FUNCTION-BASED CONTACT AND CHANNEL-MODELLING IN THE DEVELOPMENT OF AN INNOVATIVE CAR

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Keywords: Contact and Channel Model (C&CM), function-based modelling, engineering process

1 INTRODUCTION AND MOTIVATION

During the recent decades, product engineering has turned out to be characterized by an increasing complexity. One can identify two interdependent trends as causes for this development. On the one hand, products today need to satisfy multiple requirements which address customer demands as well as various boundary conditions of the market. Therefore, contemporary products are often composed of multi-technological sub-systems and features e.g. highly integrated product architectures in order to provide as much value as possible for producers and customers at the same time. In addition, today's products are oftentimes enhanced with service offers in a valuable bundle.

But not only the products themselves have become complex; on the other hand also the processes for their realisation are more and more complex today. Engineering processes are mostly carried into execution by trans-disciplinary teams that are often also distributed over several countries. The competitive conduction of product engineering projects from early ideas via embodiment design, production and finally distribution and service is a huge challenge which needs to be supported.

In the following section we review some examples of theories and methods that aim to provide this support. In Section 3 we introduce the project KI2 – Karlsruhe Innovative Individual Mobility. It exemplifies a complex engineering project and depicts requirements for assisting engineering design. One possible way to achieve this assistance is presented in Section 4: function-based modelling with the Contact and Channel Model (C&CM). This approach is part of current research cooperation. Section 5 sums up the achievements and prospects further work to bring the approach into utilization.

2 LITERATURE REVIEW AND RELATED STATE OF THE ART

Since the 1970s, the field of "Design Theory and Methodology" (DTM) has found its way into the focus of academic researchers and a considerable number of results have already been applied industrially (Tomiyama et al., 2009). Finger and Dixon propose one way to classify DTM into six categories. These are *descriptive* e.g. (Hubka and Eder, 1996) or (Pahl and Beitz, 2007), *prescriptive* such as Suh's Axiomatic Design (Suh, 1990, 2001), *computer-based* (cp. work of Gero, 85) or stand for *representations* e.g. shape grammars (Umeda and Tomiyama, 1997) and feature-based modelling (Dong et al., 1991), *Analysis* (such as optimization, CAE) or *DfX* focusing manufacturing or other life cycle issues (Finger and Dixon, 1989a/b).

In general, DTM can be distinguished by the methodology's particular focus which is either covering product modelling or process modelling. Note that there is no sharp differentiation as there is often a smooth transition between both views. DTM concerning mainly *product modelling* are e.g. design theories of (Koller, 1976) or (Roth, 1982) that aim to support engineering by providing catalogues with physical effects and solution principles. In Section 4 we use the modelling language C&CM (Contact and Channel Model). This approach to technical problem solving (e.g. for analysis tasks) aims to create a common understanding between designers by describing products in terms of Working Surface Pairs (WSP) and Channel and Support Structures (CSS) (Albers et al., 2008). One hypothesis of C&CM states that a (technical) function requires always at least two WSPs and their connecting CSSs. Thus a single component does not perform any function as long as it is not in contact to another one.

Among DTM that are mainly dealing with *process modelling*, there are descriptive approaches such as Pahl and Beitz' and prescriptive approaches such as Axiomatic Design. The next section will examine a design project in terms of the integrated product engineering model (iPeM). It delineates product engineering as the transformation of a system of objectives into a system of objects by an operation system by means of particular activities of engineering and of problem solving (Albers, 2010). The iPeM is a descriptive meta model from which prescriptive implementation models can be derived. DSM is a theory that allows both product and process modelling. Browning presents an approach to managing product complexity by showing interdependencies between a product's components in a matrix (Browning, 2001). Other theories focus on processes and here e.g. on information flows (Eppinger, 2001).

3 KI2 – KARLSRUHE INNOVATIVE INDIVIDUAL MOBILITY

The undergraduate-student's project KI2 takes place at the Institute of Product Engineering Karlsruhe (IPEK). Under supervision of four research assistants, a team of over fifteen third-year students design an innovative car. The project follows three main goals. While the monitoring of the engineering process serves as a test bed for the design methods taught at the institute, the car itself will be used as a rolling test rig for miscellaneous technologies (e.g. fuel cells). The third and maybe most important goal is the generation of a knowledge base for the institute's future research in the field of automotive engineering. For the execution of the process, the iPeM is used to organize the project.

The information for the knowledge base is being gathered by the students during the engineering process. One major research question is how the information can be assembled to consistent knowledge. According to the iPeM meta model, the product and process-related knowledge is stored in the KI2 project's *system of objectives*. This also includes information about decisions and determined target values. KI2's product profile is the market of individual mobility in metropolitan regions. In order to provide as much flexibility as possible, a modular vehicle architecture has been chosen. The core idea is to offer customers particular building blocks with which they can assemble individual mobile concepts as the need arises. Figure 1 shows the product idea in three stages of expansion. While the first stage only consists of a front module (with seats and human-machine-interface) and a rear module (with the drive train), the other stages are enhanced with additional modules for extra seats or loading space, range-extender-units and so on.

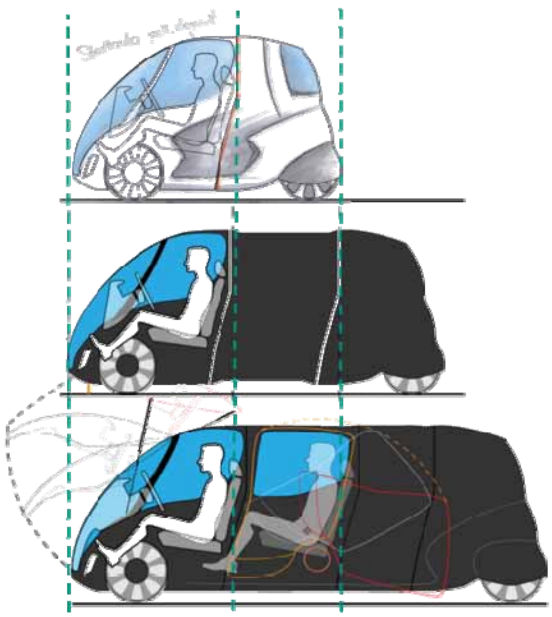

Figure 1. KI2 – Karlsruhe Innovative Individual Mobility

The system of objectives is build up hierarchically. Starting with the main goals listed above, the product profile and product idea can be broken down until the embodiment design stage. Here, the modular concept of the car is used to structure the engineering process. The *operation system* (the core team of research assistants and the students as well as their means for work) is clustered into front module, rear module and modules in between. Furthermore smaller teams concentrate on the drive train or the chassis. The challenge is to coordinate the teams and to manage the multi-technological project throughout the process.

The *object system* contains all the results of the engineering work. At the moment, a PDM system (product data management) and a Microsoft SharePoint Wiki are used to keep track of the process' output. Current research on the assets and drawbacks of this environment already identified options to implement a methodology based on the iPeM structure in order to provide a better support for designers. As the information in the mechatronic project is multifarious and interconnected, it is difficult to maintain an overview of the product design such as geometry, electronics, ergonomics etc. The following section prospects a promising approach that could solve this problem.

4 CONTACT- AND CHANNEL MODEL OF THE PROJECT KI2

C&CM is a meta model. With the elements WSP and CSS, functional dependencies of a product's sub systems can be modelled in any hierarchical level of detail (Albers et al., 2008). Hence, the product's system of objectives can be mapped directly to its components in form of additional information and attributes. A major strength of the approach is that open decisions – or sub systems where not all information has been generated yet – can be modelled as black boxes. Even though the model can be discretionarily abstract, it still contains all necessary information about the black boxes' attributes (function, objectives, etc.) and their interfaces. These interfaces and structured attributes of the car modules can be described with the help of C&CM in different hierarchic levels.

In (Albers et al., 2009) we introduced the function-based modelling approach as an implementation in P3 signposting[1] (Wynn et al., 2006) with a C&CM module extension. This computer-supported tool allows easily creating, storing and exchanging C&CM-models that can be enhanced with information from integrated databases, such as mechatronic attributes and functional systems of objectives. Figure 2 shows a product model of the KI2 car and its environment.

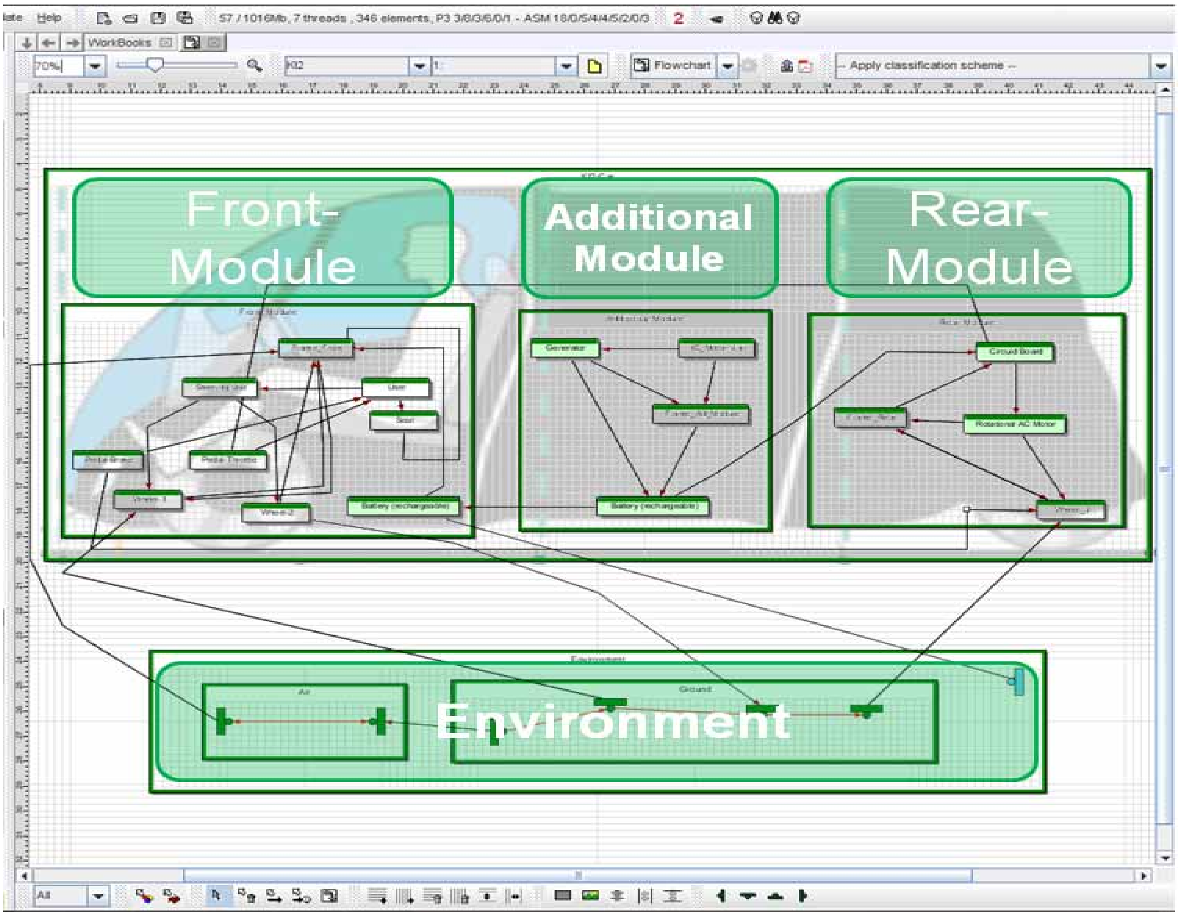

Figure 2. Model of the KI2 car in C&CM with P3

[1] The software P3 signposting is currently developed under the name Cambridge Advanced Modeller.

In Figure 2 we see the modules of the car and their connections which can be assigned functional dependencies such as loads, forces, electric fluxes etc as well as functional objectives (e.g. suspension and damping requirements that must be satisfied by the WSPs and CSSs that belong to the wheels and the frame). Within the rectangles (at a deeper level within the hierarchy) there are boxes that represent sub systems such as wheels, motors, energy storage and so on. The software allows searching and choosing parts directly from a part-library within P3 by their input and output flows. All parts can be assigned flows of energy, matter or information in order to indicate their (mechatronic) functions. Predefined flows in a database ensure that no important interdependencies between parts can be forgotten (e.g. fuel or air inputs for a combustion engine). All flows are conducted via WSPs and take effect via CSSs (connecting lines between ports of WSP) which also can be assigned additional information. As the engineering project processes, further levels of detail can be modelled until finally the whole system architecture is represented down to single parts (e.g. screws, wires etc.).

In KI2, the function-based model helps monitoring the dependencies within the product with a focus on the interfaces between the modules and components. Furthermore, the hierarchic modules can be used in the engineering process to formulate individual work packages with clearly defined boundary conditions, objectives etc. as the C&M elements contain all necessary information. This enables designers to plan time and resources in terms of project management as well. Different worksheets allow different views on e.g. electric circuits, mechanic sub-assemblies etc. in one consistent product data model.

5 CONCLUSIONS AND FURTHER WORK

The exemplary application of the function-based Contact and Channel Modelling approach in the project KI2 shows that representing the system architecture of a complex product can be done effectively with the help of the software application. The hierarchical composition of the model enables engineers to focus on relevant design problems by zooming in or hiding any but the required information. Thus C&CM can help structuring operation systems of engineering processes. With C&CM it is possible to store all necessary information about parts, their functional relationships and the related objectives in one model. The implementation as a software tool makes it easy to create large models and to keep an overview with the help of adaptable zoom or preview features. In P3 it is also possible to create different cross-linked worksheets, e.g. in order to pursue alternative solutions.

The application in the project KI2 shows, that a combination of the product modelling approach with C&CM and the process modelling approach iPeM promises valuable perspectives for further work. With the iPeM it is possible to describe the whole engineering process of the complex product, including the system of objectives, the operation system with activities of product engineering and activities of problem solving and the project's system of objects. The structure of the meta model iPeM and the possibility to integrate specific design methods such as Total Quality Management or CAX support designers both in terms of engineering design and of project management (Albers, 2010). Generally, it is of a special interest to keep track of the information and thus to manage the knowledge of products and processes in a company.

An integrated approach of C&CM and iPeM combining the advantages of the two models can lead to a holistic support tool for engineering processes. It might be applied in research, education as well as in industrial practice. Therefore further work at the IPEK will improve both models for this purpose and develop ways to combine them. Current research questions are how the integrated modelling of parts and functions with C&CM can help to bridge the gap between system of objectives and system of objects. Another issue is how information and knowledge about product and process that is generated by the operation system can be stored through Contact and Channel modelling in order to create a company-wide knowledge-base.

ACKNOWLEDGEMENTS

The authors would like to thank Adam Babik, Philipp Merkel, Gerhard Robens and Eike Sadowski for their excellent contributions to this paper.

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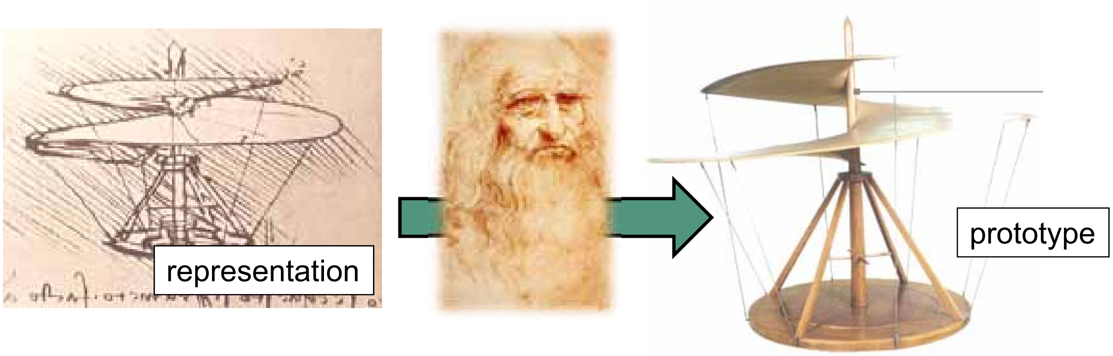
- Conclusion

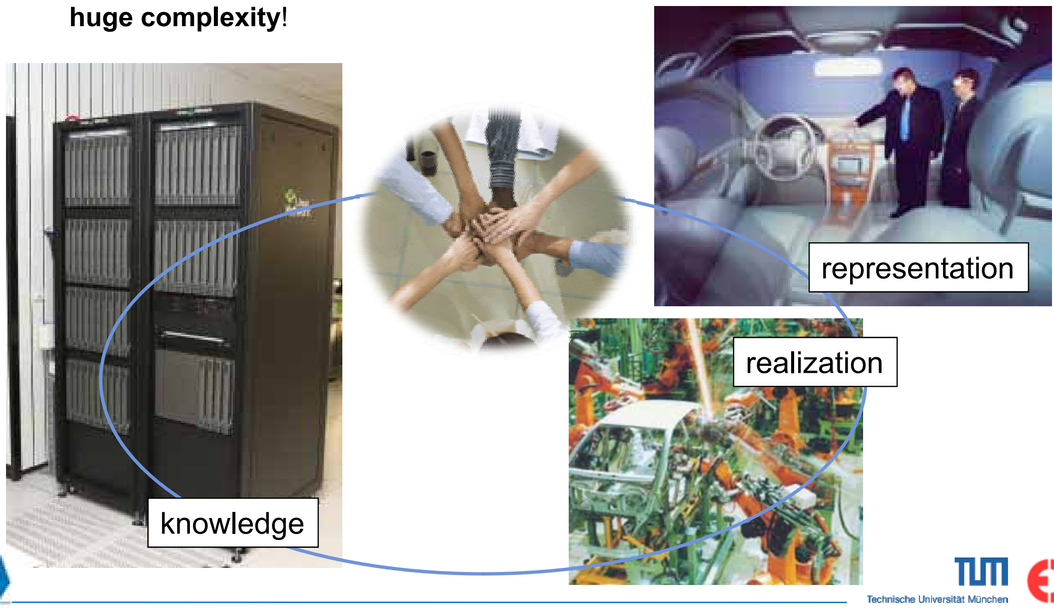
Product development in the 15th century

- “Engineering art”, handcraft → one person could handle the whole process



Product development in the 21st century

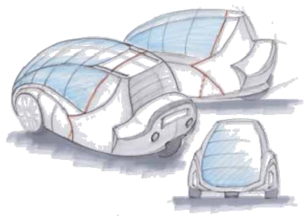
- Transdisciplinary and globally distributed engineering teams
  inter-company cooperation
- (Mechatronic) **products** as well as the **processes** for their realization are of a **huge complexity**!



Case study

- KI2 – *Karlsruhe Innovative Individual Mobility*
- Task: **“design an innovative vehicle for individual mobility”**
- Three main goals:
  - Monitoring of the engineering process as **a test bed for design methods**
  - The car itself will be used as a **rolling test rig** for miscellaneous technologies (e.g. fuel cells)
  - Generation of a **knowledge base** for the institute’s future research in the field of automotive engineering.

Karlsruher Innovative Individualmobilität
Ein Projekt des IPEK am Karlsruher Institut für Technologie

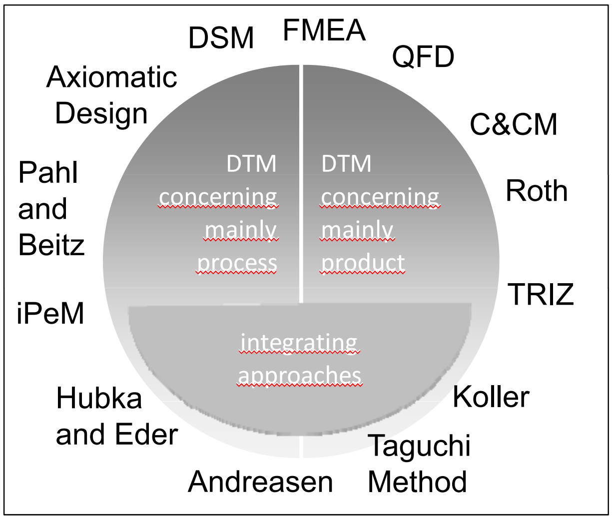


Managing complexity…

- Challenge:
  - Timescale: < 2 years
  - Project team: 18 undergraduate (!) students (4 research assistants)

http://www.timanfaya.ping.de/bilder/labyrinth1.jpg

Design theory and methodology (DTM)

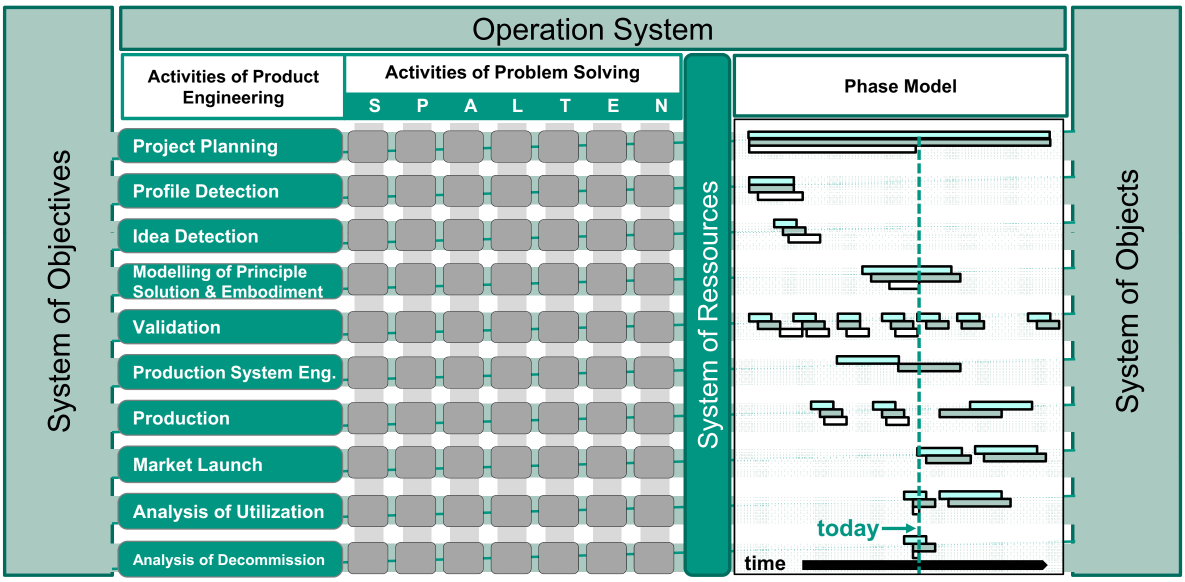


- Numerous theories and methodologies have been developed to support designers
  → DTM to manage complexity of product development
- Some DTM are only applied in academic research
- Several approaches are also in industrial use

see also: Tomiyama, T. *et al.* (2009). Design methodologies: Industrial and educational applications.

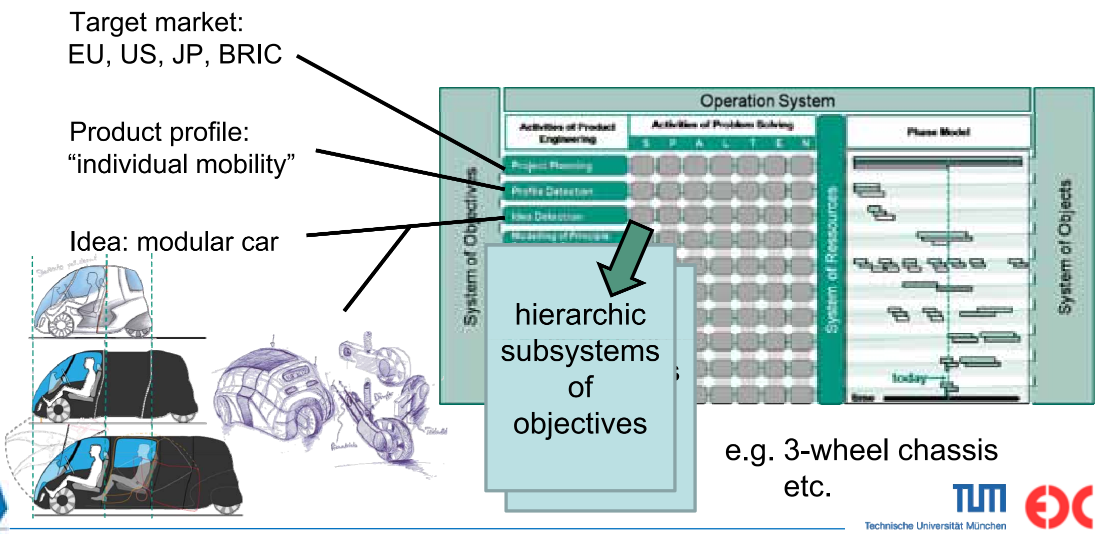
MANAGING COMPLEXITY
BY MODELLING DEPENDENCIES

The iPeM Meta-Model



System of objectives

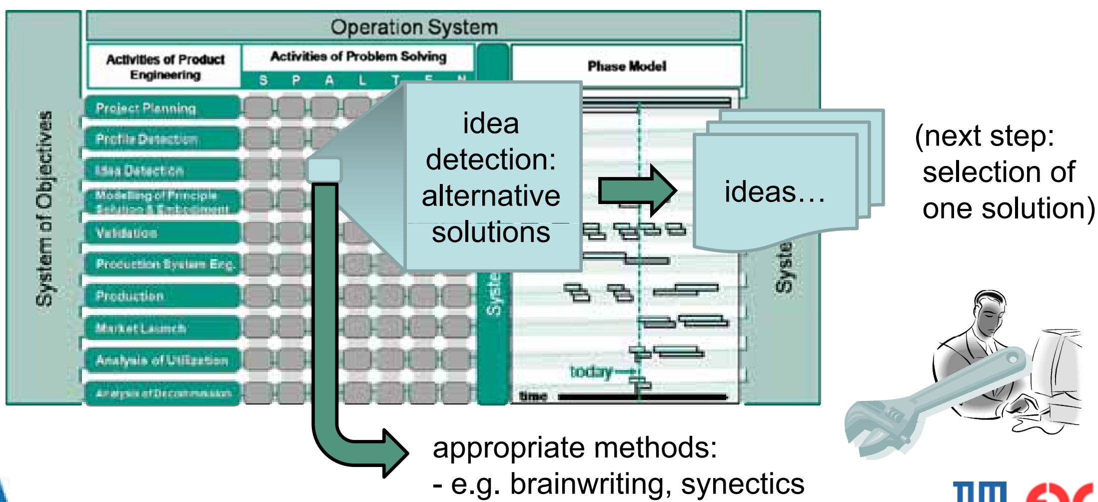
- Functions refer to the system of objectives (→ ~purpose of the artifact)
- Objectives need to be kept transparent throughout the process
  - In order to allow cooperation in (distributed) teams or across domains
  - To avoid misunderstandings and loss of information in dynamic development



MANAGING COMPLEXITY
BY MODELLING DEPENDENCIES

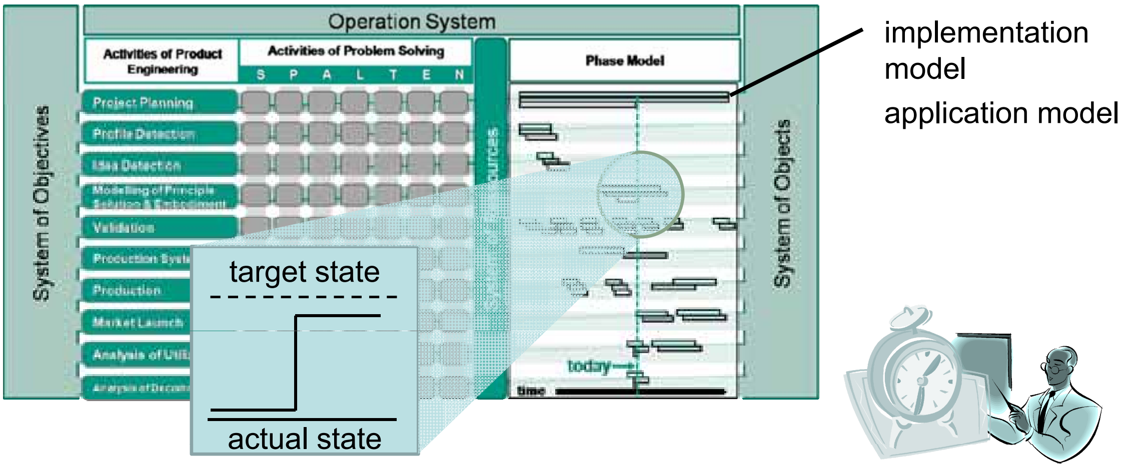
Operation system – activities matrix

- The activities matrix gives a structure to the operation system
  - Representation of information in semantic context ("object xy from activity z")
- Support of designers: guidelines, instructions, methodology
  - Toolbox for software, methods, expertise



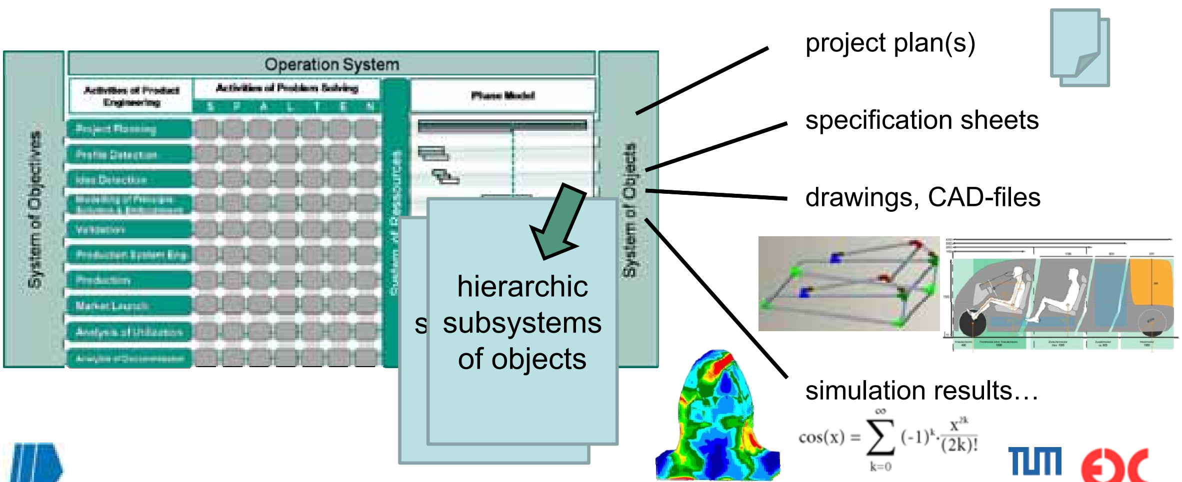
Operation system – phase model

- Support of project management in the phase model:
  - Project planning (according to knowledge from past processes)
  - Monitoring of progress, basis for set-actual comparison (time, cost, …)



System of objects

- System of objects: reasoned, clearly arranged → traceable
- Links to related objectives and activities of the operation system



The Contact and Channel Model (C&CM)

- **Functions** are modelled in reference to respective **form**

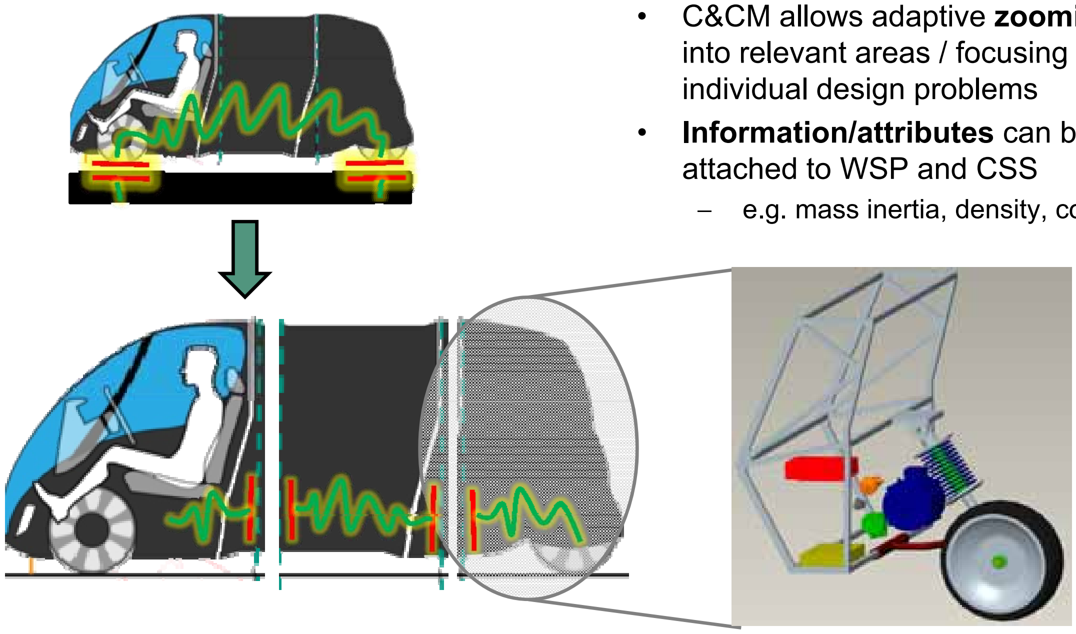
- Functional contacts are connected via **Working Surface Pairs** (WSP)
- WSP are connected via **Channel and Support Structures** (CSS)
  - solid structures, fluids or fields

function: e.g. provide axial force
store energy

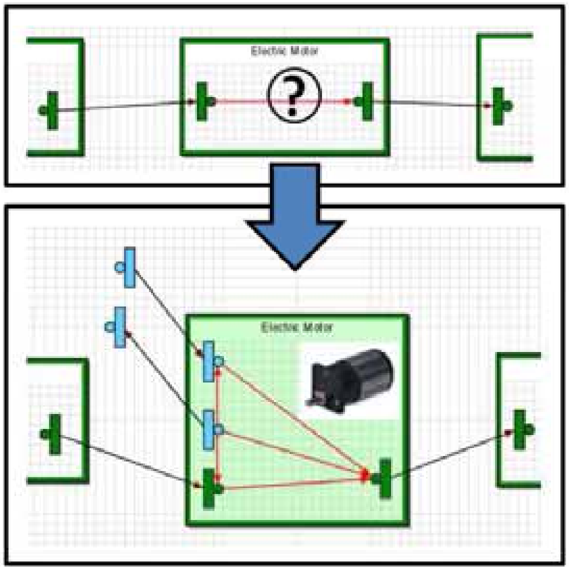
note: a component can only perform functions when it is in contact to ≥1 other components

C&CM in KI2

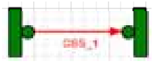
- C&CM allows adaptive **zooming** into relevant areas / focusing on individual design problems
- **Information/attributes** can be attached to WSP and CSS
  - e.g. mass inertia, density, cost



Implementation in CAM[1]

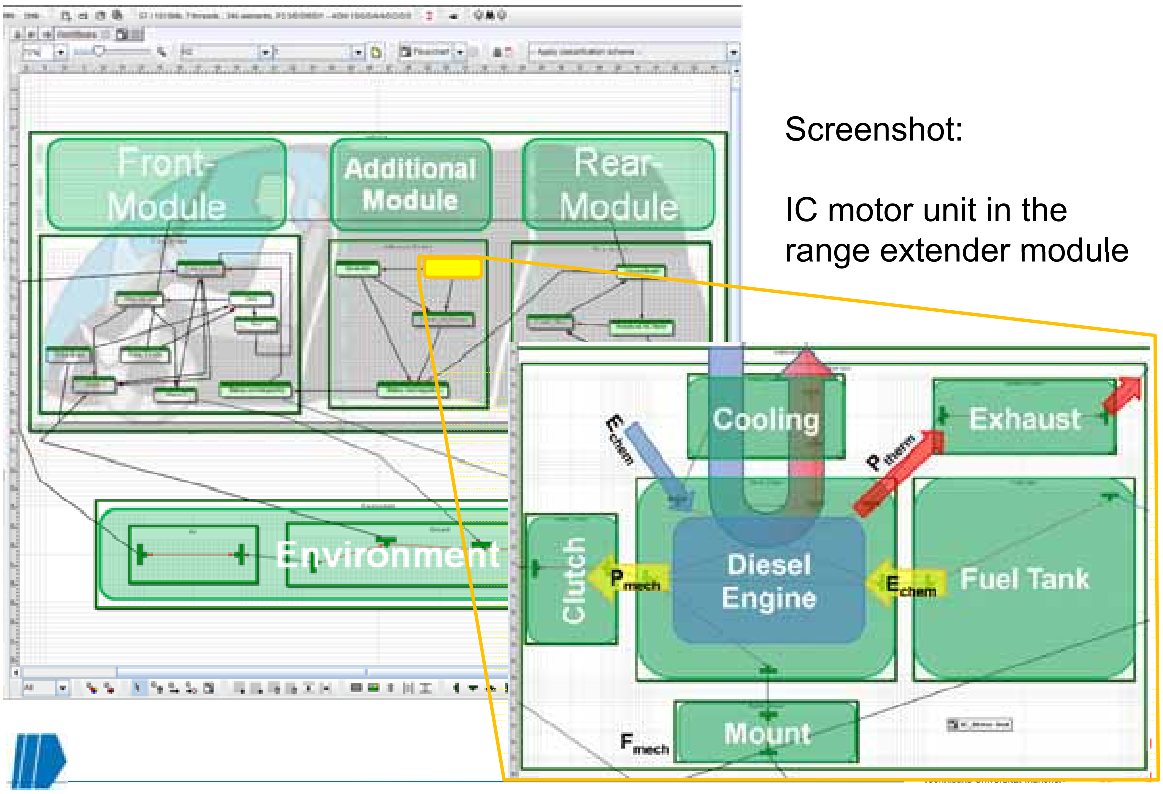


- Representation of WS 
- Representation of WSP 

- Representation of CSS 

- Modelling attributes helps creating complete models
  - Additional WSP for cooling
  - Acoustic properties
  - Project-dependent properties e.g.
    - Timescale
    - Target costs
    - Person in charge

[1] CAM – Cambridge Advanced Modeller (http://www-edc.eng.cam.ac.uk/cam)



Screenshot:

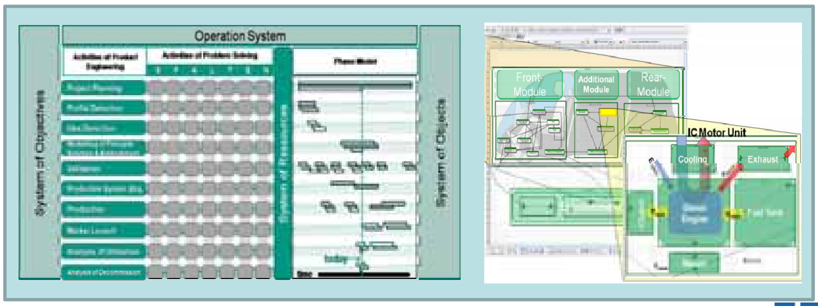
IC motor unit in the range extender module

Conclusions 1: iPeM in KI2

- Engineering processes can be modelled with the iPeM meta-model.
- To manage complexity, design problems need to be broken down hierarchically.
- Designers get **methodological support** as well as assistance in **project management** (structure, organization).

Using the approach in the project gave transparency about

who does **what**, **why**, **how** and **when**.



Conclusions 2: C&CM in KI2

- Function-based Contact and Channel-Modelling in a software implementation allows representing products in one consistent model.
- Adaptive zoom enables designers to focus on **relevant problems**.
- All necessary **information** about the product and for the process can be stored in WSP and CSS.

- C&CM and iPeM set up a **common language** for engineering design.
- Thus interdisciplinary cooperation and **cooperative work** in (globally distributed) teams becomes possible, as all elements/information of engineering processes can be **stored** and **shared** consistently.