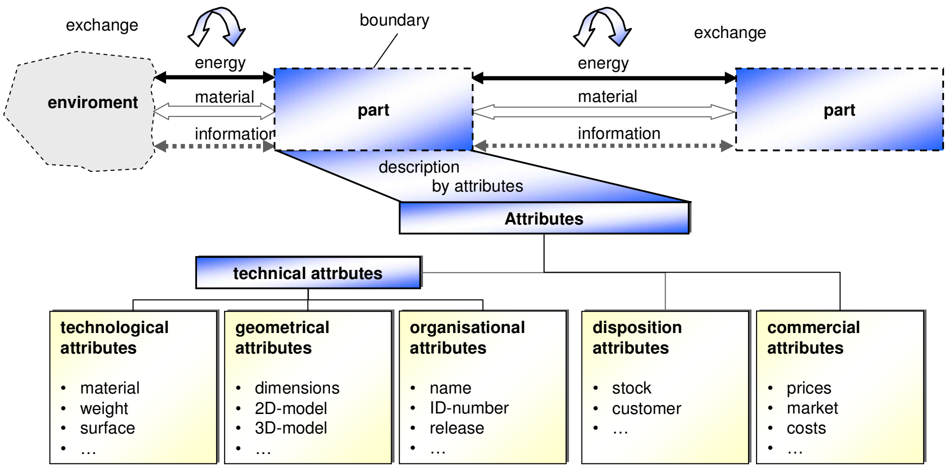

Figure 2: Definition of parts as technical objects

4.2 Ontology-based description of the product structure

After the definition of parts as technical objects the complete structure of the product is described with regard to its partonomy and taxonomy.

For the definition of the partonomy the complete structure of the product is decomposed into its main parts or components (e.g. assemblies). The relations of these parts and components are described by "part-of-relations” in an explicit and general way (Figure 3). Therefore it is possible to describe and illustrate the complete structure of the product in a hierarchical class structure. The decomposition has to be done with regard to the structure of the product and may include any number of steps. For example in the fist step a product can be decomposed into its main parts or assemblies. The main parts can also be composed into some other parts. Therefore the main parts can be decomposed by "part-of-relations" into their parts on a lower level of the product hierarchy.

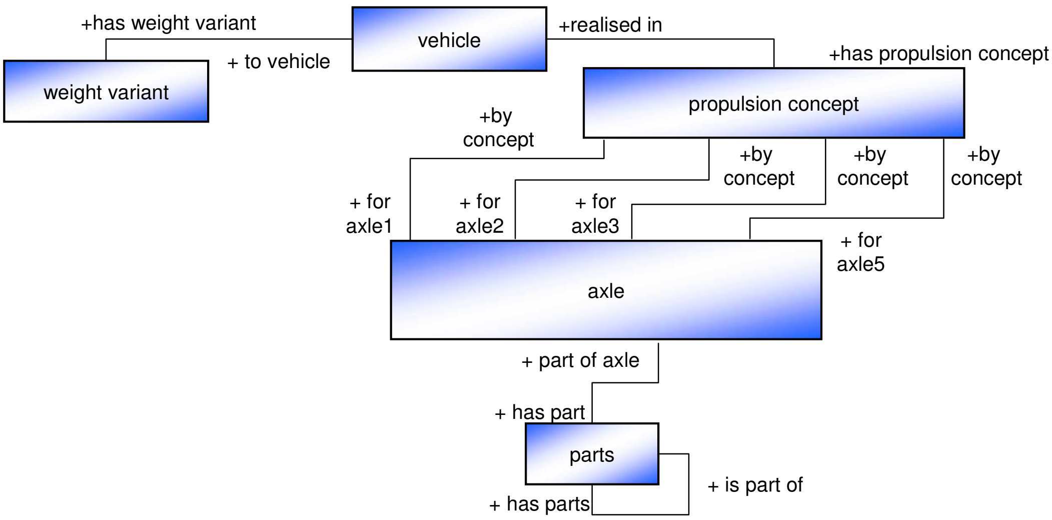

Figure 3: Partonomie of the product (e.g. Vehicle)

The developed class structure is extended by the description of the taxonomy. Components and parts are categorised with regard to their attributes in terms of "is-a-relations" in different classes and subclasses (Figure 4). The classes resulting from the classification (description of the taxonomy) characterise specifications of the classes, which were developed by the description of the partonomy.

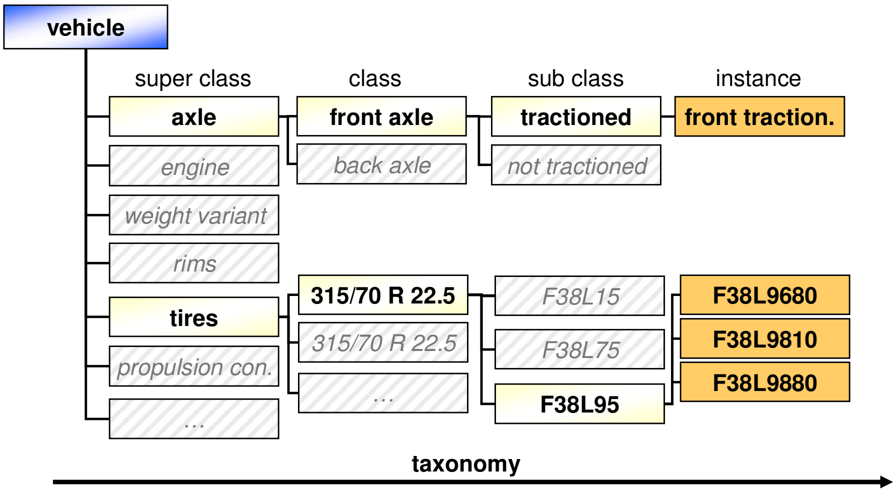

Figure 4: Taxonomy of the product (e.g. Vehicle)

On the lowest level of the hierarchy the part variants are instantiated and described in detail by their object parameters as introduced in chapter 4.1.

The description of products regarding their partonomy and taxonomy enables a simplified and structured description of complex products. The description of the partonomy enables the description of the structure of the product in a general and explicit way. The description of the taxonomy enables a structured classification of components and parts in a general and hierarchical class structure. Both general relations between the components as well as the attributes of the components can be inherited to the lower level of the class hierarchy.

4.3 Description of the interdependencies between parts

Interdependencies between parts are based on technological, geometrical, sales and legal restrictions.

Technological and geometrical restrictions include interdependencies between components with their environment. These interdependencies mark on the one hand the exchange of energy, materials and signals between components by their environment (see chapter 4.1). On the other hand packaging restrictions are considered.

For an effect-oriented description of these restrictions the technical and geometrical effects or reasons of the restrictions are described and represented explicitly and in general as conditions or equations between the parts (Figure 5). Therefore the attributes of the parts are linked with each other by the equations. The described equations are integrated into the hierarchy of the developed class structure. Thus the described equations can be inherited to lower relevant levels of the hierarchy. This way the equations are valid for all relevant part variants.

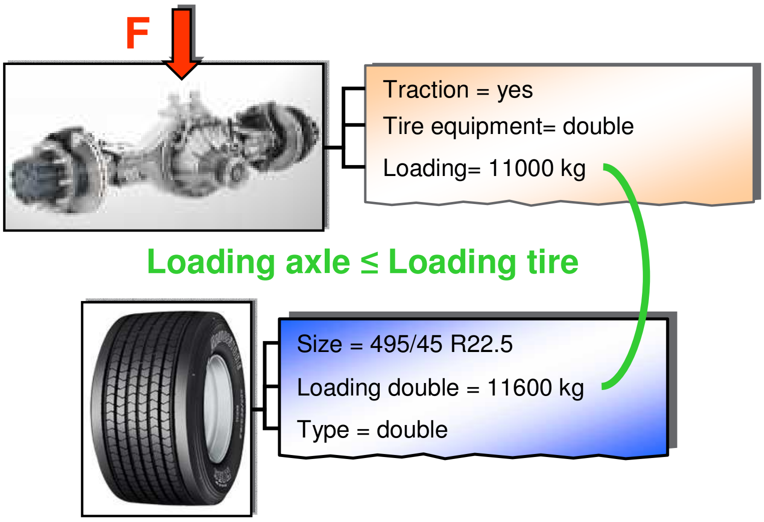

Figure 5: Effect-oriented description of technical interdependencies
(e.g. tyre and axle)

The sales restrictions are usually not based on technical or geometrical interdependencies. Thus e.g. based on marketing reasons only certain product configurations are released. Such sales restrictions cannot be represented usually as general equations. These of restrictions have to be formulated in the context of the effect-oriented documentation by “if-then-relations”, which are represented as implications.

5 Case study for an effect-oriented description of variant rich products

The introduced methodology for the effect-oriented description of variant-rich products has been evaluated in a research project at the DaimlerChrysler AG. The goal of the project was to ensure a consistent configuration and documentation of variant-rich products based on the effect-oriented description methodology. The evaluation was exemplary done for the configuration and documentation of tires and rims of the Mercedes-Benz trucks. For the evaluation the represented methodology was implemented in an IT prototype. In the following some essential aspects of the case study are described.

Starting point for an effect-oriented description is an object-oriented representation of the vehicle in an ontology. In this case study information about the vehicle model, tires, rims, weight variants, propulsion concepts, axle types and countries had to be described.

For this the vehicle is divided with regard to its partonomy (structure) in the super classes weight variant, propulsion concept, axles as well as parts (Figure 6). These super classes have general relations to each other. The relations are explicitly described. For example each vehicle always has a weight variant and a propulsion concept. The propulsion concept results from the composition of different axle types. The axles stand in relationship with other parts (e.g. wheels).

Figure 6: Description of the vehicle partonomy

The described super classes are classified with respect to their attributes. For example the vehicle can be divided into the classes Actros, Atego, Axor, Atego 18t and Econic. Within the Actros class the different variants of the Actros model can be classified for example by their vehicle type. The other components are described in the same way. Fore example tires are first classified according to their sizes. The hierarchically lower classes are built with regard to the different kinds of the profiles. On the lowest level of the hierarchy the tire variants are modelled as instances and described by their object parameters, which are represented as the attributes of the technical object tire (Figure 7).

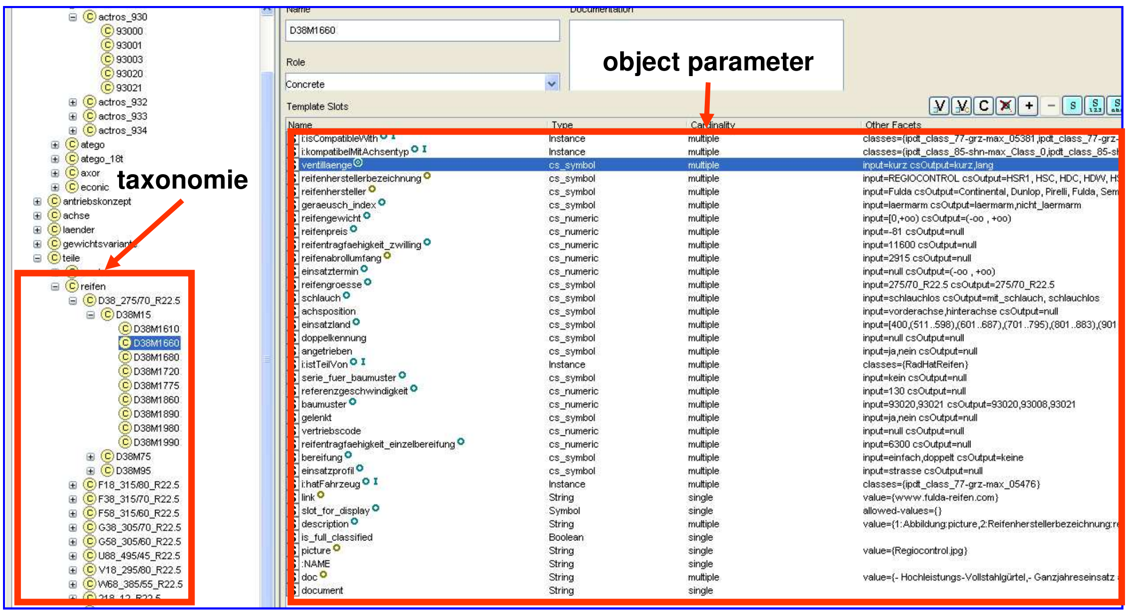

Figure 7: Description of the tires

The interdependencies between the parts and their attributes are described by general equations. In the following the effect-oriented description of the interdependencies is explained by some concrete examples.

For the identification of a valid tire for an axle the following requirements have to be considered: The tire has to be able to carry the load which is on the axle. So the load-index of the tire should be at least equal to the loading on the axle. Therefore the attribute “load-index” of the tire is connected with the attribute of the “axle load” of the axle by the equation $load\_axle \le load - index\_tire$ in a general way. This equation is valid for all variants of tires and axles and will be inherited to all objects of the lowest level (Figure 8).

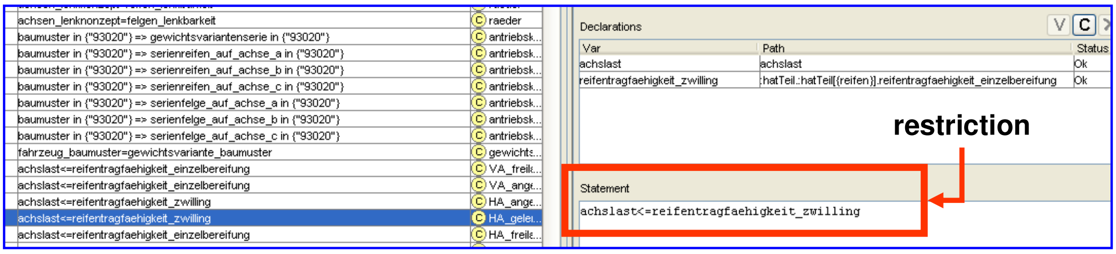

Figure 8: Description of the loading restriction

Moreover the tire has to be released for the position of the axle. For example some tires are just released for the front axle. Similar to the previous case the attribute “axle position” of the tire is connected with the attribute “position” of the axle by the following equation $position\_axle = axle\_position\_tire$ (Figure 9).

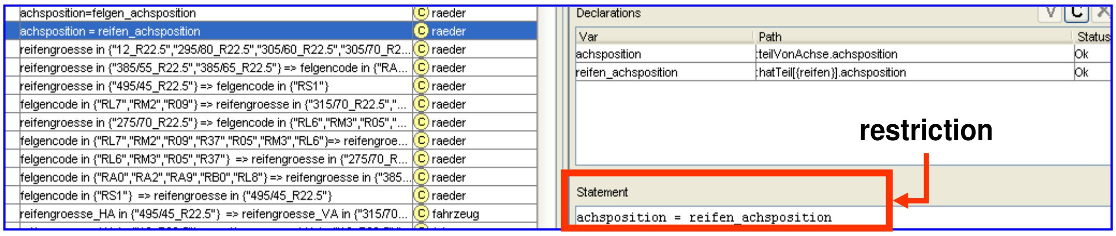

Figure 9: Description of the restriction of axle prosition

Furthermore the type of the tyre (single, double) must correspond with the type of the axle (for single or double tire). Therefore the attributes “type tire” and the attribute “type axle” are connected with each other by the following equation $type\ tire = type\ axle$ (Figure 10)

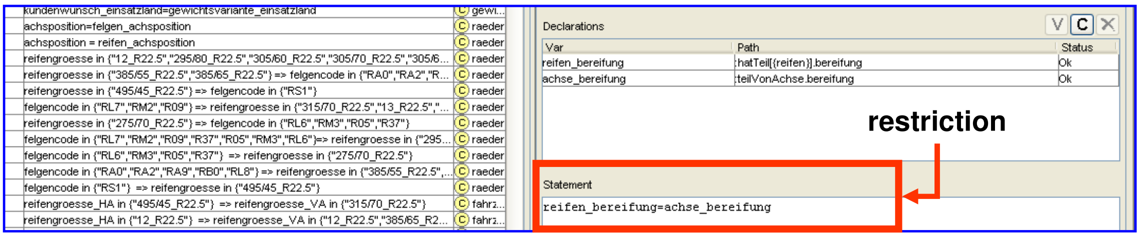

Figure 10: Description of the restriction of the tire type

Based on this description concrete combination of tires and rims were configured. The results of the configuration tests were confirmed in their quality by the experts. Therefore it can be concluded that the relevant parts and interdependencies for the case study were described completely and correctly.

An advantage of the effect-oriented methodology is the fact that a high number of technological interdependencies between parts can be described in a general way. For example in the introduced case study for a consistent code-based description of all interdependencies between the considered parts 800 – 1000 Boolean expressions (production rules) have to be documented. In comparison to the code-based description based on the effect-oriented methodology only approximately 150 equation have to be described and maintained (Figure 11).

Furthermore the formulated equations describe the effects between parts in general. Therefore the described equations are not affected by changes of the product variety. Thus the formulated equations are more robust against changes of parts or the product variety than the Boolean expression. A further advantage is the simple and understandable semantic because of the explicit description of the effects between parts. In comparison to the Boolean expressions the reasons of the restrictions are explicitly described and are not represented by codes. The comprehensibility of the interdependencies is much higher. The efforts in the technical product documentation can be reduced significantly.

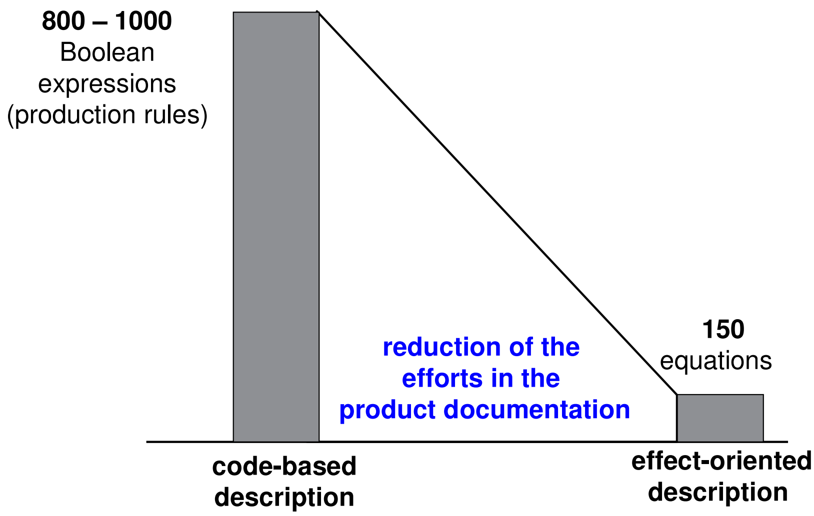

Figure 11: Comparison of the methodologies in regard to the introduced case study

6 Conclusions

The car business changed significantly in the last years. The new competitive situation is characterised by shortened innovation and technology cycles as well as individual customer's requests. Enterprises react to this situation with the differentiation of their products and services. As a consequence a noticeable increase of offered product variants as well as equipment options has to be noticed. The increase of the product variety affects the increase of complexity for a consistent description of variant-rich products and the interdependencies between parts in the technical product documentation.

Currently the description of variant rich products and parts is based on codes. The properties of the parts are represented by codes. The interdependencies between parts are described by production rules based on Boolean algebra. The more variants of products and parts are available the more codes are necessary to represent them, the more Boolean expressions are needed to describe the interdependencies between the parts. The number of codes and Boolean expression is proportional to the number of parts. Besides this the Boolean expressions describe only implicitly the causes of the interdependencies. Therefore the Boolean expressions are difficult to understand and hard to maintain. The efforts in the technical product documentation can just hardly be managed.

The methodology for an effect-oriented description offers a possibility to describe the variety of products and parts as well as the interdependencies between the parts in a simple and efficient way. The variety of products and parts and the interdependencies between parts is modelled on an ontology-based (object-oriented) approach. The parts are defined as technical objects and are described by their attributes explicitly. For the formulation of technical and geometrical interdependencies the attributes of the parts are linked by equations. These equations describe the effects between parts explicit and in general. Restrictions, which are not based on general interdependencies (e.g. sales restrictions) are described by logical implications.

In comparison to the code-based description fewer equations than Boolean expressions have to be described and maintained. The causes of the interdependencies are described in general and explicitly. The described equations are more robust against changes of parts or the product variety than the Boolean expression. The efforts in the technical product documentation can be reduced significantly as it is shown in a case study for the documentation and configuration of Mercedes-Benz trucks.

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