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PRODUCT DESCRIPTION USING CONFIGURABLE COMPONENTS

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Abstract

The topic of this paper is to present an application in a vehicle development program of the concept of configurable components that was introduced by Claesson et al. [1]. The approach taken is to use a system structure composed of configurable components as the core product description system. The applied system structure model is described as well as the implementation of this model in a commercial PDM system. An example will be used to present and explain the key elements in the applied model. Finally, the paper includes some of the experiences we have made. The focus of this paper is on the practical application of the concept in a vehicle development program.

The configurable component concept and methodology that has been used at Saab Automobile build upon and extend the research around design theory and methodology and product modeling done at the Department of Product and Production Development, Chalmers University of Technology. Among several published papers, we have chosen [2] and [3] to illustrate the concepts and model developed at Chalmers. The problem space of design of modular and platform based products have been described by several other authors. The problem area and an illustrative example of an approach to deal with modular product architecture is given by Dahmus et al [4].

Keywords: Systematic product development, product families, product platforms, product modeling, product data management, industrial experiences

1 Introduction

1.1 Background

A computer-based product description system is used at the core of most manufacturing companies that develop, produce, and provide complex products. Four generations of product description systems were described by Claesson et al [1] (figure1). Today most companies use a product description system of the third generation. There are several problems identified with the third generation of product description systems related to current business requirements. Among these are the fact that these systems traditionally only capture the results of a product development activity and on a very detailed level. One consequence of this is that the descriptions cannot adequately support the early phases of a product development task. Another consequence is that the descriptions captured are detailed data of the outcome of the design and do not include the reasons for this design or how it came to be what it is. Among the negative effects is inadequate support for modularization of design solutions in support of a product platform. Furthermore, we find a very limited support for re-use of parts, and even more important, for re-use of design solutions.

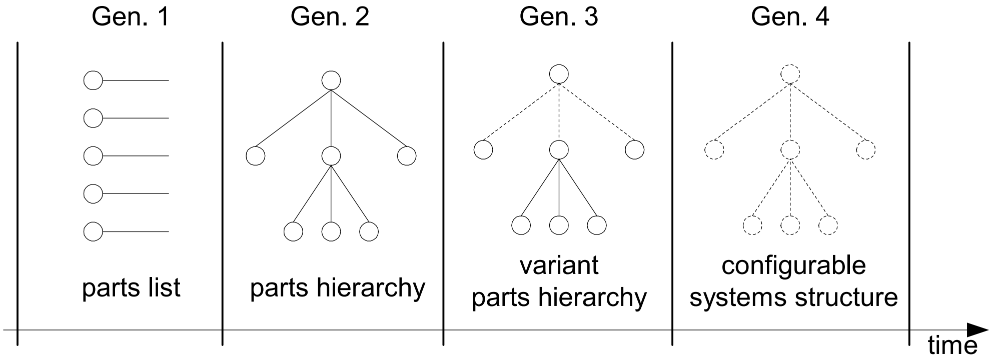


Figure 1. Evolution of Product Description Methods.

In the paper “The role of product architecture in the manufacturing firm” [5], Ulrich has the intention is to raise the awareness of the far-reaching implications of the decisions, trade-offs, and issues that are linked to product architecture. Robertson and Ulrich [6] further elaborate on balancing commonality and distinctiveness and define three key ideas that underlie a platform planning process:

- Customers care about distinctiveness; costs are driven by commonality.
- Given particular product architecture, there is a trade-off between distinctiveness and commonality.
- Product architecture dictates the nature of the trade-off between distinctiveness and commonality.

One of the main purposes with the proposed system structure based on linked configurable components [1] is to provide an information model to capture the product architecture in a platform-based product development approach. The product architecture must include all design solutions that together form the product platform as well as the definitions of all derivative products that will be based on that platform. An expected effect of the application of such an information model is that it will enable the designers and engineers to capture more aspects about the product and the product architecture that may support them in the decision-making necessary to deal with the three statements made in the bullet list above.

The almost contradictory business requirements to achieve product distinctiveness and a high degree of commonality between the products based on a platform give rise to two major requirements: (1) the requirement for modularity, and (2) the requirement for reusability. Consequently, it will be important that the product architecture can provide capabilities to identify and define how variability is achieved as well as to provide richer information about the design solutions as well as the physical parts created from these design solutions.

1.2 Research questions

The research questions to be answered by the case study at Saab are:

- How can the concept a system structure based on configurable components be implemented in order to provide a computer-based system support for the proposed approach in reference [1]?
- Can the described and expected benefits from using such an approach be validated in a real product development program?

1.3 Case study

In our case study, the scoped and framed system chosen for our investigation was a specific vehicle development program at Saab Automobile AB, Trollhättan, Sweden. The case study is interpretative [7]. In an interpretative case study, the theoretical level and degree of abstraction can vary from assumptions about relations between definitions and elements to a complete theory. The applied analysis model is inductive. The purpose of this interpretative case study is to provide insights, support and validate, or question the prescribed theoretical framework. Some risks with the case study method [7] are that it can oversimplify or exaggerate some factors in a situation, which may lead the reader to erroneous conclusions. Another risk is that has been mentioned [7] is that the case study may give the impression to completely reflect a situation or phenomenon, whereas it in reality may be limited only few aspects of the real situation of phenomena.

2 Applied model, implementation and work method

2.1 Applied model

First, we would like to highlight an important difference between the way the design results are described and defined in the new fourth generation approach versus the traditional third generation. The primary change is that we change the fundamental level of the core elements carrying the definitions and descriptions from a parts description level to a more abstract design solution description level. In a third generation product description approach, the middle layers of elements in the hierarchical structure may or may not have a mapping to an existing element in our reality. This element may be a physical entity or a more or less well-defined and well-recognized abstract entity. One problem with the third generation product description approach is that the middle layer elements often lack guiding principles and criteria's for why these particular elements have been chosen to become the organizing mechanisms for the description of the product. In our approach, we use the criteria we defined for an element representing a *system*. A *system* is a set of interrelated and interacting components that taken together fulfill a well-defined function (or functions) with well-defined boundary and interfaces towards the environment. The core elements of a configurable component model are described in figure 2, which describes the information model that have been deployed and evaluated within the scope of the case study at Saab.

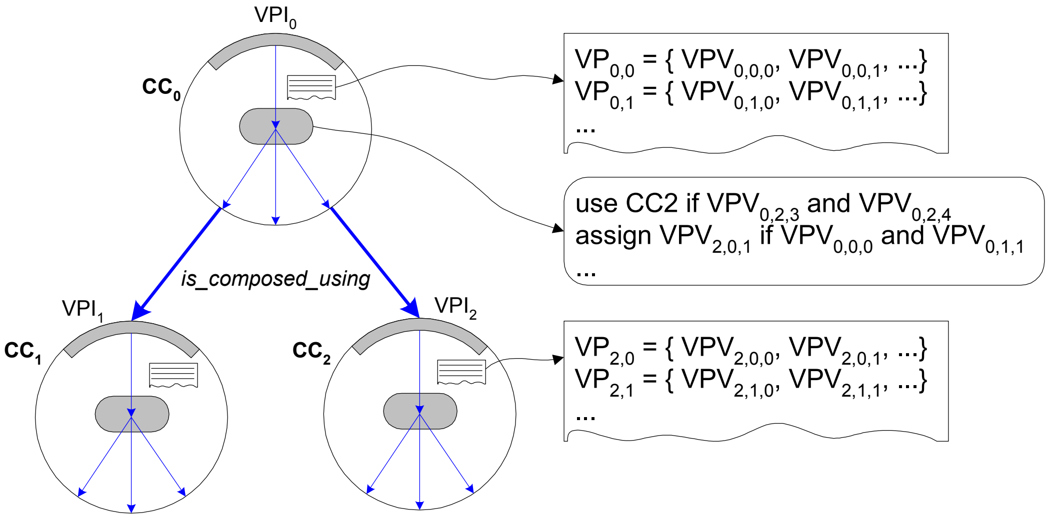


Figure 2. Structure of configurable components.

The key elements are the variant parameters and the configuration rules that are captured internally in each configurable component in the structure. The variant parameters (VP) and the set of values associated with each parameter – the variant parameter values (VPV) – are illustrated in figure 2. The primary configurability mechanisms that have been utilized within the scope of the case study are:

- The ***use*** *<component>* ***if*** *<condition>* mechanism.
- The requested configuration of a used component through the statement ***assign*** *<used component variant parameter value>* ***if*** *<condition>*.
- Design capability constraints through the statement ***invalid configuration if*** *<condition>*.

There are several other configurability mechanisms conceived within the framework of the configurable component model, but these have not been applied within the scope of the case study and will therefore be left out from this description.

In order to fulfill its role as a sub model in a forth generation product description system, the system structure need to be put into a larger context that connects it to other business systems and mechanisms and makes it useful from an operational perspective. Figure 3 show how this was done at Saab.

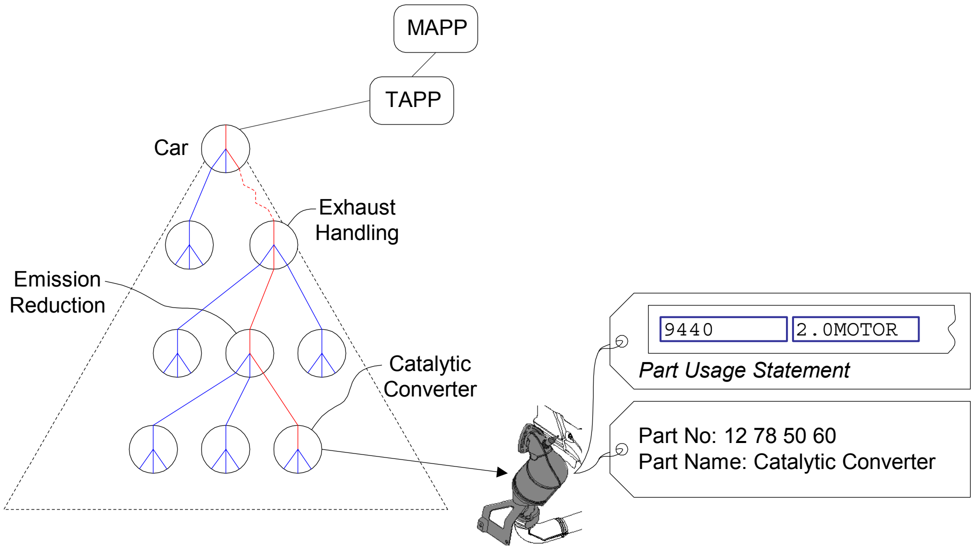


Figure 3. Operational context for the system structure in the case study.

During the production phase, a product program defines the products a customer can order. The product program also determines what may be ordered to produce. In the early phases of development, a product program defines what should be designed. The product program is represented in figure 3 by the two elements MAPP and TAPP. The interpretations of these two abbreviations are *market authorized product program* (MAPP) and *technically authorized product program* (TAPP). Figure 3 describes the positioning of the system structure in the middle between the product program and the parts. Associated with the parts are also part usage statements that are necessary in order to run and control production. The approach to deal with part usage statements presents an important difference between the third and fourth generation of the product descriptions. In generation three, the part usage statement is defined by a release engineer based on his understanding of the part and the product program. In the fourth generation, the positioning of the design solution in the system structure provides that definition. Here we derive the part usage range statement from the variability definitions of the design solutions captured in the system structure. The part usage statements are derived using a roll-up mechanism along the appearance path for a particular design solution in the system structure. The appearance path is the path from the part definition associated with a configurable component to the top element of the system structure (car) and further on to the product program definition captured in the TAPP element.

2.2 Implementation

The information model and the mechanisms described above where implemented using a commercial PDM system – in this case iMAN from EDS PLM Solutions. The functionality provided off the shelf in the base product iMAN includes most of the necessary mechanisms for the described model.

The example shown in figure 3 includes information elements representing part definition and parts. Functionality to manage these and a few other additional elements required some customization of user interfaces as well as a completely customized implementation of the roll-up mechanism in order to derive part usages. However, the main implementation effort was spent on creating interfaces to Saab legacy systems for management of the product program and towards the material logistics system (MRP).

On a few important points, the base product iMAN was not capable of delivering supporting functionality, nor was it possible to implement customized functionality in the system due to time, cost, and complexity constraints. In these cases the theoretical model framework for the system structure was compromised and reasonable (but not good) work around were deployed to overcome these problems.

The system environment was put to operational use late 1998, early 2001 the interfaces with the legacy systems were operational, and this fully functional new product description system environment was used for the definition and launch of the Saab 9-3 sport sedan.

2.3 Work method

A full deployment of a transition from a third generation product description approach to a fourth generation approach is a large scale change effort in an automotive company like Saab. In order to reduce and limit the short term scope of the change to make this transition feasible, the tasks to create the design definitions and descriptions in the new system structure was centralized to a core team of people in a new role named *product analyst*. The new role name was created in order to signal the change as well as in order to more adequately describe the tasks to be performed.

3 Experiences from case study

3.1 Exhaust handling example

The design process that takes place in respect to the creation of a system structure based on configurable components will be illustrated through an example from the development of the new 9-3 sport sedan. The selected example is the exhaust system, which we have chosen to call exhaust handling.

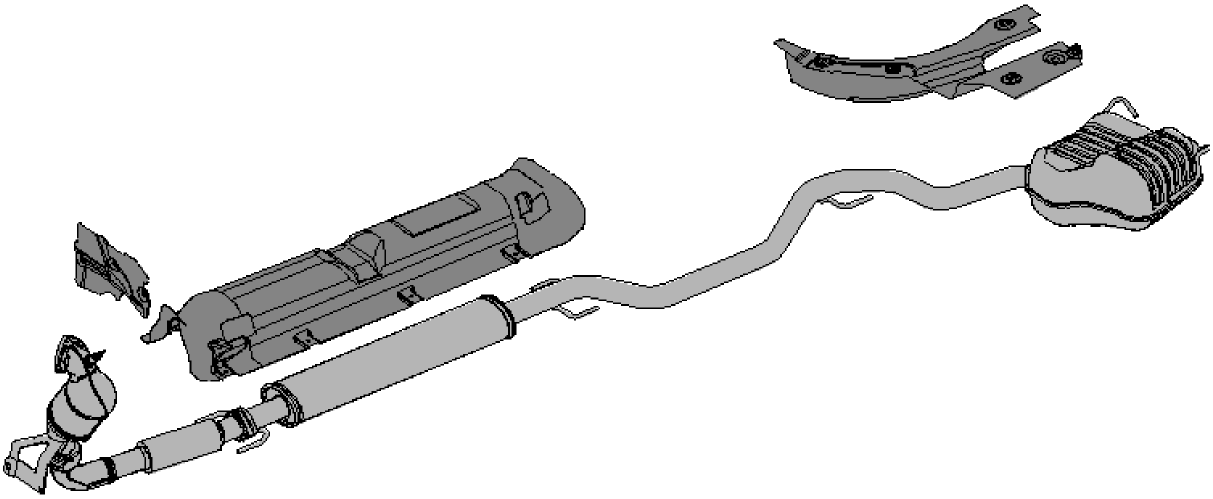
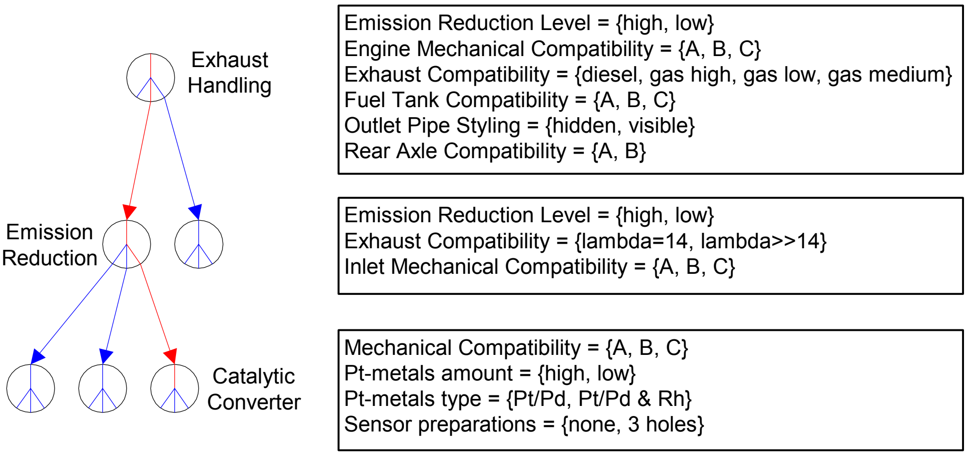


Figure 4. Illustration of a configuration of Exhaust Handling.

In order to achieve (deliver) the functionality expected from exhaust handling, several design solutions must be utilized. There are many methods available to create design solutions based on a set of established requirements. The method and process to identify and select which design solutions to encapsulate in certain configurable components is an important task. However, since vehicle development is more of a re-design type of design task than a new design task, the mentioned methods are not critical in the context of our case study. In our case, we have used an existing – traditional – system breakdown of the vehicle as our starting point and imposed a new set of requirements derived from our methodology around configurable components.



Emission Reduction Level = {high, low}
Engine Mechanical Compatibility = {A, B, C}
Exhaust Compatibility = {diesel, gas high, gas low, gas medium}
Fuel Tank Compatibility = {A, B, C}
Outlet Pipe Styling = {hidden, visible}
Rear Axle Compatibility = {A, B}

Emission Reduction Level = {high, low}
Exhaust Compatibility = {lambda=14, lambda>>14}
Inlet Mechanical Compatibility = {A, B, C}

Mechanical Compatibility = {A, B, C}
Pt-metals amount = {high, low}
Pt-metals type = {Pt/Pd, Pt/Pd & Rh}
Sensor preparations = {none, 3 holes}

Figure 5. Emission reduction example.

Compared to the traditional system breakdown, our approach with configurable components put requirements on identification of the variability of each element in the structure. The outcome of the identification is a set of variant parameters defined within the boundary of the configurable component. These sets of variant parameters are illustrated in figure 5.

Figure 5 also show that the exhaust handling component uses the emission reduction component, which in turn uses the catalytic converter. All these components are configurable. Therefore, the using component must inform the used component about how it is expected to be configured, figure 6.

```
assign EmissionReduction.EmissionReductionLevel.low            when    ExhaustHandling.EmissionReductionLevel.low
assign EmissionReduction.EmissionReductionLevel.high           when    ExhaustHandling.EmissionReductionLevel.high

assign EmissionReduction.ExhaustCompatibility.lambda=14        when    ExhaustHandling.ExhaustCompatibility.gas_low or
                                                                       ExhaustHandling.ExhaustCompatibility.gas_medium or
                                                                       ExhaustHandling.ExhaustCompatibility.gas_high

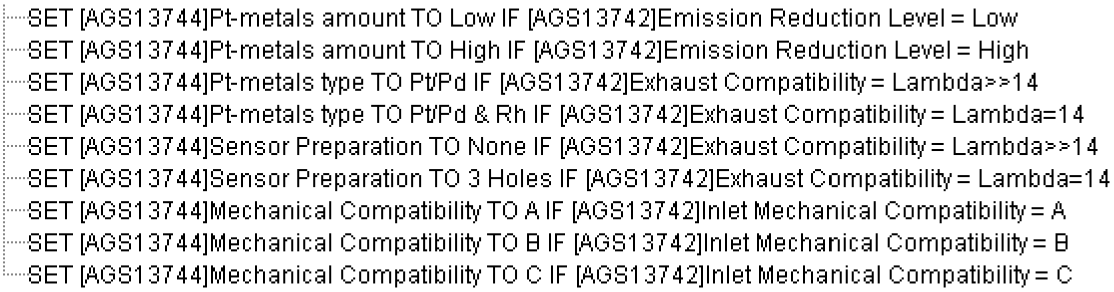
assign EmissionReduction.ExhaustCompatibility.lambda>>14       when    ExhaustHandling.ExhaustCompatibility.diesel

assign EmissionReduction.InletMechanicalCompatibility.A        when    ExhaustHandling.EngineMechanicalCompatibility.A
assign EmissionReduction.InletMechanicalCompatibility.B        when    ExhaustHandling.EngineMechanicalCompatibility.B
assign EmissionReduction.InletMechanicalCompatibility.C        when    ExhaustHandling.EngineMechanicalCompatibility.C
```

Figure 6. Exhaust Handling configuration requests on Emission Reduction.

The emission reduction component has two principal approaches to optimize the emission reduction depending on the expected exhaust gas mixture given by the lambda value. Exhaust from gas engines are best reduced using the lambda 14 optimization, whereas exhaust gas from diesel engines will achieve better reduction performance from using the lambda larger than 14 optimization principles. This is reflected by the configuration rules shown in figure 6. Similar reasons exist for the other configuration rules.

One of the components that emission reduction uses in order to fulfill the required functionality is the catalytic converter component. In a similar way as the one described above the emission reduction component need to establish configuration requests to the catalytic converter component.



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SET [AGS13744]Pt-metals amount TO Low IF [AGS13742]Emission Reduction Level = Low
SET [AGS13744]Pt-metals amount TO High IF [AGS13742]Emission Reduction Level = High
SET [AGS13744]Pt-metals type TO Pt/Pd IF [AGS13742]Exhaust Compatibility = Lambda>>14
SET [AGS13744]Pt-metals type TO Pt/Pd & Rh IF [AGS13742]Exhaust Compatibility = Lambda=14
SET [AGS13744]Sensor Preparation TO None IF [AGS13742]Exhaust Compatibility = Lambda>>14
SET [AGS13744]Sensor Preparation TO 3 Holes IF [AGS13742]Exhaust Compatibility = Lambda=14
SET [AGS13744]Mechanical Compatibility TO A IF [AGS13742]Inlet Mechanical Compatibility = A
SET [AGS13744]Mechanical Compatibility TO B IF [AGS13742]Inlet Mechanical Compatibility = B
SET [AGS13744]Mechanical Compatibility TO C IF [AGS13742]Inlet Mechanical Compatibility = C
```

Figure 7. Emission Reduction configuration requests on Catalytic Converter.

Figure 7 shows these configuration rules. In this case, the set of rules have been taken from a screen capture from the actual representation used for these configuration rules in iMAN. In the figure 7 AGS13744 identifies the catalytic converter component and AGS13742 identifies the emission reduction component.

In figure 5 we have shown the variant parameters available for the catalytic converter component. However, the design solutions encapsulated within the catalytic converter component can not support all combinations of the available variant parameters and variant parameter values presented. In order to restrict the possible combinations according to the actual capabilities provided by the encapsulated design solutions, the component provide a mechanism to define design capability constraints. If these constraints are not satisfied, the requested configuration is invalid. We distinguish between three different situations where we want to provide design capability constraints. The first and most basic situation is when the inherent principles, upon which the design solutions are based, cannot be used in order to achieve the requested configuration. In this case, we would define an *impossible design* constraint. If the basic principles used for the design solutions probably have the capability to deliver the requested configuration, but the design solutions have not been fully defined to support this configuration we refer to an *incomplete design*. The third case is when the design solutions have been created in order to actually support the requested configuration, but the required validation has not been performed with an accepted outcome, we will refer to a *not validated design* constraint. Figure 8 below show the design capability constraints that have been identified for the catalytic component converter in our example.

Incomplete Design	when	Pt-metals_type.Pt/Pd_&_Rh and MechanicalCompatibility.B
Incomplete Design	when	Pt-metals_type.Pt/Pd and (MechanicalCompatibility.A or MechanicalCompatibility.C)
Incomplete Design	when	Sensor_preparations.3_holes and MechanicalCompatibility.B
Incomplete Design	when	Sensor_preparations.none and (MechanicalCompatibility.A or MechanicalCompatibility.C)
Incomplete Design	when	Pt-metals_amount.high
Incomplete Design	when	MechanicalCompatiblity.C

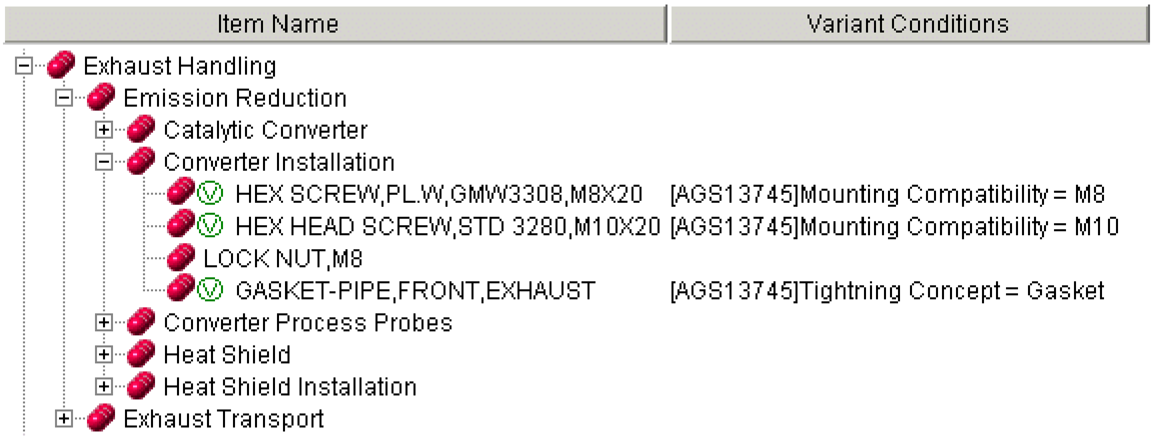
Figure 8. Design Capability Constraints on Catalytic Converter.

Furthermore, because of these constraints, the emission reduction component will have to be constrained as well. The design capability constraints identified for the emission reduction component is shown in figure 9 below.

Incomplete Design	when	ExhaustCompatibility.lambda=14 and InletMechanicalCompatibility.B
Incomplete Design	when	ExhaustCompatibility.lambda>>14 and (InletMechanicalCompatibility.A or InletMechanicalCompatibility.C)
Incomplete Design	when	EmissionReductionLevel.high
Incomplete Design	when	InletMechanicalCompatiblity.C

Figure 9. Design Capability Constraints on Emission Reduction.

In figure 10, that show design solutions required for the mounting of the catalytic converter in the car, we can identify components (encapsulating design solutions) that are strikingly similar to what would be found in a traditional bill-of-material as part representations. However, this is not the case. These elements are still abstract configurable components and require an additional part definition and part representation. As an example we will probably find more than one part definition and part representation in the more detailed description of the configurable component *gasket-pipe, front, exhaust* in order to provide part solutions to different variants of interfaces between the engine and the exhaust handling system.



Item Name	Variant Conditions
Exhaust Handling	
Emission Reduction	
Catalytic Converter	
Converter Installation	
HEX SCREW,PL.W,GMW3308,M8X20	[AGS13745]Mounting Compatibility = M8
HEX HEAD SCREW,STD 3280,M10X20	[AGS13745]Mounting Compatibility = M10
LOCK NUT,M8	
GASKET-PIPE,FRONT,EXHAUST	[AGS13745]Tightning Concept = Gasket
Converter Process Probes	
Heat Shield	
Heat Shield Installation	
Exhaust Transport	

Figure 10. Low level design solution components.

3.2 Experiences and benefits from using the system structure approach

The more systematic approach to create elements based on established criteria (system definition) on higher levels in the structure compared to traditional hierarchical structures improve the clarity and understanding of the documented design solutions. Improved clarity and understanding of the structures is vital both in order to support communication in the on-going development programs and in support of future re-use of the design solutions.

In some cases, the introduction of the system structure has contributed to provide a more holistic and complete understanding of the systems being designed. The requirement to more formally define and describe variability have in some cases created a better understanding of the design solutions and their contexts, which have led to identification of design weaknesses and subsequently to design improvements.

4 Conclusions

The case study have shown that the proposed concept of a system structure based on configurable components can be implemented using a commercial PDM system and that many of the expected benefits from using this approach will be achieved. The recently released Saab 9-3 Sport Sedan is defined and released using a new product description system based on the proposed approach.

5 Acknowledgements

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