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AN APPROACH FOR EFFICIENT COLLABORATION IN VIRTUAL PRODUCT DEVELOPMENT ENVIRONMENTS

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ABSTRACT
The benefits of Concurrent Engineering, being an accepted and widely applied approach especially in the automotive industry, are commonly known. Also, the supportive application of Product Data Management (PDM) and Product Lifecycle Management (PLM) systems in Concurrent Engineering environments has proven to be effective. Yet, the efficient planning and implementation of the mentioned approaches as well as the coordination and technical support of collaborating departments in industry turn out to be difficult. The intensive analysis of processes and interviews with engineers of the cooperating company show that the inherent potential is not completely exploited, so methods need to be defined to tap the full potential. The core problems addressed are time and cost consuming processes due to inefficient communication, organisation and coordination between embodiment design (CAD) and simulation (CAE) departments. To overcome the shortcomings in the application of existing approaches, a systematic approach was defined, which allows for a systematic definition of efficient collaboration between interdisciplinary departments. The considered problem domains hereby are the product itself, being scope of all activities in the company (product domain), the involved departments and engineers (people domain), the relevant information flows and sources (data and tools domain), and finally the process designed to coordinate all activities (process domain). The empirical data for the shown example resulted from a close collaboration with one of Germany's largest manufacturers in automotive industry. The collaboration of Concurrent Engineering departments was coordinated in terms of a comprehensive product model, human resources, information exchange, and processes.

Keywords: Concurrent Engineering, efficient collaboration, CAD-CAE-integration, process integration, DSM, DMM

1 INTRODUCTION
Concurrent Engineering, especially in the automotive industry, has changed the sequential way of cooperation in companies and caused enduring effects in numerous ways, aiming at the reduction of time to market and rework costs as well as quality improvement and team work, as stated by [4]. Integrated Product Development, a similar, more method-oriented approach, inherits comparable goals in terms of quality, time and costs of both products and processes [13].

The existing tools of Concurrent Engineering can be grouped as computer-based and non-computer-based tools. Whilst [4] describe computer-based tools as CAD-systems, analysis, simulation and modelling, and geometric modelling, the non-computer-based tools are exemplified by tools and methods of human resources and management. Statistical and quality methods, playing a major role in Concurrent Engineering, might be either computer-based or not. Additionally, numerous methods and tools exist supporting different activities of Concurrent Engineering processes in all phases of product development [13, 17]. As virtual product development becomes more and more important in Concurrent Engineering processes, especially in the automotive industry, integrated solutions for data and product lifecycle management developed as well, with the aim of providing a platform for the digital information flow within companies and their external partners [15].

Without a doubt, Concurrent Engineering is state of the art in automotive industry; its tools, methods and philosophy proved to be of positive effect, concerning the overall goals such as quality, time and costs of products and processes. Nevertheless, the parallelisation of tasks and the thereby evoked division of labour, resulting in the reorganisation of companies, causes the necessity to coordinate and integrate the existing teams. With Concurrent Engineering being successful in different areas of automotive industry, such as chassis, engine, transmission or body design, the computer-based and non-computer-based tools have proven to be an essential part of successful companies; so are the aspects of cooperation and teamworking [4]. Yet, the management and coordination of cooperating units and interdepartmental teams, not being continuously supported by the existing methods and tools, still is a major challenge in Concurrent Engineering [5]. Reasons for this situation are manifold and therefore not yet dealt with as a whole by the tools and methods of Concurrent Engineering. The arising problems due to the division of labour can exemplarily be shown by the different problem domains in which they occur [2]. One problem domain is the product domain itself, as different departments obtain different perspectives onto the product, resulting in different product representations and comprehension; the people domain plays a major role, as human factors such as different objectives within the project exist; the data and tools domain is represented by product-related information which is generated by engineers in Concurrent Engineering environments, using different tools and interfaces and possessing heterogeneous information demands depending on their perspective onto the product and obtained objectives within projects; finally, the processes on micro- as well as on macro-level differ in terms of milestones and releases, with unclear roles and dependencies between departments, representing the process domain.

2 RELATED WORK

Integrated product development aims at the integration of all specialists involved in the product life cycle. Therefore, a common goal orientation in terms of quality, time and costs of products and processes is hereby inevitable [13]. The similarity to Concurrent Engineering [4] is obvious, aiming also at the parallelisation of tasks, especially focussing onto the development of products, production and sales. The minimisation of the loss of efficiency due to the parallelisation of tasks serves as overall aim for the integrated product development approach as well as differentiation between conventional and integrated product development. Furthermore, integrated product development sees itself as the basis for the common goal-orientation and collaboration of individuals [13]. As the design department is in focus of the considerations, the related departments in close collaboration mentioned by [13] are for example simulation, suppliers, purchasing, testing, management, etc. The empirical data of this paper focuses on the collaboration of embodiment design and simulation departments, being part of the integrated product development approach and serving as an example for the proposed strategy in this paper. The integration of both worlds, embodiment design and simulation in a virtual product development environment, turns out to be difficult, not only by means of data exchange but in terms of strategic and operational demands [1].

Virtual Product Development has gained importance in industry over the years, enabling the significant reduction of the length of development time and reduction of costs for physical prototypes. The embodiment design (CAD) and simulation (CAE) departments turn out to be the key players of virtual product development, accompanied by the virtual testing (CAT) and production (CAP) departments. The integration of embodiment design and simulation departments is mostly addressed as an issue of the interoperability of IT-systems (see [8, 10, 16] for example). Growing demands on the information infrastructure and methods to support the transfer of knowledge, information and data among the designers, engineers and management are measurable [12]. Existing approaches in that field propagate the use of online technologies with support of semantic webs or ontologies [9, 16]. Nevertheless several authors point out, that the STEP and IGES formats are still state of the art and not yet replaced by satisfying new solutions [12, 16]. Interfaces and data formats as well as standardisation and harmonisation efforts do not address the core of the interoperability problem [5, 7]. Results are ad hoc work-around procedures being costly and inefficient [12]. The mentioned issues in CAx-Integration according to [12] are:

- Differing format
- Differing representation
- Differing behaviour
- Incompatible content

[9] differentiate the issues between horizontal collaboration (sequential collaboration, downstream) and hierarchical collaboration (bi-directional communication and interaction). They compare solutions

of different approaches, systems and interfaces; unsolved challenges remain the integration of horizontal and vertical collaboration, as well as new web-based feature-based formats, allowing for different views onto the data and the use of online streaming technologies. Finally, they propose the access of all different applications on CAD data in its native file format, until then, STEP and IGES solutions remain the “minimum” of interoperability covered by standard file formats at the moment, as also stated by [12, 16].

Closely related to the mentioned efforts of standardisation and formalisation is the interoperability between collaborative CAD and Product Data Management (PDM) systems. Product Lifecycle Management (PLM) as a follow-up technology of Engineering Design Management (EDM) and PDM approaches include the whole product development process with all inherent aspects. Thereby, the PLM infrastructure inherits data models and their reproduction in PDM systems [7].

Current studies [5, 7] have shown, that the continuous process chain is still an illusion, due to gaps in the communication- and information-flow. Efforts to establish continuous engineering processes by increasing the degree of standardisation are not successful due to too much formalisation of the working process, reducing the amount of creative engineering activities by 10 % [7]. Most beneficial of PLM is not the implementation of new technologies or the enlargement of existing technologies, but the optimisation of the engineering process as such [7].

As surveys [5] have shown, it is a misbelieve that a solution in terms of bits and bytes solves the issue of collaboration and interaction, when only the exchange of data between systems is solved, but not the exchange of information between humans. Additionally, the reduction of the amount of creative work due to the high level of standardisation and the always existing work-around procedures cause a significant reduction of the pursued effects. Of course, the necessity of technical solutions is undoubted and a necessary prerequisite, but can not solve the problem of efficient collaboration alone.

Therefore, the proposed strategy in this paper aims at a systematic adaptation of the integrated and Concurrent Engineering approaches to support the efficient collaboration of departments and teams by the example of embodiment design and simulation departments. The focussed domains for the approach are in particular: product, people, data and tools, and the process. They were derived from corresponding literature [7, 10, 13, 17], whereas the domains mentioned in literature are combined to the four steps of the approach. Concrete challenges in all domains and between domains were derived and summed up by [3]. Furthermore, they present an approach to provide the groundwork for efficient communication between departments by the interrelation of the different perspectives of embodiment design and simulation, namely the component view and the functional view.

3 OBJECTIVES

As the related work has shown, the integration of embodiment design and simulation departments for coordination and collaboration is still lacking a systematic, holistic approach. Therefore, a complete strategy was developed, based on the related work, a survey [5] and the close collaboration with a large German manufacturer in automotive industry. As a superior aim for the work presented in this paper, a continuous proceeding has to be developed to integrate all problem domains concerning inter-departmental collaboration and point out the dependencies between them [2]. The outcome has to reflect not only the mentioned domains and interdependencies, but also the relevant information in which order the numerous existing problems need to be addressed. Thus, all necessary aspects of the problem are treated in a way suiting the requirements of industry.

The derived sub-ordinate targets of the approach as defined in collaboration with the partner in industry are:

- Customer orientation, thus focussing onto the product and its functions
- Avoidance of organisational changes within the company
- Support of the day-today business of the involved employees
- Easy utilisation and implementation
- Transparency of information-flows, involved persons, processes and procucts
- Adaptation of existing methods of Concurrent Engineering and management

Specific targets within the relevant domains are:

- **Product**: systematic modelling of dependencies between product functions and customer demands on the one hand and the topological product hierarchy on the other

- **People**: efficient use of existing resources; identification and definition of roles and responsibilities
- **Data and Tools**: survey of involved data-formats, interfaces and IT-systems
- **Process**: enabling the coordination and control of processes; structuring of the interactions between embodiment design and simulation in concept- and serial development; definition of a coherent collaboration process with respect to all involved domains

4 APPROACH

In consideration of the presented circumstances, a systematic approach was conducted, based on existing research in Concurrent Engineering (see [1, 6, 10, 11, 13], for example) and addressing the problem in four steps, reflecting the identified problem domains:

1. **Function-Oriented Product Structure**: To break up existing barriers of communication between departments, the different views onto the product are combined in a function-oriented product structure. After the algorithmic optimisation of the structure, it reflects both views and allows for the identification of related parts and functions.
2. **Product-Focused Team-Building**: Based on the product structure and the logical interrelation between parts and functions, positions and engineers are assigned to the parts and functions they are responsible for, allowing in advance the establishing of teams and communication channels and packages.
3. **Allocation and Flow of Information**: As a third step, the identified communication needs are mapped onto the existing IT-infrastructure of the company. As a result, the existing systems are used most purposefully and advantages and shortcomings of the existing IT-infrastructure show. Thus, the improvement of current IT-systems can be conducted goal-oriented in the future.
4. **Process-Integration**: The last step of the approach encloses the definition of milestones and their integration into the development process. The identified work- and information-packages are thus not only assigned to the product and engineers, but also to process steps and projects.

4.1 Function-Oriented Product Structure

A major existing problem when speaking of the collaboration of different departments, in this case embodiment design and simulation departments, are the different perspectives onto the product which the different departments inherit due to their roles in the company. The results are barriers of communication due to different goals and a lack of understanding concerning the counterpart's position. To break these barriers of communication, a product structure was defined, combining the different views and enabling transparency for all parties concerned. The method used was derived from existing approaches [see 14, 18 for example], using matrix representations of the product. The established approaches of the square Design structure Matrices (DSM), allowing for the picturing of interdependencies in one single domain, and the non-square Domain Mapping Matrices (DMM), allowing for the modelling of interdependencies between domains, provide the methodical basis for the defined product structure (see Figure 1).

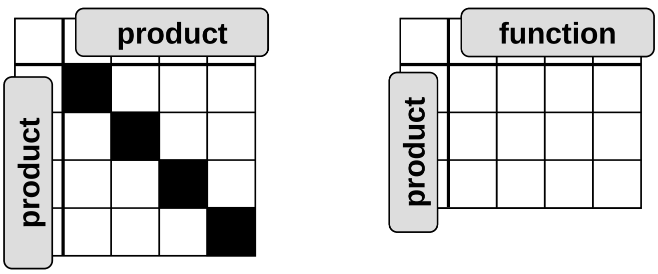

Figure 1: DSM (square) and DMM (non-square) matrices [6, 18]

For the goal of logically combining different views, the DMM-technique was used to grasp and picture the product structure. According to the involved departments, the topological product structure in terms of assemblies and components was used as one domain, reflecting the view of the embodiment design engineers. The component structure was then mapped to the product's functions being evaluated by the simulation engineers, as a second domain. A function thus represents the simulated (mis-)use-cases of the product. The matrix was filled out according to the involvement of certain assemblies and components in the simulations conducted by the simulation engineers. Figure 2 shows a section of the thus gathered representation of the product in matrix form, containing more than 400 components (rows) and more than 130 functions (columns).

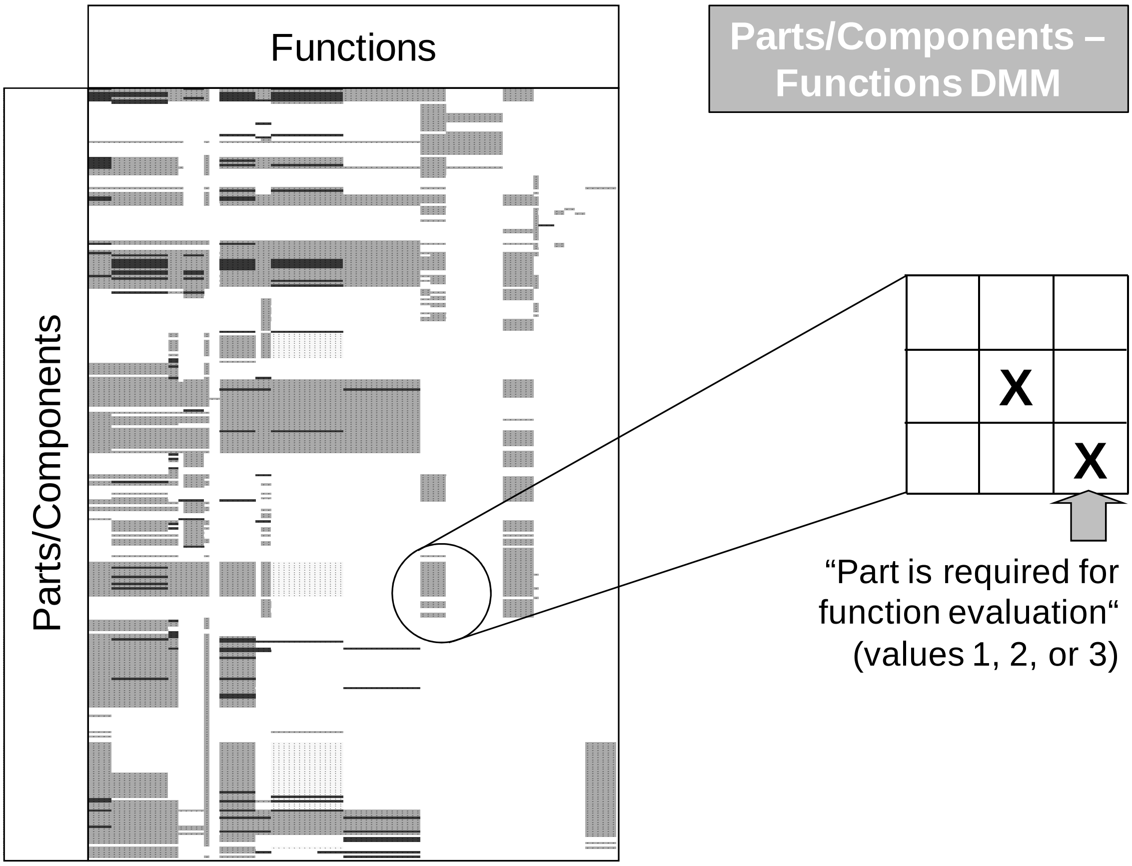

Figure 2: Representation of interdependencies between components and functions

To analyze and optimize the structure and use it for the following steps of the approach, an algorithmic optimisation was conducted, based on the similarity of rows or columns. The resulting effects are the identification of synergies by grouping either similar involved components or on the other hand functions demanding for similar components in their simulation models.

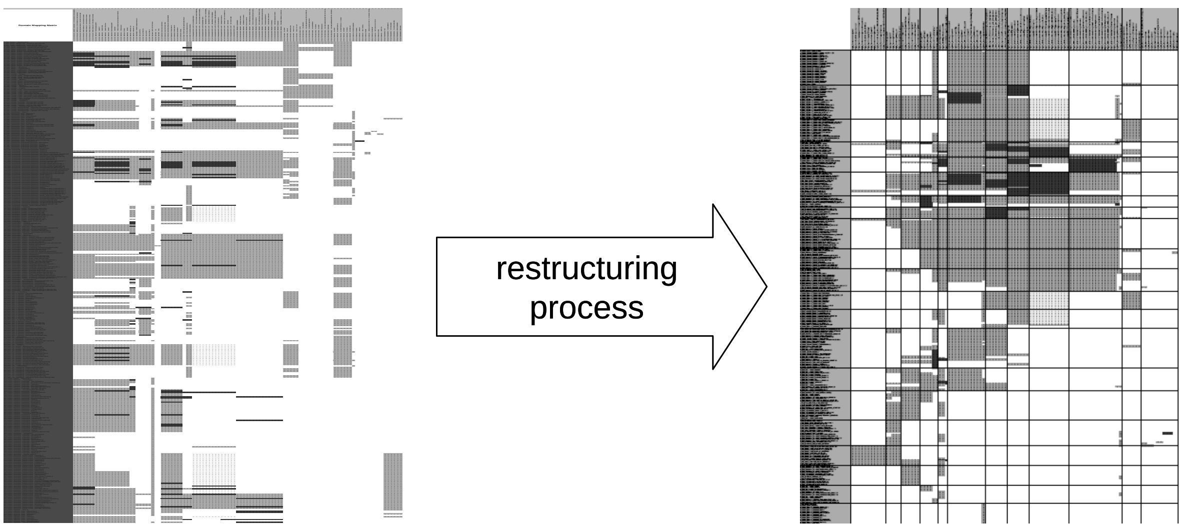

Figure 3: Optimized representation of product structure

Additionally, the interdependencies between components and functions were weighted in three steps, allowing for a more precise restructuring of the product. The weighting is represented in the matrix by color of the interdependencies. The resulting optimized structure is shown in Figure 3. The matrix shows 12 groups of functions, 22 groups of components and 264 clusters – of which 153 contain information – as intersection of both. The clusters represent standard exchange situations between embodiment design and simulation departments, as they reflect the information necessary to create and run simulations (function evaluation) in columns and the information relevant to design engineers (function integration) in rows. As an effect of the proposed structuring of the product, transparency is achieved for all involved persons, as well as providing the groundwork for controlling and coordination from a management perspective. The following steps, such as team-building or the allocation and flow of information are based on this structure, pointing out the importance of the use of reliable data for data collection and structuring of the product.

4.2 Product-Focused Team-Building

Based on the product structuring, an extended DMM analysis was conducted, allowing for the attribution of staff by attaching further matrices. The logical interrelations of parts and functions are thus translated into team-structures, as positions and engineers are assigned to the parts and functions they are responsible for. Again, interrelations between simulation engineers (more than 50 positions in number) and functions and between embodiment deign engineers (more than 150 positions in number) and components are weighed in three steps, allowing for a more precise team-building. Figure 4 shows a section of the resulting structure. The interrelation of components and functions in the lower right as proposed in step one is complemented by the interrelations between simulation departments and functions above and the interrelations between embodiment design engineers and components on the left. Given this structure, the interrelations of staff members are clear due to their responsibility. The structure supports the coordination and orientation of the involved partners by derivation of team structures: related people are grouped across components and functions and in accordance to the weighing of their involvement grouped into 12 teams for function evaluation (simulation) and 22 teams for function integration (embodiment design). Furthermore, the 32 densest clusters of the matrix are transferred into one core team for coordination of activities, as arising conflicts of objectives have to be solved and synergies used effectively. The resulting teams are made up of 5 to 10 persons, their number reduced according to the weighting of interrelations and thus keeping the size and activities manageable (see [19] for details concerning the team-building process).

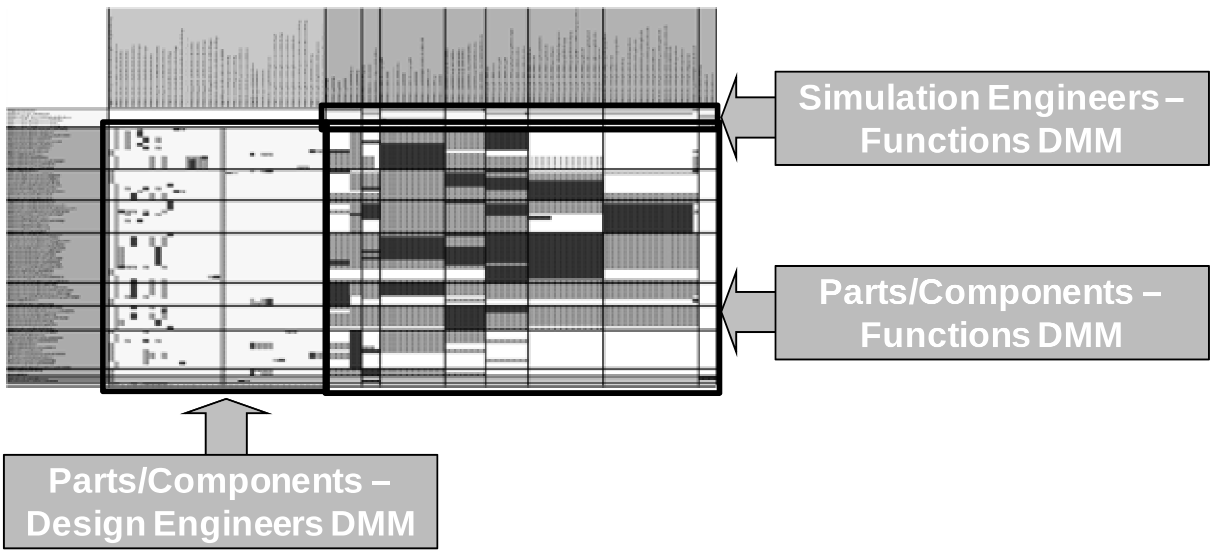

Figure 4: Allocation of people to the product structure (section)

4.3 Allocation and Flow of Information

The third step consists of the support of the teams by attaching the relevant data and information flow to the identified clusters and thus characterizing the collaboration between departments in detail by work-packages. To gain this information, a detailed process analysis was conducted, gathering information about process steps and the therefore relevant data and information. The result of the analysis is a generic process model of the modelling and simulation process. By analyzing the information and data packages (white rectangular boxes in Figure 5) within this process, a classification and characterisation of information necessary for modelling and simulation was possible, allowing for the definition of templates for the information exchange.

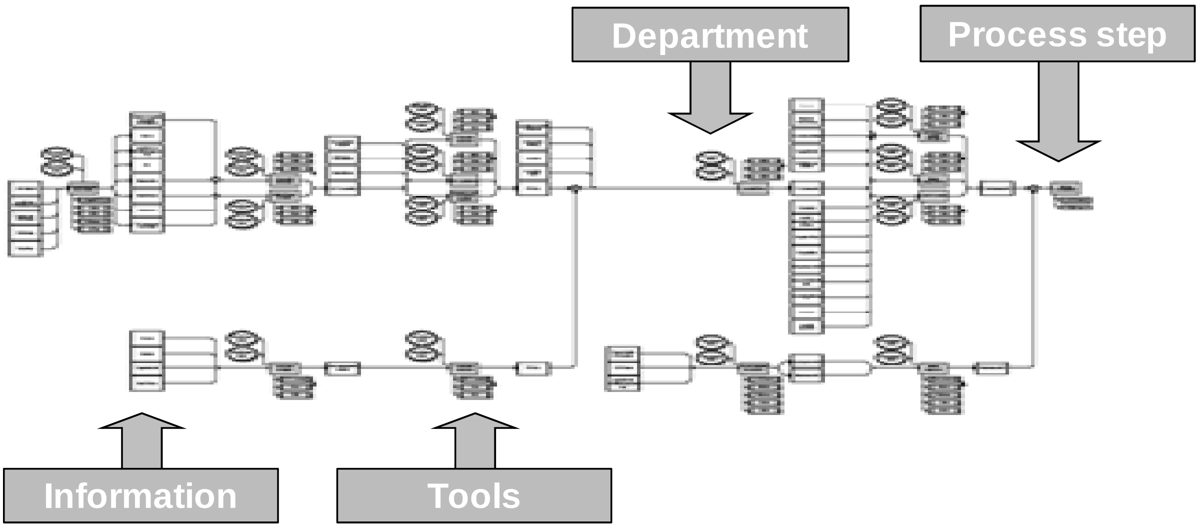

Figure 5: Section of the process analysis

The templates represent the due work-packages and contain information about quality and quantity of information as well as sources and recipients according to the matrix established in the second step of the approach. Due to the detailed precedent process analysis, the characteristic demand of information of the simulation departments can be grasped within the templates. The classification of information furthermore contains component spanning structural information (techniques for joining parts, contact definitions, interfaces between parts, etc.) as well as part properties (level of detail of the geometry models, material, sheet thickness, mass, etc.) and meta-data (version, part number, etc.). The templates are then allocated to the identified clusters in the product structure, supporting the teams as proposed in step 2 in their collection of information (see Figure 6). In doing so, the information is not only allocated to persons, but conform and consistent in respect to the recipient of the information. Based on the packaging of information and the definition of templates, requirements can be derived on data storage, access and filtering. At present, these requirements support the efficient use of existing data storages, file formats and interfaces. On the long run, the potential for restructuring the digital data storage in terms of a customized PDM or PLM system by mapping the information demand is accessible. The process and information analysis for the embodiment design departments are not mentioned here, but are existent and accessible, thus completing the picture in the other direction.

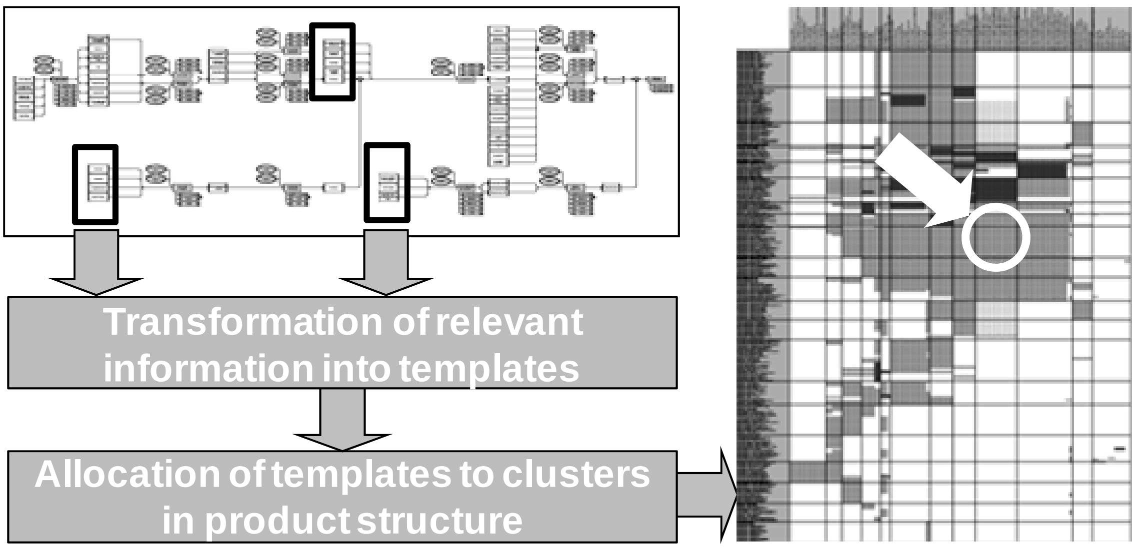

Figure 6: Proceeding of data collection and assignment

Steps 1 to 3 of the approach so far allow for the transparent structuring of product and people, resulting in teams with precisely defined information and data flows between them. The final step of the approach is now the temporal coordination of activities in the overall design process.

4.4 Process-Integration

The process orientation of the defined work-packages is conducted by the extension of the existing product development process. Assuming that the whole product is evaluated at the stage of each milestone, the necessary information is to be delivered in time before the final milestone. Therefore, the identified information flows in direction “design to simulation” (M’’) and “simulation to design” (M’) in the product structure are due a defined number of weeks before the final milestone (M), as pictured in Figure 7. Basis for the process coordination is the analysis of the design and simulation processes (see Figure 5, for example). As a result, different intervals between the pre-releases and milestones exist for different simulations.

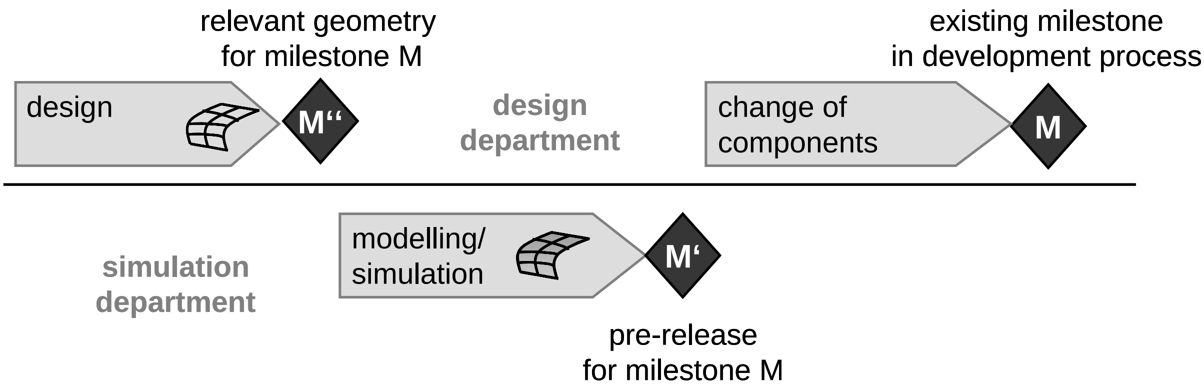

Figure 7: Extension of existing milestones in the development process by simulation

The statistical distribution of carried out simulations of concluded projects is interpreted to identify when different simulations are usually performed. The thus defined process consolidates the role of the simulation departments in the process and enables the coordination and controlling of the collaboration between embodiment design and simulation.

4.5 Results

The novelty of the approach can be shown by two aspects. First, the applied methods represent an improvement and combination of existing methods, thus contributing to the research in the field of DSM and DMM methods. Furthermore, the generality of DSM and DMM methods allows for the application of the approach onto different problems with similar domains. As second aspect, no approach is currently known that allows for the systematic integration of simulation and design departments in all four domains of the problem, namely product, people, data and tools, and process.

The results of the presented approach allow for the derivation of virtual teams, and requirements of IT- and communication-infrastructure as well as for the product- and function-oriented restructuring of Concurrent Engineering processes. Understanding between departments and the goal-orientation of conjoint tasks are supported by the given transparency of the structure and controllability of the process. The definition of work- and information-packages enables the systematic derivation for the IT-support of Concurrent Engineering processes and related Product-Lifecycle-Management-Systems.

The improvement of the development process due to the transparency and controllability are well accepted among the engineers within the cooperating company. The time-consuming process of data collection has been reduced, and the processing of tasks takes place with a common goal-orientation and thus communication between departments turns out to be more efficient.

5 CONCLUSIONS AND FURTHER WORK

The discussed results answer a number of questions concerning the organisation and coordination of Concurrent Engineering processes in the context of virtual product development as well as communication within them. The validation of the comprehensive approach within a company is currently in progress, and the acceptance and improvement are noticeable. Yet, a number of issues needs to be solved in the near future to improve the existing approach, some of them are mentioned in the following.

Routines and procedures need to be designed in order to ensure that people work as the defined teams. Hereby, it is inevitable to retain a certain degree of freedom to ensure the formalisation is not reducing the amount of creative work of the engineers.

The analysis of interrelations among components and functions in DSMs has not yet been conducted, allowing for further interpretations of the interrelations between components and functions and the definition of teams amongst the design and the simulation engineers. Additionally, a prioritisation of simulations can be conducted, reducing the number of executed simulations and thus reducing time and cost-consuming processes in the simulation departments.

The scope of the approach has to be increased, involving the CAT and CAP departments as well to improve the development process as a whole. The incorporation of suppliers offers further potential, as does the consideration of the multi-project environment in automotive industry.

As next steps, the definition and classification of product maturity will be conducted, enabling the differentiation between concept and serial phase for example. The implication of changes within design or simulation models and the effect onto the results has to be detailed in order to improve the change management processes. The information flow between departments is not yet controllable and fully supported, the implementation of a more powerful and target-oriented IT-infrastructure seems to be inevitable.

Nevertheless, the inherent principles and methods of the proposed approach have proven to be effective and improve the Concurrent Engineering process between embodiment design and simulation by systematically extending and combining the existing approaches and consolidating the domains product, people, data and tools, and process.

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