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# FUNCTION DRIVEN PROCESS DESIGN FOR THE DEVELOPMENT OF MECHATRONIC SYSTEMS

**Stefanie C. Braun, Holger Diehl, Markus Petermann, David Hellenbrand and Udo Lindemann**

Technische Universität München, Institute of Product Development, Germany

*Keywords: Interdisciplinary Processes, Mechatronic Systems*

## 1 MOTIVATION

Mechatronic systems provide additional functionality by integrating electronic and software elements into a mechanical structure. Due to growing comfort requirements, increasing safety standards and a rising demand for environmental sustainability, they are omnipresent in today's automobiles. However, the synergistic integration of different engineering domains causes significantly higher complexity levels for the complete system [1]. In order to handle the development of complex but still robust mechatronic systems, improved interdisciplinary system understanding is essential: Regarding the steps of function validation there is the necessity of an effective and on schedule integration of the three disciplines' deliverables, even in early stages of product development. Therefore discipline-specific development processes will have to be more effectively interlinked. Typical ways of thinking in electronic/software engineering and mechanical engineering – e.g. function driven vs. component driven understanding of mechatronic systems – further complicate this issue.
Process modeling techniques currently applied in industry do not enough enhance overall system understanding and generate too little awareness for the importance of discipline-integrating milestones. This is due to a distinct decoupling of the representations of the development and production processes on the one hand and the system under development on the other.

An approach for the function driven process design and modeling has been developed at the Institute for Product Development. It aims at an effective integration of the disciplines by generating product and process representations that are easy to understand – even across disciplines. These research efforts are carried out within the cooperation project CAR@TUM, which is jointly worked on by the Technische Universität München and the BMW Group, Munich.

## 2 BASIS AND RELATED RESEARCH

In order to merge the function and component driven understanding of mechatronic systems their functions and system elements can be linked in one product model. An exemplary model consists of the functional hierarchy, the functional structure (functional dependencies), the system hierarchy, the system structure (working structure [2]) and the linkage between the functions and the system elements on the most detailed specification level currently available [3] (Figure 1). This allows for the parallel detailing of both domains in the course of the further development process [4].
In order to handle the functional and the system domain as well as their interactions, a multi domain matrix (MDM) can be used. There the domains are arranged in a symmetric matrix [5]. Networks consisting of only one domain type, like e.g. the functional structure, are located on the matrix diagonal (according to the approach of the design structure matrix, DSM [6]). The rest of a MDM is made up of networks that describe the interaction of two different domains (according to the approach of the domain mapping matrix, DMM [6]).
A product model in form of a MDM allows for single domain as well as for cross domain analysis [7]. So the usage of indirect relations e.g. enables the mapping from the functional responsibility of a person to its component responsibility and vice-versa.

## 3 OBJECTIVES

Building up on the described MDM-based product model function driven process design assists in the planning of the further development and production processes. Thereby the following goals are pursued:

- Assistance in the setting up of multidisciplinary processes
- Transparent presentation of the chronological correlation of multidisciplinary processes
- Preparation of a basis for structural analysis and optimization of the process structure
- Illustration of the process structure on different hierarchy levels
- Consideration of different views on the milestone system
- Degrees of maturity with regard to functions and system elements
- Expression of the degree of maturity by means of an additional time measure
- Transparent allocation of responsible persons
- Traceability of the impact of changes of the product structure on the process structure

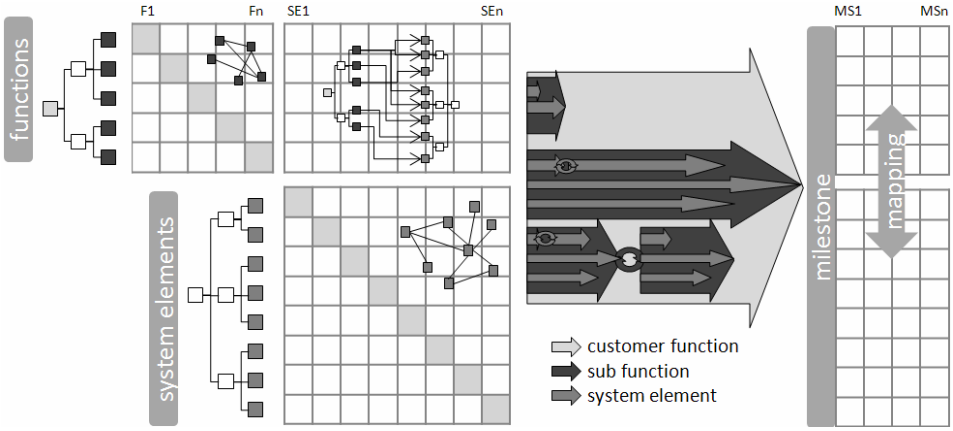


*Figure 1. Symbolic illustration of the chronological correlation of processes*

## 4 APPROACH FOR A FUNCTION DRIVEN PROCESS DESIGN

In function driven process design the MDM-based product and process model are linked through the deliverables produced. There are direct (●) and indirect (○) linkages between the six domains of the overall model (Figure 2):

- Functions
- System elements
- Deliverables
- Work Packages
- Milestones
- Responsible persons (not depicted in Figure 2)

As one consequence the sequencing of the work packages can be simplified: Assuming the rough logical structuring of the process by customer function milestones the time between two milestones is determined by the work packages needed to produce the deliverables which are the result of the regarded development phase. Starting from a milestone the work packages can be arranged forward or backwards in time where the sequence of work packages can be deduced from the sequence of deliverables.

The representation of the sequence of work packages in form of a DSM allows for structural process analysis and optimization in consideration of time and cost aspects as well as schedule risk [9]. Through the deliverables the milestones are associated with functions and system elements which meets grown conditions in departments of different disciplines. In addition the linkage of product model and process model offers the possibility to easily trace impacts of changes of the product structure on the process structure.

The work progress is associated with the deliverables produced and the work packages completed. As a consequence the degree of maturity can be linked to functions and system elements through the

MDM. Additional to the broadly used percentage values [8] a time measure is used to express the degree of maturity (Figure 2). That is beneficial as it does not leave as much space for interpretation.

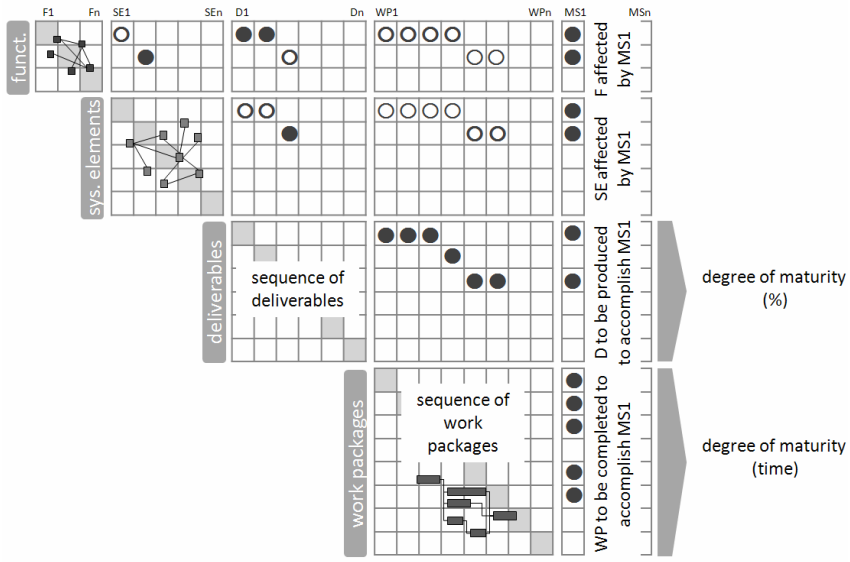


*Figure 2. Symbolic illustration of the presented approach*

## 5 CONCLUSION AND FUTURE WORK

The presented approach allows for a networked view on complex mechatronic products and their interdisciplinary design processes. Thereby it meets the requirements of grown corporate structures as it does not aim at changing but handling them.

The next step will be the validation of function driven process modelling on the basis of an example application. In the following an approach for the tool based implementation will be developed. Special attention will be paid to the definition and design of the different disciplines' views on the models and the hierarchy levels. This is supposed to enable an individual information search for different users and also avoid a surplus of information.

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Contact: Stefanie C. Braun
Technische Universität München
Institute of Product Development
Boltzmannstr. 15
85748 Garching, Germany
Phone: +49 89 289 15126
e-mail: stefanie.braun@pe.mw.tum.de

9TH INTERNATIONAL DSM CONFERENCE

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Stefanie C. Braun, Holger Diehl,
Markus Petermann, David Hellenbrand
and Udo Lindemann

Technische Universität München
Institute of Product Development
Germany



IN COOPERATION WITH BMW GROUP
CAPITALIZE ON COMPLEXITY

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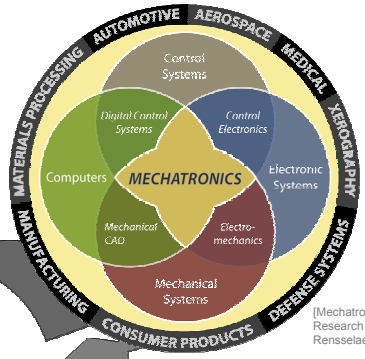
Product Development
Technische Universität München

## Introduction: The Dilemma of Mechatronics

### Potentials

- Reduction of constructed size, weight und energy consumption
- Raise of functionality and performance
- New fields of application
- Adaptive and cognitive systems
- Improved price-performance ratio
- Individual adaption to specific customer requirements




[Mechatronics Teaching & Research Laboratory, Rensselaer Polytechnic Institute]

### Challenges

**Growing product complexity**

multitude of components, diversity of components (heterogeneity), dependencies (interfaces, change dependencies), …

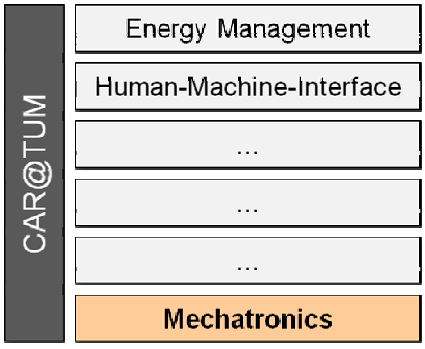
**Growing process complexity**

many participants, multidisciplinarity, dependencies of deliverables and process steps, variants, time/cost pressure, …





## Cooperation between TUM and BMW Group




### About the cooperation

- long-term strategic partnership with the Technische Universität München
- 35 postgraduates in six new interdisciplinary high-tech projects
- faculties: mathematics, mechanical engineering, information technology, physics, electrical engineering
- work on important topics detached from „day-to-day business“
- combination of fundamental research an real project conditions

[Technische Universität München: Pressemitteilung 14.5.2007]

## Motivation

growing comfort requirements

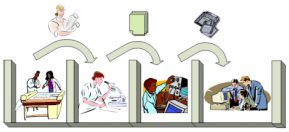
increasing safety standards

rising demand for environmental sustainability

…


rising complexity

different disciplines with different views on technical systems and grown procedural structures



[Jan Meyer: Modellierung von Softwarekomponenten für mechatronische Systeme in UML auf Basis von Systemstrukturen]

necessity of improved interdisciplinary system understanding

handling of oppositional ways of thinking

transparent matching of discipline specific development processes

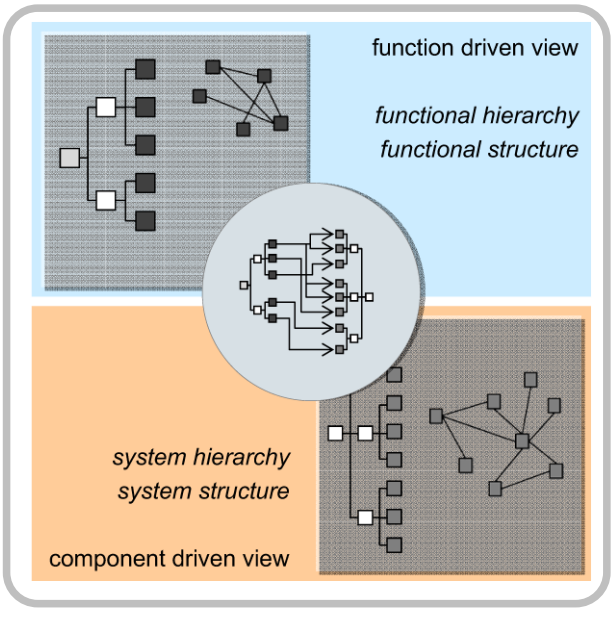
effective and on schedule integration of discipline specific deliverables

…





## Initial problem extracted from preliminary studies




Two different – insufficiently integrated – views on mechatronic systems:

**Function driven**

•functional hierarchy from customer functions down to elementary sub functions

•functional structure with functional dependencies

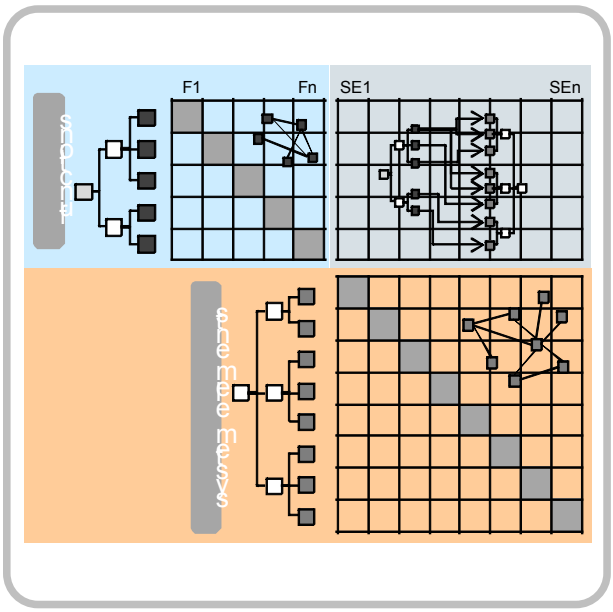
**Component driven**

•system hierarchy from modules down to system elements

•sytem structure (working structure)

➔ combination of the views in one product model

## MDM-based product model




Combination of the different sub models and their integration to a product model via MDM:

**DSM** (design structure matrix)

functional/system structure on different levels of detail (levels connected via hierarchies)

**DMM** (domain mapping matrix)

linkage between sub functions and system elements on the most detailed specification level

**MDM** (multi domain matrix)

combination of DSM and DMM to represent the overall model

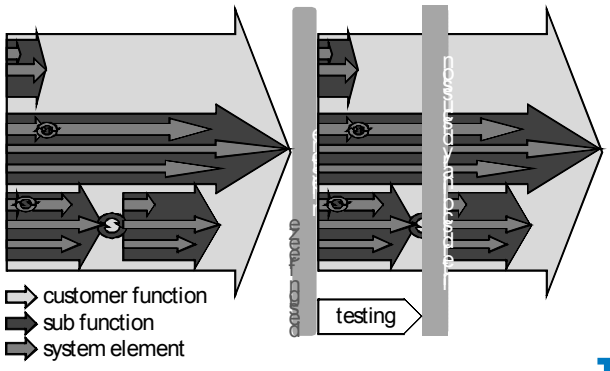
➔ usage of advantages offered by DSM/DMM representation





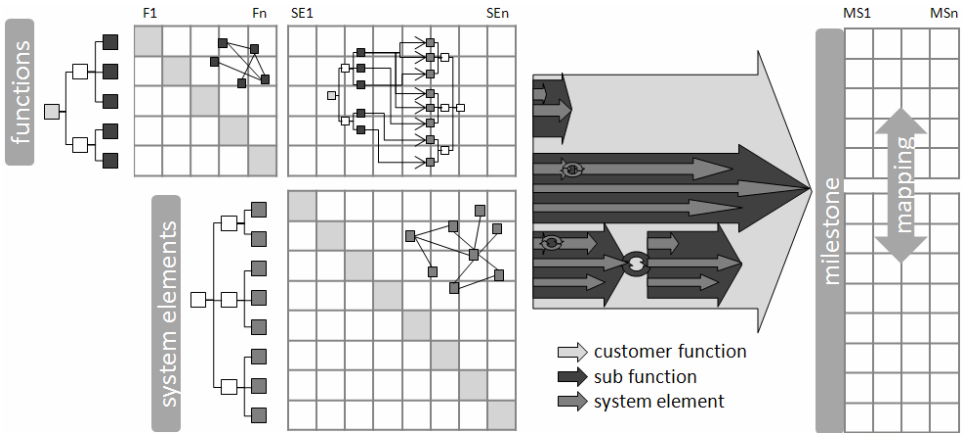
## Objectives of function driven process design (I)

- Assistance in the setting up of multidisciplinary processes
- Transparent presentation of the chronological correlation of multidisciplinary processes
- Preparation of a basis for structural analysis and optimization of the process structure
- Illustration of the process structure on different hierarchy levels
- Transparent allocation of responsible persons



## Objectives of function driven process design (II)

- Consideration of different views on milestone system
- Degrees of maturity with regard to functions and system elements
- Expression of the degree of maturity by means of an additional time measure
- Traceability of the impact of changes of the product structure on the process structure

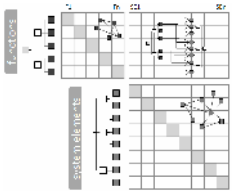







## Overall concept of function driven process design

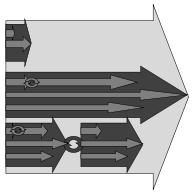
**product model**



*functions*
*system elements*

*deliverables*

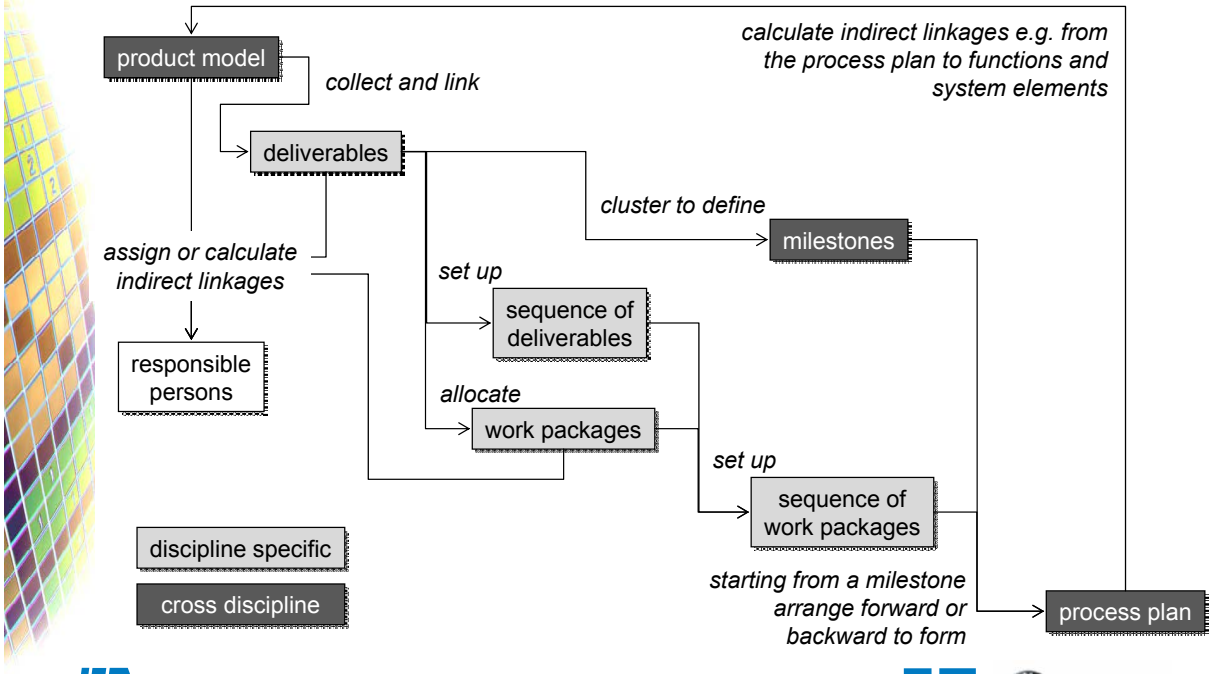
**process model**



*work packages*
*milestones*
*responsible persons*

- product model and process model linked through deliverables
- 6 domains of interest: functions, system elements, deliverables, work packages, milestones and responsible persons
- direct and indirect linkages between these domains in order to allow for a change of the view point
- integration of domain-specific models in an overall model/framework

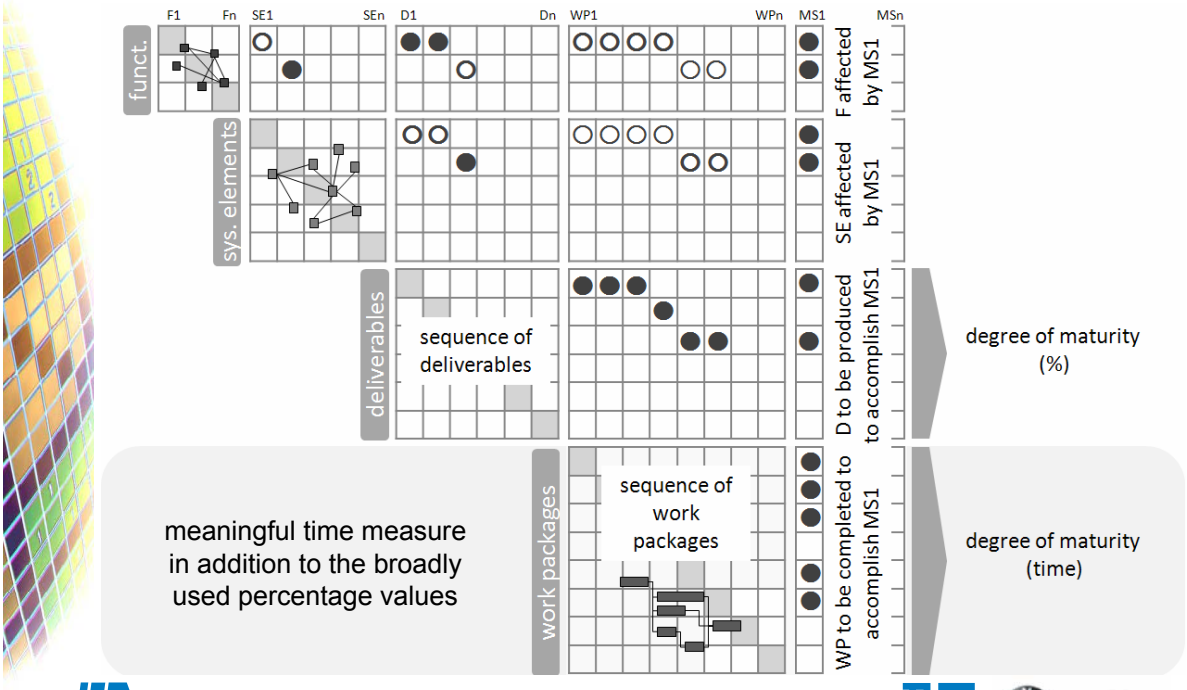
## Steps of function driven process design








## Degree of maturity



## Additional potentials

- by integrating filters different views on the overall model can be offered
- impacts of changes of the product structure on the process structure can be traced
- a basis for structural analysis and optimization of the process structure is provided

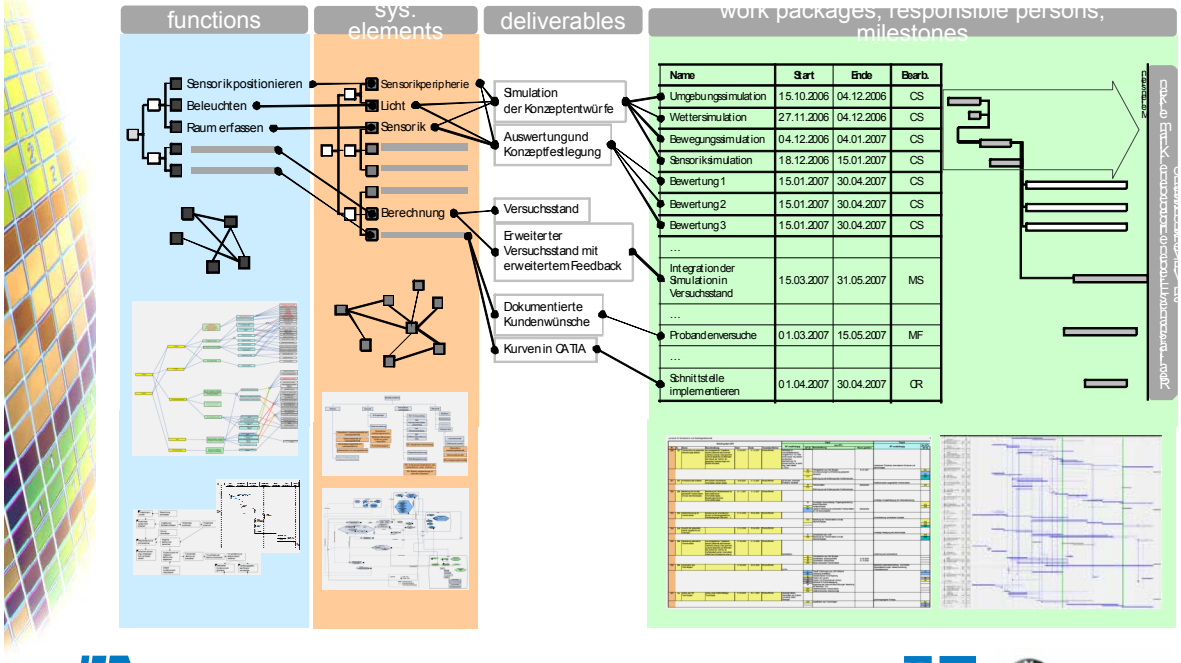




## Example application in a scientific environment

- complex task of great novelty
- automotive industry
- 11 research assistants
- 5 institutes
- 3 disciplines
- 3 years
- in close consultation with several operating departments of the industrial partner

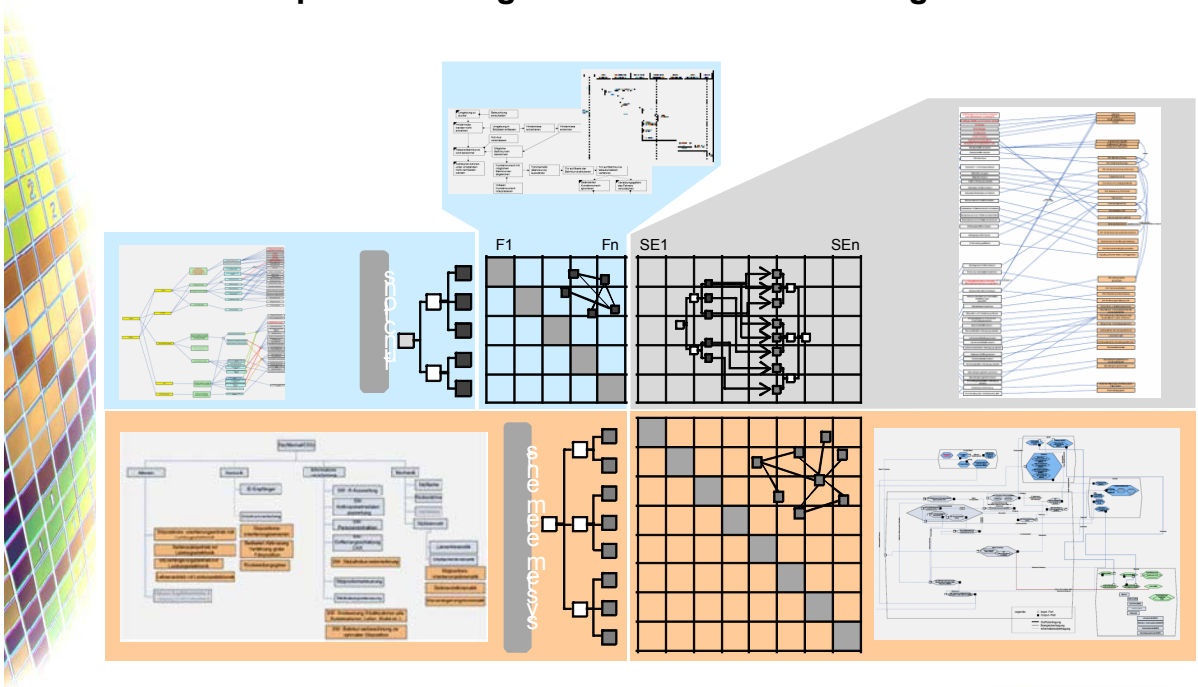
## Starting point: No identifiable linking of the sub models



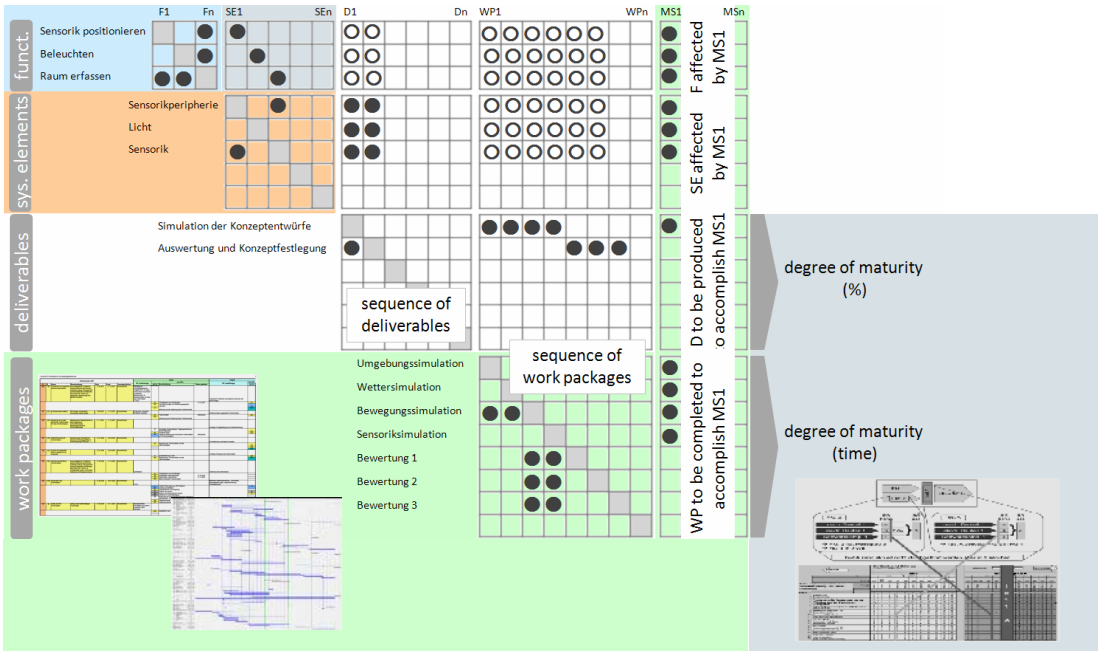





## Transparent linking of the sub models through MDM



## Process Planning on the basis of the MDM-based product model








## Future Work

In order to fill the presented framework of function driven process design several steps have to be taken:

- definition of the considered granularity of data
- tool support
- support for the extraction of data from domain and discipline specific sub models and its integration into the overall MDM model
- development of a comprehensible visualization
- definition of reasonable filters in order to meet different users' needs
- solution to handle the dynamics of the overall model
- verification of the approach through its application to industrial processes
- …

## Conclusion

- Mechatronic systems in automative industry offer decisive potententials along with major challenges.
- Interdisciplinary system understanding has to be improved and discipline-specific development processes have to be better interlinked.
- Thereby grown corporate structures must not be ignored but picked up and integrated into the optimization process.
- Therefore the presented approach assists in linking existing domain and discipline specific sub models so that their dependencies become more apparent.
- This assists in the planning of multidisciplinary processes and as a result in the effective and on schedule integration of discipline specific deliverables.