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COMPLEXITY MANAGEMENT USING MULTIPLE-DOMAIN MAPPING – DEVELOPMENT OF HIGH PRESSURE PUMPS FOR COMMON RAIL SYSTEMS

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1 INTRODUCTION

It is the business of the Diesel Systems (DS) division of the company Robert Bosch GmbH to develop, produce and distribute Common Rail systems. The high pressure pump, which is in charge of compressing the fuel up to 2000 bar pressure, is an essential element of the Common Rail system. More than 100 OEMs are customers of Bosch DS, who place their trust in Common Rail systems that are integrated in the OEM's engine.

The main function of the high pressure pump is to deliver a defined quantity of fuel at the required pressure level. However, there are several further functions of the high pressure pump which increase the complexity of the product such as all the functions which provide the interface to the customer's engine such as the inlet and outlet of low pressure fuel, the electrical control unit for metering the low pressure fuel inlet quantity, the high pressure fuel outlet, and so on. The properties of the high pressure pump have to be adapted to the different OEM's requirements.

Diesel Systems face the challenge of delivering a highly customized product which covers different customer requests including meeting the requirements for the interface of the high pressure pump to the engine while reducing the number of variants of components.

In cooperation with Teseon GmbH, which provides methodical consultancy and tool support for complexity management, Bosch DS optimized its building block concept for efficiently handling the variety of customer requirements. Different types of high pressure pump were subject of modularization and potential for carry over parts (COP) was identified.

2 METHOD

In order to manage the above mentioned challenge the Multiple-Domain Matrix approach [1] was implemented and the complexity of different high pressure pump families was analyzed. Figure 1 shows the identified domains and different types of dependencies between the domains. Each field of the Multiple-Domain Matrix represents a DSM (Design Structure Matrix) or DMM (Domain Mapping Matrix) depending on the domains involved.

Types of high pressure pump	Co	Fu	Ch	Pr
Components Co	Co has influence on Co (geometry, package)	Co serves Fu	Co has influence on Ch	Co implicates Pr
Functions Fu	---	Fu requires Fu (functional model)	---	---
Characteristic Ch	Ch has influence on Co $=(Co \rightarrow Ch)^T$	---	Ch has influence on Ch	Ch implicates Pr
Production boundary conditions Pr	Pr determines Co (production constraint)	---	Pr determines Ch (production constraint)	Pr has influence on Pr

Figure 1. Domains and dependency types in Multiple-Domain Matrices

The next step of the complexity management project was to identify and document the cross-linking in the different matrices (DSMs and DMMs) for different high pressure pump types. This was carried out in several workshops by interviewing the relevant experts from the departments involved. The acquired data then served as basis for visualization and analysis of the complexity framework of the high pressure pumps.
The Multiple-Domain Mapping approach allows for visualizing and analyzing the dependencies of one domain – especially components – from different points of view which is particularly relevant for the purpose of modularization. Figure 2 shows different views of the product structure of a high pressure pump type which each represent characteristics, function or geometry dependencies. By cluster analysis, specific optima for certain views can be found.

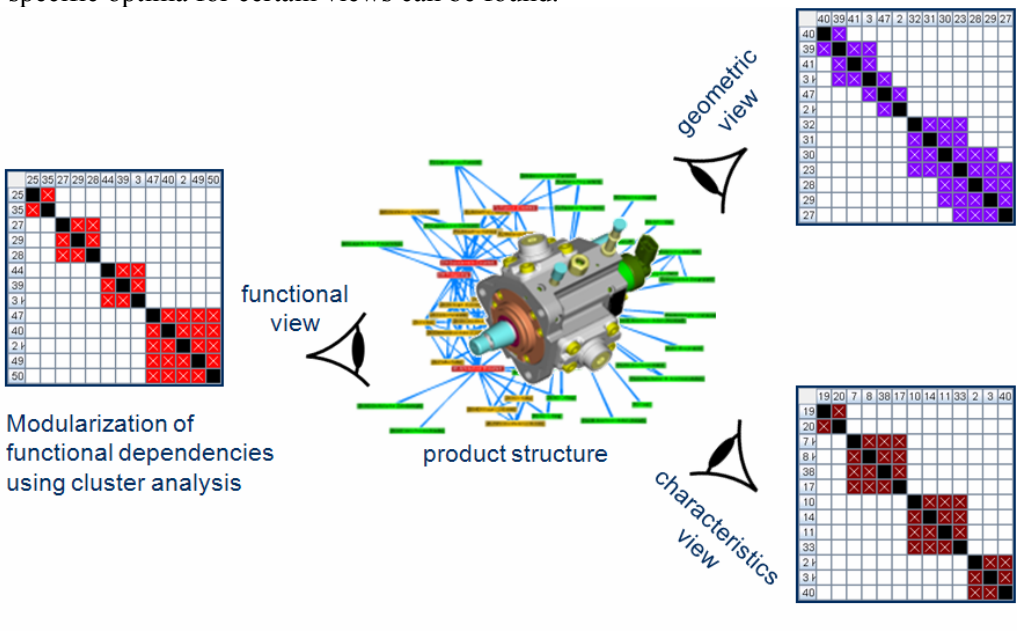

Figure 2. Different views on the product structure derived from a Multiple-Domain Matrix

To find a holistic optimum for modularization the different views have to be placed "over each other". For carrying out the cluster analysis in the aggregated view, functional dependencies between components were chosen as starting point, as shown in figure 3. The clustering result had then to be discussed with experts. It had to be determined, in which cases aggregated modules can be built or single geometric dependencies or characteristics dependencies can be eliminated. In this way necessary changes of the product structure can be elaborated in order to optimize the overall high pressure pump structure.

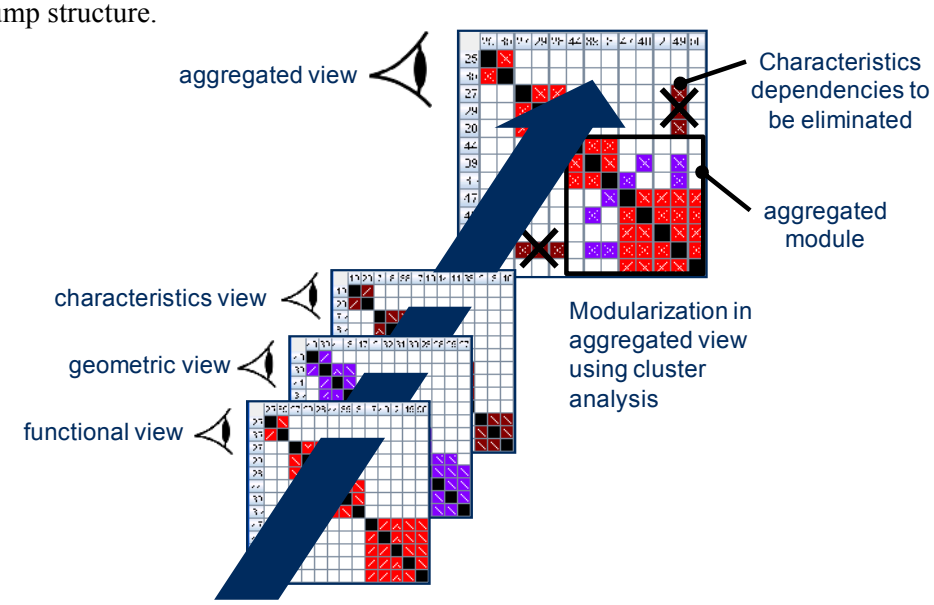

Figure 3. 3D-Clustering of component dependencies, derived from Multiple-Domain Matrix

The modularization of individual pump types provides the basis for the identification of potential for carry over parts, which is the next step for defining an efficient set of building blocks. Figure 4 shows the product structures of two different pump types that were analyzed using the geometric and functional view (see colour of dependencies). Carry over parts can be identified by comparing the structural embedding of corresponding elements and modules.

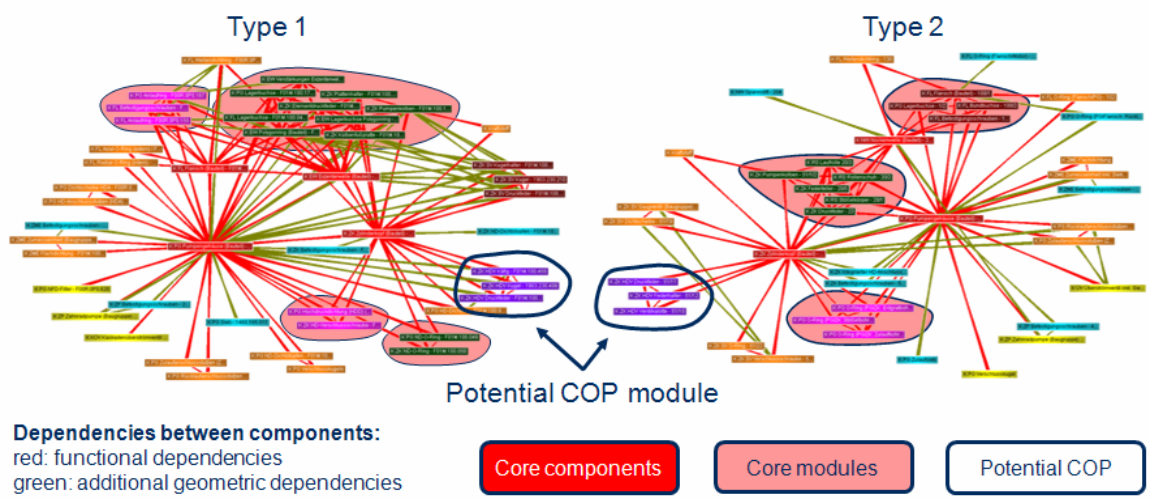

Figure 4. Structural comparison of types of high pressure pump for identification of COP potential

A certain element or module can be identified as carry over part, if its functional embedding is identical in both types and its interfering geometric dependencies can be eliminated (e.g. by defining a standardized geometric interface). Of course, the characteristics view also has to be checked. For instance a potential carry over part "metering unit" would have to provide the required characteristics (e.g. maximum of metering quantity) in every type of high pressure pump. Finally, the underlying production boundary conditions, the fourth domain in figure 1, allow for an overall economic assessment of carry over parts.

A proposition for building block alternatives can finally be derived by considering the following aspects:

- Modularization of high pressure pump types from different views
- Aggregation of different views and analysis of structural embedding of components and identified modules
- Identification of potential COP by structural comparison of types of high pressure pump

3 RESULTS

The application of the Multiple-Domain Mapping approach makes the management of high complexity in development of Common Rail high pressure pumps possible. Product structures of different types of high pressure pump have been recorded, visualized and analyzed from different views. These different views of component dependencies have been derived from the elaborated Multiple-Domain Matrix. Modularization advices and design recommendations have been derived by cluster analysis of single and aggregated views. Identification of potential for carry over parts leads to gains from economies of scale and forms the basis for an optimized building block concept. Bosch DS is well prepared for managing an increasing complexity due to steadily increasing customer requirements.

REFERENCES

[1] Maurer, M.; Lindemann, U.; Facing Multi-Domain Complexity in Product Development. In *CiDaD Working Paper Series 3;* 2007 1, pp 1-12.

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9TH INTERNATIONAL DSM CONFERENCE

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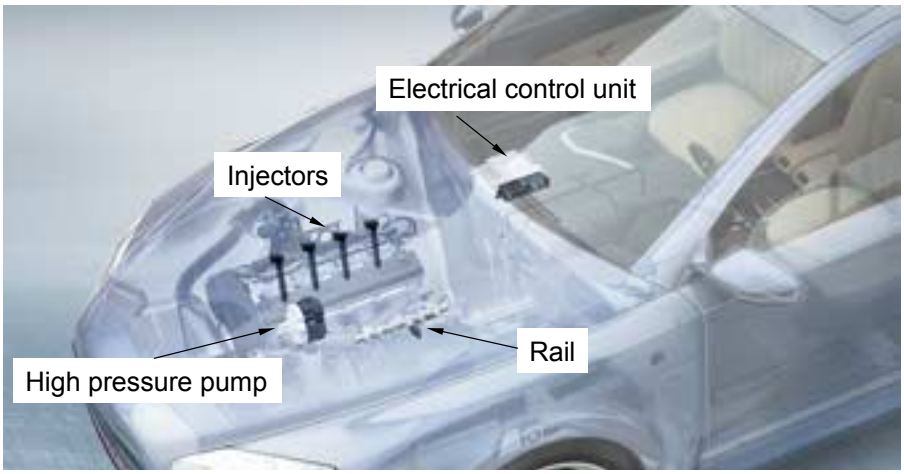
Introduction

- Bosch Diesel Systems (DS) develops, produces and distributes Common Rail systems to more than 100 OEMs.
- The Common Rail system is integrated in the OEM's engine



Introduction

- Main function of the high pressure pump:
  Deliver a defined quantity of fuel at a required pressure level (up to 2000 bar)
- Highly customized product
- Portfolio includes several high pressure pump families

Facing the challenge of an increasing complexity

- Properties of the Common Rail system and its components have to be adapted to a steadily increasing amount of OEM requirements
- **Challenge:**
  Covering multiple customer requirements while keeping number of variants low
- Bosch's strategy for a efficient management of product variety:
  - Product modularization
  - Deployment of a high degree of carry over parts
  - Efficient building block concept

Multiple-Domain Matrix – Basis for complexity management

Types of high pressure pump	Co	Fu	Ch	Pr
Components Co	Co has influence on Co (geometry, package)	Co serves Fu	Co has influence on Ch	Co implicates Pr
Functions Fu	---	Fu requires Fu (functional model)	---	---
Characteristic Ch	Ch has influence on Co $=(Co \rightarrow Ch)^T$	---	Ch has influence on Ch	Ch implicates Pr
Production boundary conditions Pr	Pr determines Co (production constraint)	---	Pr determines Ch (production constraint)	Pr has influence on Pr

- Definition of domains and dependency types by means of Multiple-Domain Matrix

Information acquisition

Types of high pressure pump	Co	Fu	Ch	Pr
Components Co	Co has influence on Co (geometry, package)	Co serves Fu	Co has influence on Ch	Co implicates Pr
Functions Fu	---	Fu requires Fu (functional model)	---	---
Characteristic Ch	Ch has influence on Co $=(Co \rightarrow Ch)^T$	---	Ch has influence on Ch	Ch implicates Pr
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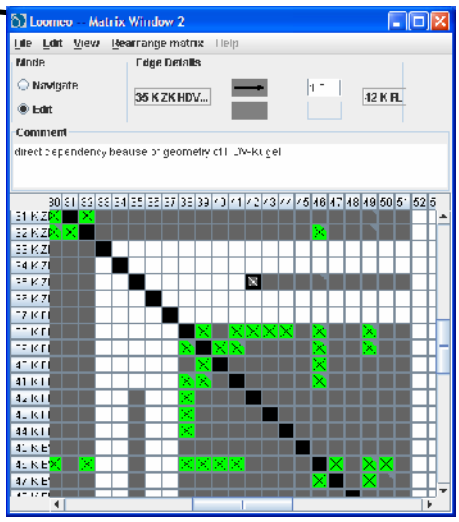
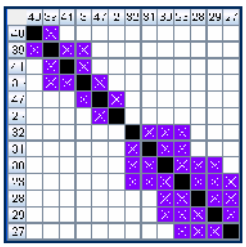


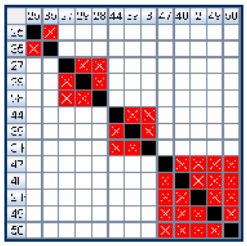
- Acquisition of DSM and DMM information:
  - Workshops with experts
  - Recurrent plausibility checks

Component dependencies from different points of view

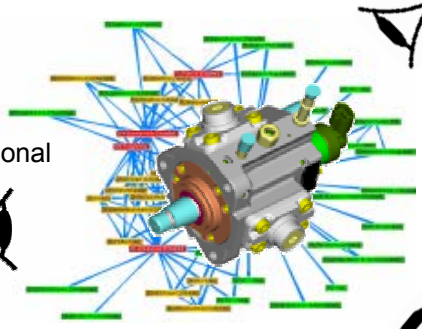
- Different views on component dependencies: geometry, function, characteristics, production boundaries, costs, …
- Modularization of product structure from different points of view



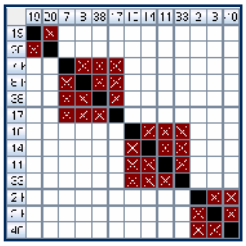
geometric view



functional view



product structure

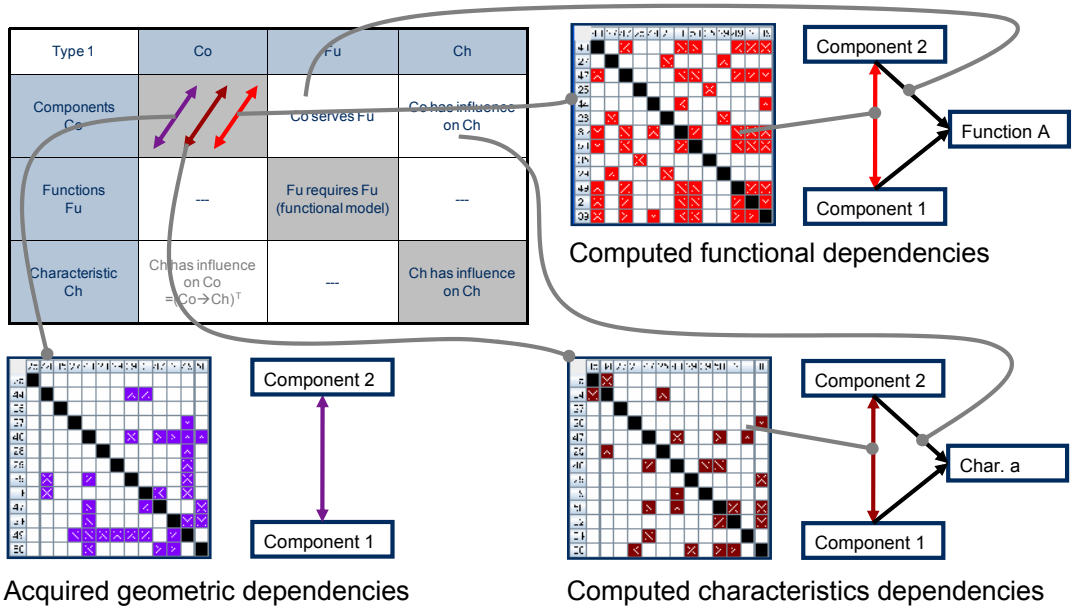


characteristics view

Modularization of functional dependencies using cluster analysis

Deduction of different views from the Multiple-Domain Matrix

Type 1	Co	Fu	Ch
Components Co		Co serves Fu	Co has influence on Ch
Functions Fu	---	Fu requires Fu (functional model)	---
Characteristic Ch	Ch has influence on Co $=(Co \rightarrow Ch)^T$	---	Ch has influence on Ch



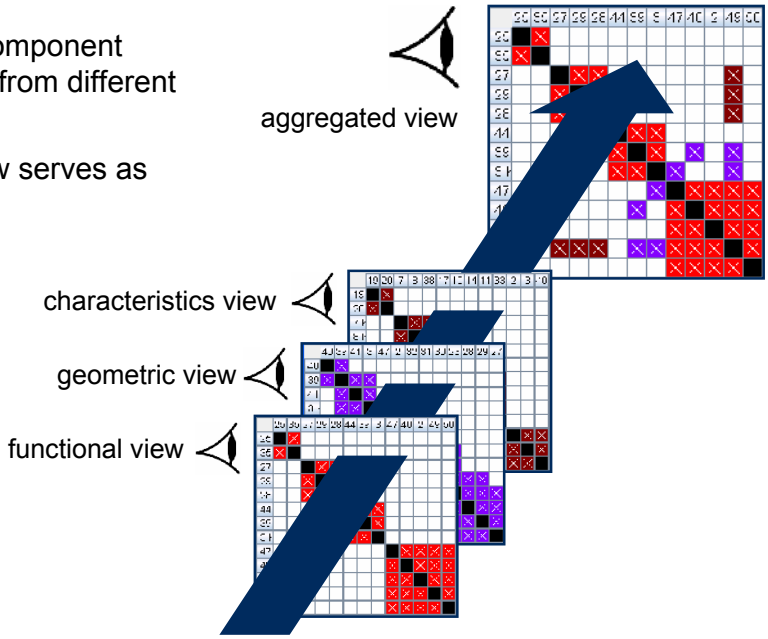
Computed functional dependencies

Acquired geometric dependencies

Computed characteristics dependencies

Aggregation of different views

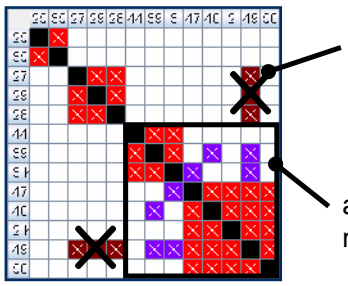
- "Addition" of component dependencies from different points of view
- Functional view serves as starting point



Holistic optimization in aggregated view

- Management of dependencies that augment the functional structure
- Optimization possibilities:
  - Identification of aggregated clusters → deduction of aggregated modules in product structure
  - Targeted elimination of geometric and characteristics dependencies

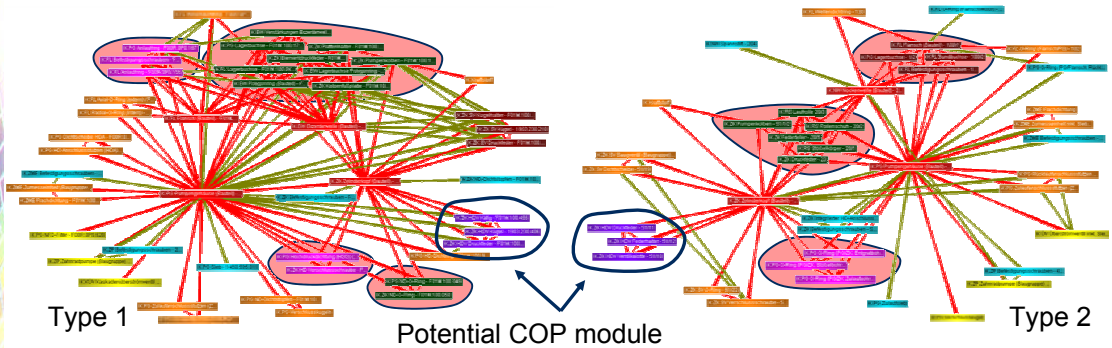
Aggregated view:



Modularization in aggregated view using cluster analysis

Potential for carry over parts

- Modularization of present high pressure pump types from different views
- Analysis of structural embedding of components and identified modules
- Economic assessment of potential carry over parts



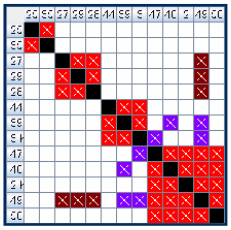
Dependencies between components:
red: functional dependencies
green: additional geometric dependencies

Core components | Core modules | Potential COP

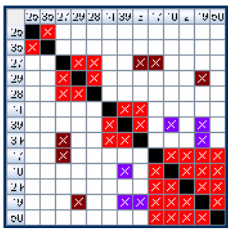
Identification of building blocks alternatives

- Modularization of present high pressure pump types
  - analysis of different points of view
  - aggregation of views
  - → optimized type concepts
- Identification of potential COP (components and modules)
- Structural comparison of high pressure pump types
- Deduction and evaluation of building blocks alternatives

Concept 1

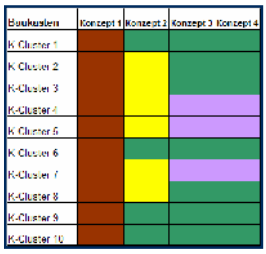


Concept 2



Concept …

Building blocks system



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Summary – Results

- Multiple-Domain Mapping approach serves as a powerful basis for complexity management
- Optimized product structures in consideration of different points of view
- Economies of scale using carry over parts
- Efficient building block alternatives derived from structure analysis

→ **Bosch DS is well prepared for managing an increasing complexity due to steadily increasing customer requirements**