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TEAM COMPOSITION TO ENHANCE COLLABORATION BETWEEN EMBODIMENT DESIGN AND SIMULATION DEPARTMENTS

M. Kreimeyer[1], F. Deubzer[1], M. Danilovic[2], S.D. Fuchs[1], U. Herfeld[1], and U. Lindemann[1]
[1]Technische Universitaet Muenchen, Institute for Product Development, Germany
[2]Jönköping International Business School, Sweden

ABSTRACT
Efficient collaboration between design and simulation departments is a key factor to efficient product development. There are numerous efforts to systematically "integrate" product development activities using CAD- and CAE-systems.
This paper presents a team-based approach to render collaboration, i.e. communication and coordination, between the engineers involved in designing and simulating the product more efficient. It is part of an overall integration strategy to support collaboration between the departments in question in terms of the product architecture and the engineers involved as well as information objects, tools, and the process.
The team structures proposed combine the different ways of organization prevailing in design and simulation. Based on a product architecture regarding both functional and geometry-oriented perspectives onto the product, virtual teams attributed to parts of this component-function-structure serve as a basis to enhance communication. This is intended to offer a means of orientation to coordinate common efforts between engineers involved. The paper lines out a method to compose teams that merge the necessary competences and responsibilities involved to foster communication across different engineers involved in a set of functions and components.

Keywords: team composition, collaboration, CAD-CAE-integration, communication

1 INTRODUCTION
To raise efficiency in industry, the design process has come into focus over the past years; as part of it, it is commonly acknowledged that replacing physical prototypes by virtual ones by using CAE systems is both cost- and time-efficient [2]. Hence, efficient collaboration between design and simulation departments is a key factor for efficient product development [9].
In a current project with a German automotive manufacturer, the collaboration between engineers using CAD and CAE for the interior and exterior design of the car's body is being optimized to obtain a well-tuned process. The project is approached in five dimensions to achieve a most beneficial outcome; respectively, data, tools, and the process are regarded as well as the product and the engineers involved [6]. The overall strategy to enhance collaboration is also explained in detail in [7]. This paper addresses in particular the correlation between the dimensions 'product' and 'people' by establishing team-based communication-structures.
The human factor (i.e. communication, goals, hierarchies,…) must be especially stressed in this context, as many projects carried out to enhance collaboration have solely regarded technical aspects (see e.g. [12]). However, as e.g. [22] or [15] show, mere IT solutions or product models that do not respect the user's way of structuring a problem, are often incomplete and do not succeed in industry.

2 COLLABORATION BETWEEN EMBODIMENT DESIGN AND SIMULATION
Product development nowadays necessitates the exchange of information between all development engineers who collaborate on aspects of the product (parts, functions,…) that it is internally interconnected on [26], hence communication between almost all persons involved in the design of such a product. Aggravatingly, labour is highly subdivided to allocate all competences necessary for

the development. Being regrouped either according to parts of the product topology or particular fields of competence, these groups form the organizational structure of a company, enabling control and command through limited team sizes [20]. In most cases, it takes the form of a matrix-organization, characterized by the coexistence of hierarchical and project-oriented structure.
To ensure efficient collaboration between the numerous persons involved, both communication of relevant information and coordination of the tasks involved have to be ensured. Communication, however, can be understood as a means of coordinating common efforts [17]. Transfer of information is therefore crucial. Commonly, the question of what information has to be transferred from whom to whom at what point of time is asked. This paper addresses the correlation of content, sender and recipient by delivering a means of orientation to avoid an information overflow among the development engineers.

2.1 Information Driven Management – Handling collaboration as a complex system

The interaction between embodiment design and simulation can be understood as a complex system as defined in systems' engineering [21]. It can be broken down into a set of dependencies between elements of organizational structure, product architecture and the process structure. Its elements are linked, above all, through information transfer dependencies.
The Information Driven Approach (IDM) is able to process these dependencies purposefully [5]. It is based on the Dependence Matrix Analysis (DMA). The DMA approach comprises two complementary analyses of relations and interdependencies, Dependence Structure Matrix (DSM) [3, 27] and Domain Mapping Matrix (DMM) analyses [4], in order to manage uncertainty through systematic understanding of interdependencies and needs for information exchange. The combination of DSM and DMM approaches can capture the dynamics of product development, enable the transformation of information between different domains of product development, create traceability of information and dependencies in different domains, open up the boundaries and create transparency between domains, synchronize actions carried out in different domains, verify the captured information in one domain against another domain, integrate an individual system into a cohesive project or program, and improve decision making among engineers and managers by providing a basis for communication and learning across domains [5].
Following the approach of IDM, the "logic of decomposition", i.e. the break-down of a system into elements is followed by the "logic of integration", i.e. the (re-)combination of elements into modules based on their dependencies (see figure 1). In the context of CAD-CAE-integration, the dependencies between embodiment design engineers and components are relevant as well as the involvement of single components and individual functional properties ("load-cases"), and ultimately the load-cases need to be linked to the simulation engineers. Each of these mappings can be modelled using DMMs to represent the interaction between the embodiment design engineers and the components, the components and the load-cases, and ultimately the load-cases and the simulation engineers [4].

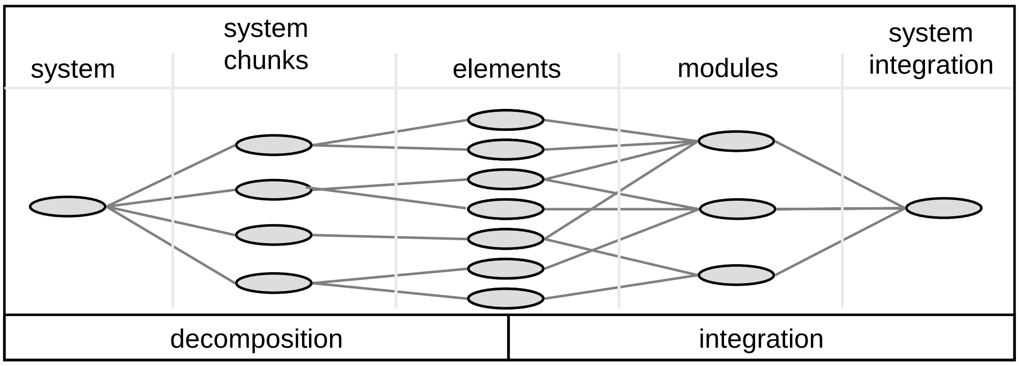

Figure 1: decomposition and integration in Information Driven Management [5]

2.2 The interface between embodiment design and simulation engineers

Simulation departments are nowadays in transition from supporting the design process to being an important and decisive player [9]. Design departments, however, still act as the backbone in product development, having to ensure achievement of the overall goals and fulfilment of requirements as best possible compromise of all relevant requirements [11].

Characteristics of the colloboration between embodiment design and simulation engineers

Simulation is focused mainly on meeting the functional properties of the product, referred to as "load-cases" (i.e. a set of information that is fed into a simulation tool to answer one specific question about a functional property, e.g. crashworthiness according to EuroNCAP) that can be simulated, whereas the embodiment design has to look at the product requirements in a holistic way, which means the designer has to consider all requirements, as for example producibility, maintenance, etc. Hence, both departments take different perspectives onto the same product.

These perspectives overlap, but they are neither identical nor additive in any linear manner. In fact, the product architecture, i.e. the component structure as created by the embodiment design engineers, is related to the functional properties of the product, i.e. load cases or functions as accounted for by the simulation engineers, in the form of a dense network [13], as shown in figure 2. Thus, one simulation engineer needs to collect information from a number of his colleagues in embodiment design; all the same, one embodiment design engineer is interested in the results of a number of different simulations and has to interact with a number of different colleagues in simulation.

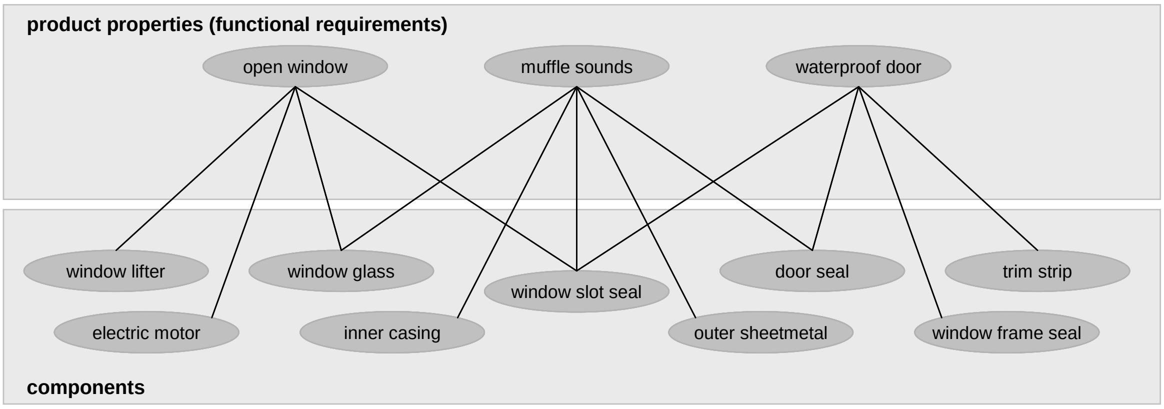

Figure 2: Product architecture involving components and properties

Depending on the property regarded, components are involved differently. Whereas sometimes only the mass of a component is of importance, in other cases the exact geometry may be needed. In turn, the results of the different simulations have a different impact onto the component.

At the same time, these efforts have to be coordinated on an overall level. This is especially true for core components, i.e. those that are essential to the product's properties. Whereas the components and product's properties form a dense network of dependencies, it cannot be expected that it is a self-regulating one. Therefore, the core functions need particular regard to focus all development efforts according to the market's demands and to comply with all regulations and requirements set.

Specifics of collaboration for the empirical study of this research

At the company, a larger case study was carried out involving the organization of approximately 800 engineers in embodiment design and about 50 engineers in simulation. The study focused on the development of the so-called "trimmed body" of a mid-size premium-class sedan. This scope comprises the car's body, all doors and hatches as well as the interior panelling, including more than 400 components that are exposed to more than 130 structural load-cases related to comfort and safety.

As the numbers show, single engineers need to navigate a highly complex system in search of specific information about the product. The overall goal of this research was therefore to design a strategy to ensure a purposeful transfer of information from the right senders to the right recipients, i.e. from the embodiment design engineers to the simulation engineers and back. This was aspired to create a higher level of interaction and better coordination between the departments in question. Specifically, integration and coordination between the three following aspects was aimed at:

- between different load cases (evaluated properties of the whole car's trimmed-body, e.g. crash, harshness, vibration)
- between core components evaluated through simulation
- between the core elements in both embodiment design and simulation

The methodology was therefore designed to answer the question how, through teams of manageable size, coordination of all engineers could be achieved so that, at the same time, information transfer in both directions could be ensured. These teams were to be supported by a core team to coordinate the overall efforts and, in particular, be responsible for the core components and load-cases.

2.3 Communities of practise and virtual teams

To foster information exchange between development engineers in different disciplines so-called communities of practice or virtual pluridisciplinary teams are accepted approaches. First introduced by Lave [14], communities of practise attempt to interlink personnel across hierarchical, organizational, project-based, timely, spatial, cultural and lingual barriers [24]. These communities are not to be seen as a new form of organization, but as a “new cut on the organization’s structure” [29]. They form informally around a common problem or interest with the purpose of sharing information. Hence, they are fundamentally self-organizing on a membership-basis [28]. They do not directly impact the existing command structures in a company but coexist with them. Normally, they cannot be created but come into being if need arises [24].

Virtual teams - also known as Geographically Dispersed Teams – are teams that work in regular team structures but do not meet face to face on a regular basis. A good overview is given by [25].

Combining the two ideas creates an effective means of enabling collaboration between personnel across a company’s basic organizational structure (as needed for efficient collaboration between embodiment design and simulation engineers), creating a virtual team that combines different disciplines that share a common goal and purpose across a number of (usually geographically dispersed) departments.

3 METHODICAL TEAM COMPOSITION

Team composition responds to requirements from different influences: Psychology regards the human behaviour and interaction within teams [15], the process imposes the team members’ relation to the artefacts within the design process [18], the company organization provides the different jobs and competences involved [23]. The focus in this paper is primarily the latter one, attempting to algorithmically compose the necessary competences to form teams that efficiently collaborate in the embodiment design and simulation of automotive bodies.

The basic idea for methodical team composition was already published in [13]. At its core, components and load-cases are mapped in a DMM. This matrix is then clustered using a refined algorithm based on [19] to obtain groups (“clusters”) of components and properties which are highly alike within each cluster. [10] looks closer into the potentials of such a product topology. Figure 3 shows the outcome of such a clustering.

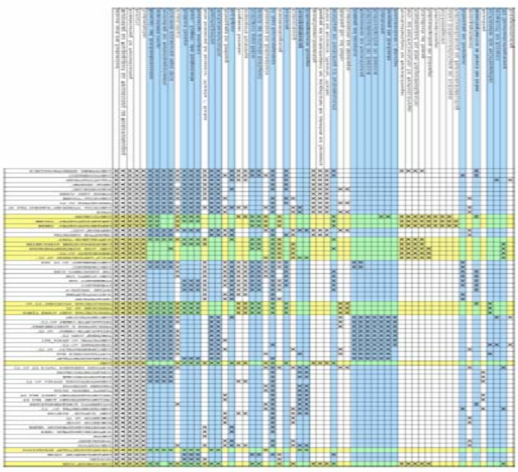

Figure 3: Example of a clustered DMM of components and load-cases [13]

The methodology proposed was extended involving the following steps:

1. a weighting of the involvement of each component in each load case
2. an attribution of the engineers, weighted according to their level of involvement
3. a configuration of team building blocks including all engineers involved in each cluster, including their strength of interaction to designate their importance to the overall team and to focus on important members in case the team size has to be limited

4. a strategy to design integrated (virtual) teams according to the direction of information flow
5. a coordination team that regroups the most important staff in both embodiment design and simulation departments to oversee the overall coordination

Each element is detailed in the following chapters.

3.1 Weighting of the involvement of each component in each load case

To represent the quality of involvement, the linkage between components and load-cases is represented in the DMM using a weigh according to the importance of a component for a certain load-case. The matrix is then clustered to form (more or less) coherent clusters that contain elements that can be considered self similar on the individual level (see figure 4). They therefore represent each a particular situation or entity of information exchange between the involved engineers that can be standardized up to this level of self-similarity. The levels considered for the weighing are the following:

- level 3 - component is evaluated by load case (strongest linkage)
- level 2 - component is a significant part of the model
- level 1 - component is an element of the models border area

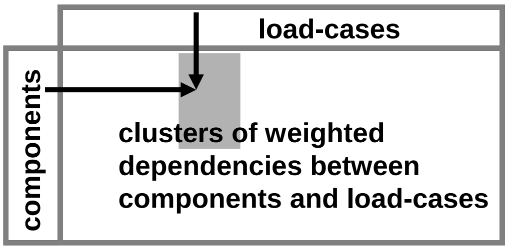

Figure 4: schematic of clustering weighted dependencies of components and load-cases

3.2 Attribution of personnel weighted according to the level of involvement

Depending on how much an engineer is responsible for a component (in embodiment design) or a load-case (in simulation), his involvement in that element is weighted accordingly. This assures at a later stage that those people of higher relevance to a cluster of components and load-cases can be identified easily. Again, the linkages are modelled as DMMs (see figure 5). The levels considered for the weighing are the following:

- level 3 - engineer is responsible for component or load case (strongest linkage)
- level 2 - engineer conducts the embodiment design/simulation of component/load case
- level 1 - engineer supports embodiment design/simulation of component/load case

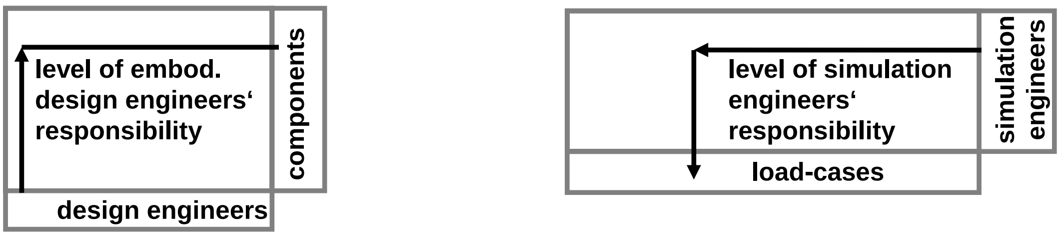

Figure 5: schematics of mapping the engineers' involvement in components/load-cases

3.3 Configuration of team building blocks

Joining the three DMMs, the engineers involved in each cluster of in the component–load-case–DMM can be computed as shown in figure 6. Given that each block represents a group of components and load-cases that is rather similar in terms of collaboration, the groups of engineers found need to collaborate particularly closely, as their scopes of the product are closely related and similar.

Depending on the size of the initial cluster, these teams can be very large. In such a case, one large team is not desirable, as again one large team (as the worst case) is no improvement. In such a case, the overall strategy can either be applied on a finer level (much like a fractal approach), or the strength of involvement can be used to compute the relevance of each person engineer to the overall team building block. If an engineer is only supporting the embodiment design (= weight 1) of one component that only borders the simulation area (= weight 1) and only has to interact with a simulation engineer who's supporting the simulation of a load-case (= weight 1), their collaboration is of little relevance. In this case, the interaction strength is 1 * 1 * 1 = 1. If, however, another person is responsible for a the embodiment design of a component (= weight 3) and conducts the embodiment design of yet another component (= weight 2), and each component is evaluated (= weight 3) by a simulation engineer responsible for that load-case (= weight 3), the interaction strength comes to 3 * 3 * 3 + 2 * 3 * 3 = 45. Thus, he is important in comparison to the first one.

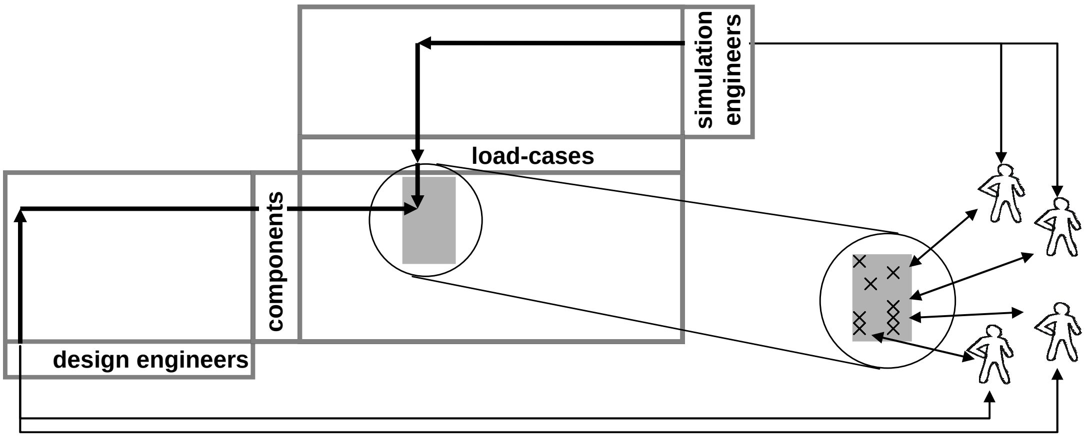

Figure 6: schematic of designating engineers involved in one team building block

3.4 Strategy to design integrated (virtual) teams

Up to this stage, a number of team building blocks have been set up. These cannot exist solely, as the evaluation of a simulation will usually involve a number of these blocks to be "run" to collect all component-related information necessary for one load-case. The same is true for the integration of different simulations into one cluster of components. Therefore, for each direction of information exchange, the team building blocks have to be combined as necessary to for integrated virtual teams.
For the direction of function evaluation, those team building blocks that integrate all embodiment design engineers involved in cluster of load-cases are collected. Respectively, for function integration purposes, those team building blocks that collect all simulation results relevant to a cluster of components are combined to form a function integration team. Hereby, the networked structure of the product architecture from both a functional and a topology viewpoint can be recreated in the organizational structure to offer orientation for all engineers involved. Figure 7 depicts the overall strategy in its two possible implementations.

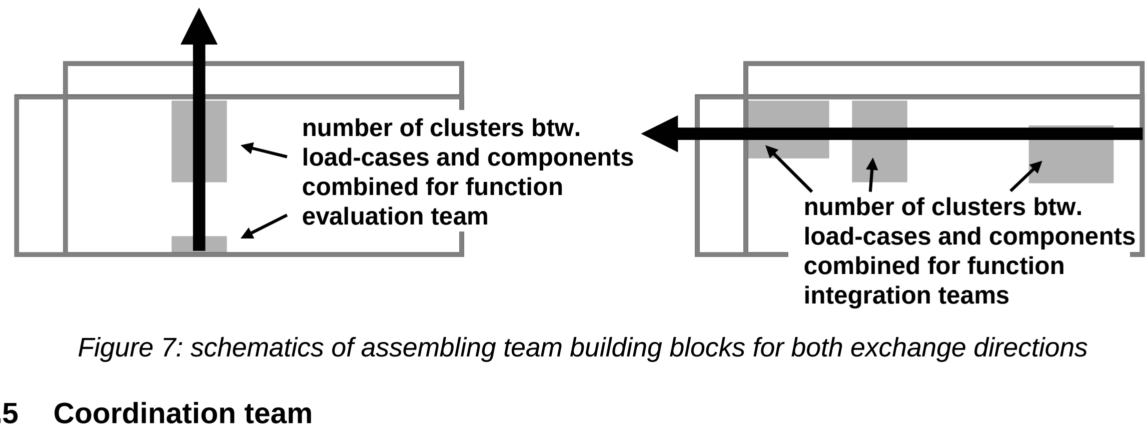

Figure 7: schematics of assembling team building blocks for both exchange directions

3.5 Coordination team

While the networked structure of the product architecture used tends to ensure that all components are linked to all load-cases, discussions in industry and the large number of people necessitated a controlling authority that oversees the collaboration between all engineers regarded, prioritizes tasks and settles conflicts. For this, only the key stake holders within the overall product architecture were extracted to act as a core team. Only those engineers that bear responsibility (= weight 3) for components that are evaluated (= weight 3) are eligible. This way, all core components of the product as well as all core functional properties are included. Figure 8 shows how the overall matrix-scheme is reduced to represent only the core team.

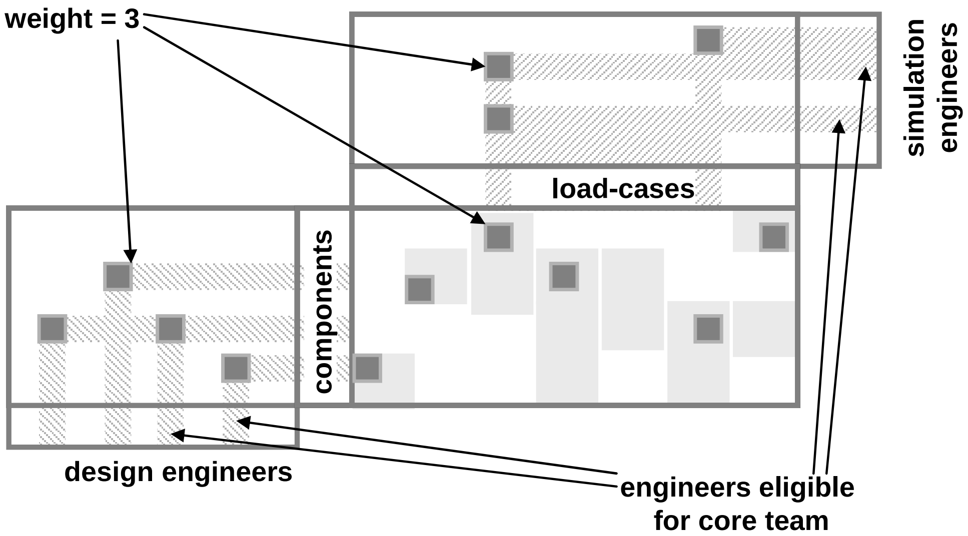

Figure 8: schematics of eligibility for core team

4 PRACTICAL APPLICATION

In collaboration with the partnering company, an empirical study was carried out to better understand the concept designed as well as to verify the outcome within the company. For a limited scope, the necessary matrices were collected. The outcome was compared to actual proceedings and communication structures.

4.1 Case study

Data collection

As the company collaborating in this research is undertaking this project to establish a new process standard, data collection proved to be difficult as no prevailing standards could be resorted to. In turn, the weighing for the matrices could not fully be respected as proposed. The main problem turned out to be the fact that responsibilities and involvement in work procedures were only irregularly formalized and could not be accessed at all as only little documentation was available. Globally, two modes of participation could be detected through research in documents, attendance in meetings and workshops/interviews (these contributed to the design of the weights as presented):

- process participation called “roles”
- functional participation called “competences“

Roles describe the participation of a person in terms of person’s responsibility within the process [8]. So the interaction between the person and the subject of development is in focus. In turn, consulting project plans or release-procedures granted information about roles. Equally, individual interviews, product documentation in product-data-management systems provided further insight. All of these sources were used to gather the presented information.

The competences focus the discipline which a person is working for, i.e. the function within the department represented for the embodiment design and simulation engineers. In fact, for the purpose of the case study and application within the project, a higher degree of detail than mere departments was chosen to reflect the different competences prevailing in the company to describe the technical background each involved engineer has. As sources both job descriptions from the human resource management as well as entries in phone-lists, individual documents and ultimately the organizational chart were used to compile the necessary data.

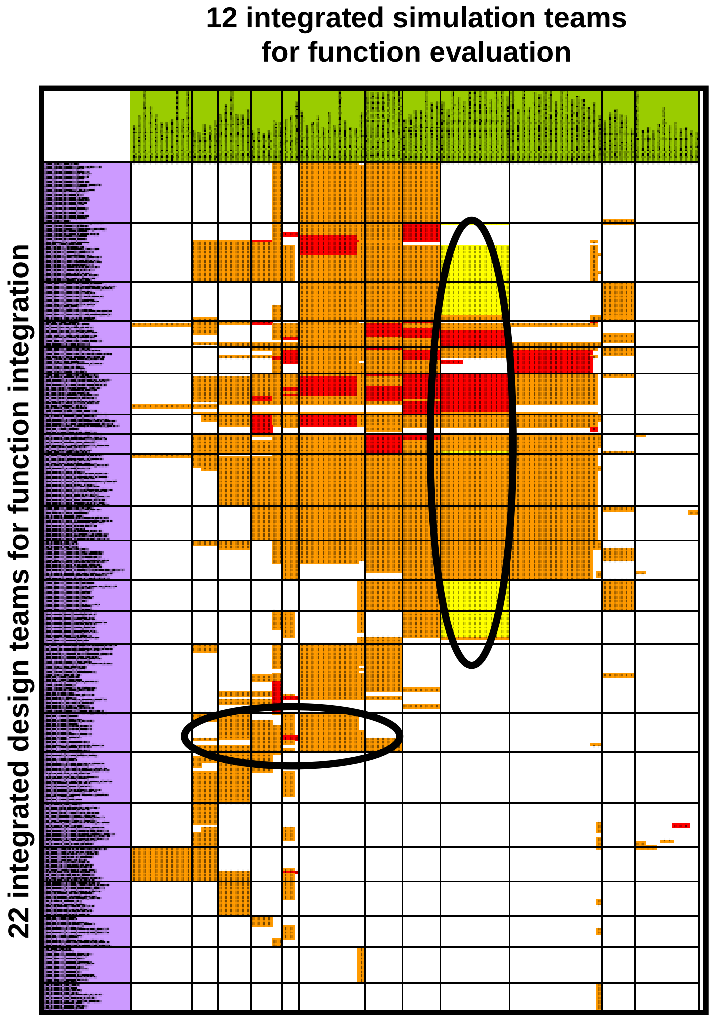

Figure 9: overall DMM linking components and load cases (clustered), showing two exemplary integrated teams and the necessary team building blocks (other matrices relating engineers components/load-cases not shown)

Assembly of matrices and team composition

The product example chosen was the so called “trimmed-body”, i.e. the automotive body involving all sheet metal parts including doors as well as the interior panels and equipment. In developing such a system, approximately 800 people are involved in embodiment design, designing more than 400 components. In the simulation departments, more than 50 persons supervise about 130 load-cases. Accordingly, the DMM for components and load- cases involves >400 components in its rows and >130 load-cases in its columns. For each dependency, the weight is shown in a colouring scheme (yellow = 1, orange = 2, red = 3). After clustering, 153 relevant clusters could be identified. Figure 9 depicts the outcome, thus detailing the schematics shown in figure 4.

Following the logic explained in section 3.4, 12 teams for function evaluation (i.e. simulation of the product’s properties) and 22 teams for function integration (i.e. embodiment design) were found. These were exemplarily compared to existing work-structures within the company through interviews, and showed remarkable resemblance to prevailing informal team structures. Furthermore, part of the company’s organization was transformed during the time of this research to form a central department that is concerned with a limited number of load-cases relevant to safety in traffic; this department now covers both design and simulation engineers as well as test engineers. Of the two former ones, most of those found in the adequate teams as shown in the matrix are now part of that department. Unfortunately, due to reasons of nondisclosure, this cannot be detailed further.

Figure 10 furthermore shows the three DMMs reduced to those relations elements that are weighted at level 3 to compute engineers eligible for the core team as schematically shown in figure 8. As can be seen, the matrix of components and load-cases contains only rows and columns with at least one red element. The DMM for the simulation engineers turns out to be rather small, as only six simulation departments are involved in the 65 remaining load-cases. Furthermore, no simulation engineer actually bears responsibility for any function, which is due to the way releases are handled in that company (the simulation has no formal involvement in the release-procedure). As it turned out that a large number of design departments was represented, again, the level of activity was computed to enable pinpointing the most important team members. Furthermore, the outcome needs to be manually adjusted, as e.g. the vertical orange line in the centre of the yellow matrix (linking embodiment design engineers and components) shows. This line represents the DMU activities conducted by a centralized service department that is, however, not relevant to the core team.

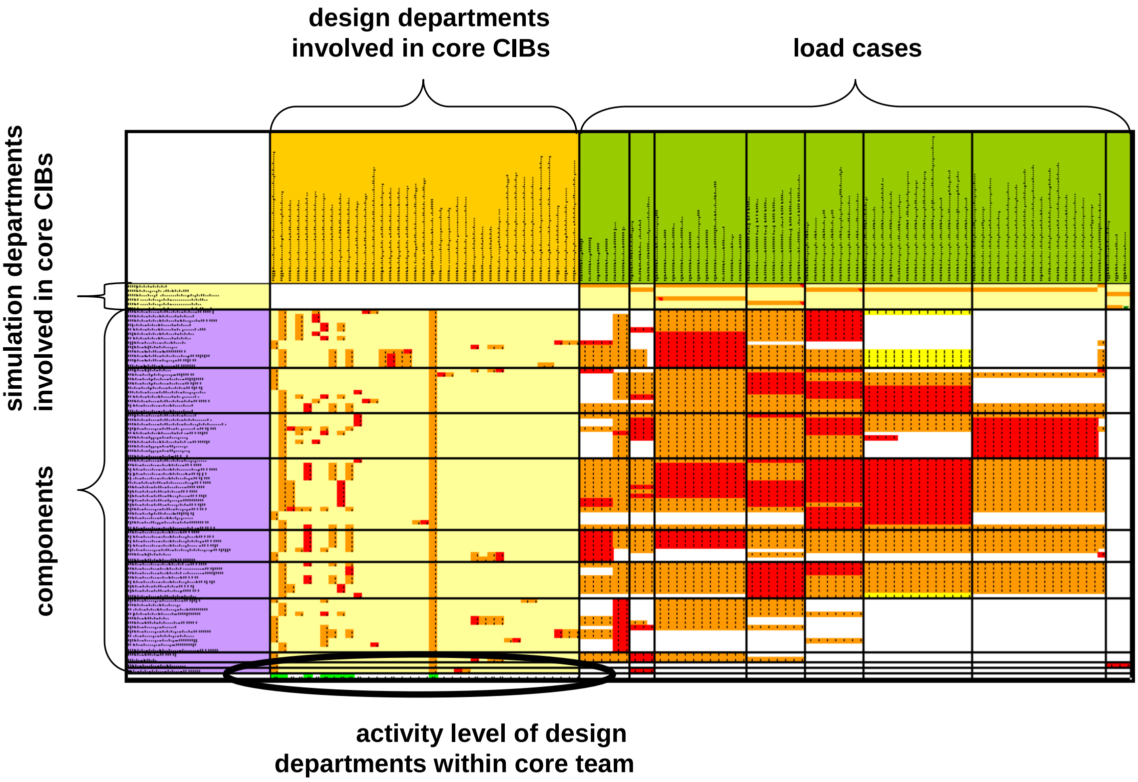

Figure 10: all three DMMs to compute engineers eligible for the core teams

4.2 Validation and results

Two techniques for validating the results obtained were used as suggested by [1], i.e. the so-called member-validation and triangulation. In contrast to the natural sciences where findings are validated or verified by their replication by a second independent investigator, in sociological problems, validation cannot occur through subsequent replication, since identical circumstances cannot be re-created outside the laboratory.

Validation of input

As described in the second half of chapter 4.1, the input data was difficult to assemble. Based on process charts and general procedures as explained by senior experts within the company, the input matrices werer therefore reviewed and (where necessary) adapted. As, however, the majority of input data was based on descriptions of product specification, this data was considered of high quality, as the specifications undergo a meticulous review process prior to their application in any new project in the partner company.

Validation of output

Firstly, the results were fed back to the participants of the study through individual meetings, a final presentation and a written report by the researchers. Upon each stage, feedback from the participants was encouraged. So far, all statements about the evaluation were taken in very positively by the participants and seen as accurately representing the actual status of communication between CAD and CAE engineers. Secondly, the results were cross-referenced (‘triangulated’), as an adapted version of the matrix relating components and load-cases has been implemented by the partner company for the direction of CAD-CAE information exchange. To this end, it is used to determine all information objects necessary to build-up a simulation and to direct the simulation engineer to all relevant sources of information.

4.3 Reflection

The teams found have proven adequate. Whereas the company is still largely organized according to hierarchical component structure, parts of the organization have recently been regrouped into integrated departments that match the team compositions proposed by the algorithmic procedure described in this paper. Also, interviews with management staff and individual engineers as well as the authors’ knowledge of the company’s work structures confirm this.

For efficient collaboration between design and simulation departments, the team structures serve as an organizational means of orientation for the engineers involved. The teams are furthermore supported on the other domains of integration (data, tools, process) by checklists and standardized procedures that are set up to suit the team structures proposed. It is in the context of this project that the teams are run – so the team organization is adapted to the needs of the collaboration between the engineers in question (size, meetings, kick-off,…) as suggested by [16].

The teams are, therefore, an essential building block in an overall strategy for process integration between the departments in question (see also [7]).

4.4 Managerial implications

The approach shown presents a network-oriented form of organization that correlates to the product architecture in terms of embodiment design and simulation. It therefore represents more realistically the networked character of the product architecture than a functional or hierarchical company organization. Thus, it provides both engineers and management with a higher transparency of how the product is structured. In turn, information needs are much clearer, enabling all participants to exchange information more actively. Furthermore, the relevance of information and data objects becomes more visible. Therefore, special attention can be paid to these objects.

Secondly, having broken down the product architecture into smaller blocks of manageable size, unambiguous responsibilities can be attributed to each team, stating at the same time their goals. That way, self-monitoring is enabled. Also, key stakeholders and important carriers of information and experience can be identified more easily.

The product architecture and the belonging organizational structure are, at the same time, linked to the product’s functions, which are the focus of all customers’ attention, who buy an automobile to obtain a number of functions (speed, safety,…). Insofar, this form of organization can be used to support the transition from a component-oriented work breakdown structure to a function-oriented one, which must be considered much closer to the customer’s perception of a product.

5 CONCLUSION AND FURTHER WORK

Whereas design-analysis-integration is typically addressed as a purely technical problem [12], the proposed teams have turned out to be an effective means to enhance communication throughout the development process that has been well-received by industry.

Above all, situation visibility is created for all involved engineers. This also facilitates the creation of an arena for communication, i.e. the individual team and its participants. At the same time, the form of organization proposed has little or no impact on the existing organizational structure and matches the engineers’ expectations. Hence, it is more easily accepted.

With the approach, a multilevel and multidimensional integration between CAD and CAE environments through a manageable number and size of teams has been achieved. Being supported by a suitable data-management-system in the future and a purposeful line-up of the teams within the overall design process of the company, the approach proves to be helpful to provide more effective and efficient communication between the engineers involved. It fosters synchronization and coordination of values, tasks and actions within design (function integration) and simulation (function evaluation) departments. Ensureing overall coordination by a core team, the coherence and adjustment of the overall product is made certain as well.

The team-based approach incorporates different perspectives on the product structure simultaneously, hence providing integration in the very sense of combining two different aspects into a common one. The clusters detected in the overall structure of the matrix thus represent building blocks for information exchange so far. In a next step, they need to be supported by requirements and checklists for both directions of information transfer. Whereas a simulation engineer demands for certain files or data to build a simulation model, he returns a different kind of information later in the process. This is only partly represented so far. Also, communication media and expectations to each of those information exchanges should be fixed to allow for the creation of certain standards. These form the basis for defining routines and procedures to be designed in order to ensure that people actually work as teams.

The approach shown can be extended in a number of ways:

- time: research can be extended to incorporate all phases of product development
- analytical level: the focus of the apporach can be broken down onto a level of finer granularity (e.g. work packages)
- scope: suppliers and other development project teams can be integrated (multiproject environment)
- intensity of communication: research can be extended to cover the design of organizational routines in order to ensure the desired level of collaboration and communication

Ultimately, the presented approach is actually more of a strategy for CAD-CAE-integration. It doesn’t allow for closer conclusions about how the process is actually run. Especially the micro-process of each individual iteration between embodiment design and simulation needs more detailing as to how information is transferred, how it can be located and at what level of maturity it needs to be transferred to allow for a particular kind of interpretation.

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Contact: Matthias Kreimeyer
Technische Universitaet Muenchen
Insitute for Product Development
Boltzmannstrasse 15
85748 Garching
Germany
Phone: +49 89 28915136
Fax: +49 89 28915144
e-mail: matthias.kreimeyer@pe.mw.tum.de
URL: http://www.pe.mw.tum.de