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INFORMATION MANAGEMENT FOR THE DIGITAL FACTORY – BRIDGING THE GAP BETWEEN ENGINEERING DESIGN AND DIGITAL PLANNING

H. Burr, M. Vielhaber and C. Weber

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1. Introduction

The situation today in product development processes is changing. In the automotive industry, in particular, which is still one of the most dynamic industrial sectors, these changes are quite evident. Development times are continually subject to heightened time constraints, while high quality standards nevertheless have to be maintained. Further, the products themselves have changed, becoming more and more complex and being far away from the purely mechanical assemblies they used to be some years before. This has led to the introduction of a number of approaches in design methodology for such products in order to react to the interdisciplinary character of this trend. Moreover, this is accompanied by the introduction of new simulation tools to proof the quality of the developed products. The situation on the product side has had a great influence on the related manufacturing and assembly tools, with the invention of the so-called digital factory being one of the most important consequences. In this context, new software tools have emerged: not only do these enable simulation of the manufacturing and assembly processes of the products, they also support the planning engineer in many activities such as line balancing, manufacturing layout generation, or cost estimation. As a third contributing area, the resources involved in manufacturing and assembly have also been subjected to change with regard to paradigm shifts in automotive engineering.

Such complex development processes must be supported by a proper and efficient handling of the generated data, which comes from a variety of different engineering disciplines and the relevant departments. Once the information is created, it must be accessible to downstream processes without essential information losses, which unfortunately still occur today. The information society includes the industry, making the handling and transfer of information one of the key factors to assure competitiveness in today's highly dynamic markets.

In this article, the so-called shell model is introduced. The shell model is a data model for a seamless support of product development processes, integrating information regarding products, processes, and resources. The concept described is derived from requirements from the body-in-white process chain in automotive development, dealing with data management in the transition between design engineering and production planning. Yet, this concept is applicable for a variety of other disciplines that have to cope with similar boundary conditions. In chapter 4 some alternatives for the application of the shell model in heterogeneous, domain-spanning data management environments are presented.

2. Boundary conditions

As mentioned in the introduction, some important boundary conditions have to be considered when dealing with product creation processes. The following chapter sets out some of the influencing factors for the concepts and data models investigated by the authors. The boundary conditions are subdivided into those relevant for the product and its characteristics, those referring to processes, and those dealing with the resources.

2.1 Products

Products and the requirements they should fulfil are still the main drivers of the product creation process. Yet their characteristics have also changed in some essential ways. In the past, a passenger car consisted mainly of mechanical components with some wiring and only few electrical components. But today, more and more electrical, electronic, and software components have to be integrated. The modern domain of mechatronics aims at the inclusion of modern information technology into products in order to create adaptive technical systems that are able to interact with their environment. According to an annual study of the German Automotive Council VDA, the actual value percentage of electronic components in cars runs from roughly 25 to 30 per cent and is said to increase to as high as 40 per cent in 2010 [VDA 2005]. This has led to the integration of domains such as software engineering into the product creation process, including their "home-grown" IT tools and methodologies. The incorporation of these new domains into legacy processes is still one of the most important research fields, since almost every large car manufacturer has, at some time, had to deal with cost-intensive call-backs caused by the failure of electronic or software components.

Another challenge has arisen from the ever-increasing number of variants in car production. Due to the keen competitive situation in the market, most manufacturers try to find inroads into new markets and niches, which has resulted in an extensive product portfolio. But, in the same breath, this is accompanied by a decline in lot sizes for the respective models. In [Burr 2003], the authors showed the evolution of variants in one special model line of a leading German car manufacturer, which started with one body variant and four different engines in 1983 and by 2000 was producing five different body variants to be combined with seven engines, three design lines, and 80 per cent optional equipment. This trend leads to the phenomenon of only 1.4 identical cars per year! Car-makers speak of so-called mass customization: their customers influence the equipment of the car they order to a great extent, which results in the diversification of the related products. Thus, the the product configuration is changing towards a more modular character with discussions held about variant-neutral and variant-specific areas even at the component level.

2.2 Processes

As stated, not only have the products changed but also the processes in which these products are developed, manufactured, and finally assembled. And the time pressure in product creation processes has a number of crucial consequences. The different stages in product creation, which used to be sequential, are more and more being parallelised to allow concurrent engineering. These overlapping process phases result in downstream departments not being able to wait until the predecessors have finished their work. Instead, they are forced to start their activities with product information that is still "work in progress". The ambition of steadily optimising the product leads to a high number of design changes, which have to be maintained along the process chain. This shows the antagonistic character of today's development processes. On the one hand, most of the decisions regarding certain variants or details of the product are pushed towards late phases as far as possible; yet, on the other hand, the existing information about the product must be accessible as early as possible. This process can hardly be maintained without using a data management system in the background to cope with the change management.

The variants on the product side mentioned above of course influence process design. For almost each product variant, a corresponding production planning phase must be considered in order to avoid surprises when it comes to real production. So, special boundary conditions have to be taken into account. For example, different variants may be built at different plants all over the world, with each of these plants having their own characteristics that reflect both market demands and socio-cultural aspects. Another challenge is the tendency to manufacture and assemble more than one variant in a production line. Only years ago, it was common to build a production line for each car model as the model cycles were much longer. However, the lifecycle for a car model has changed dramatically: from about 9 years in 1990 to 5-6 years in 2004, including a facelift at the halfway mark [Magna-Steyr

2003]. Sometimes new variants are introduced in the production line with a temporal delay, which results in two ramp-up phases within the same production line.

As a last contributing factor, the reduction in lead times needs to be mentioned. According to the Harvard Business Review [Krause 2004], the time spent from the initial concept phase until start of production (SOP) was about 50 months in the 1980s, while today, in some cases, the same process is completed in 30 months! For the certain process phases, this means less time for the development of more variants to be manufactured in more complex production lines—while still maintaining the high quality standards demanded.

2.3 Resources

The last step in product development is the development of the relevant resources needed to implement the production line and to bring the product from the digital world into reality. Within the body-in-white process chain in automotive engineering, in particular, the layout and development of the tools is linked very closely to the product development itself, with the product's exact geometry being the core information within this process phase. Since a certain production process can be seen as the organisational description of the interaction between physical products and the relevant resources, the challenges described in the two sections before have a great impact on the field of resource layout and setup. Flexible production lines have been mentioned, resulting in growing flexibility in the resources of car assembly lines. Tools must be able to manufacture and assemble different variants. The problem of the ongoing parallelisation of process phases includes resource development, since high product turnover has to be managed here, as well. For an optimised change management, statements about influences on production costs when changing the product geometry—and thus changing the resources—must be generated quite quickly.

Another upcoming and quite new trend is the so-called design for re-tooling, which means the re-use of existing resources in production lines for newly developed derivates of existing car models. This trend necessitates that all the relevant data be captured during resource development and simulation to be able for re-use during product development of the new model.

3. The shell model – a concept for data integration

All of the above factors underline the need for a well-designed information management along the process chains in automotive engineering. Especially in the context of the digital factory, the amount of data is enormous and emphasises the call for an intelligent and efficient data management [Bracht 2005]. The integrated and seamless management and propagation of all relevant information is one of the most important factors if car-makers are to cope with the challenges of modern development processes. In this section, a special data model that is able to bridge the gaps between the different process phases is introduced.

Since the overall target of each product development process is to generate a high-quality product, the related product-describing data can be seen as the core and driver of all process chains. Hence, the product data itself can be subdivided into two categories. The first is the manufacturing data of the product mainly at the part level, which means the description of certain production stages necessary to reach the final shape of the single component. For example, a side panel starts as a blank sheet and runs through several stamping steps until it reaches its final geometry. The second category is the part-spanning assembly information, since a complex product such as an automobile consists of thousands of single components that have to be assembled in the final-production line.

When developing complex products such as passenger cars, the maturity of the data generated grows over the time. The geometry of the product changes from rough styling shapes at the beginning towards fully detailed and validated geometries at the end. Different prototype series are built, with testing results fed back to the next iteration cycle in order to continuously optimise the product.

When talking about data management, it is not sufficient to focus only on the management and distribution of product data. All the related data coming from other design engineering disciplines as well as from resource layout and process planning also have to be managed. In line with the boundary conditions set out in section 2, the following main requirements for a data management concept at the transition between product development and production planning can be manifested:

- Integration: Data coming from several disciplines must be linked to allow an integrated view of the products and the related resources interacting in a certain process
- Efficiency: The data model must be efficient enough to cope with the highly dynamic character of the development process, i.e., the high frequency of changes and different maturity levels.
- Organisation: The concept itself must be able to reflect special needs coming from the organizational setup of the development process, e.g., different responsibilities at different times.

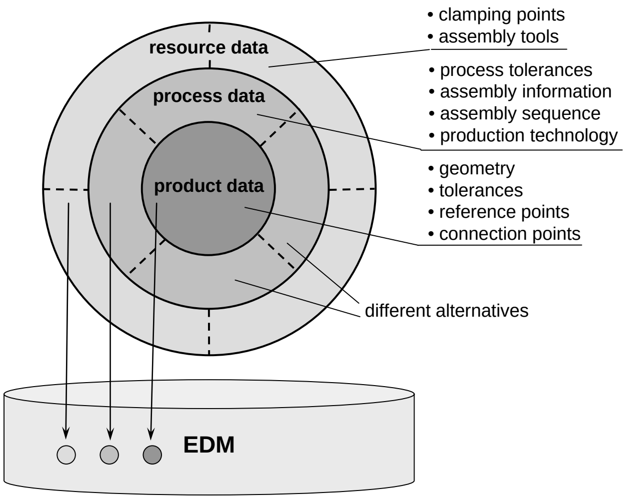

Figure 1. A model for integrated data management, bundling product, process, and resource information

The so-called shell model, which is depicted in figure 1, aims at a decoupled storage of information in an EDM/PDM system. The core of the model is the geometric manifestation of the product together with its metadata. Additionally, part-spanning data are contained within the core, representing such things as connection points or reference points for the tolerance management. As these are not meaningful when used in a single part context, the geometric core consists of part bundles. This inner core lies primarily in the area of responsibility of the design engineer. The first circlet surrounding this core represents the process-describing information. Within the EDM system, this hull is represented by an own data object, derived on the basis of the geometric core but containing additional information. An example could be a connection point between two parts. In the core, only the spatial coordinates of the point are documented, probably with a required rigidity for the interconnection. In the process hull, this point is detailed in line with the manufacturing process, whether laser welding or resistance welding or, most likely, gluing. In the third hull, the related resource data are added, again as an own object in EDM/PDM. This resource description could be a certain clamping and fixture plan, or any kind of information necessary for the resource layout and development. The interaction of the different hulls is shown in figure 2.

As need be, these hulls could be subdivided into several sections with each of them representing an alternative solution. Using knowledge-based approaches or template technology within the supporting applications in this phases, the different alternatives can be evaluated more quickly and easily. For instance, an intelligent start-up model for a weld-point description could check the underlying product's geometry regarding the feasibility for resistance welding by examining thickness values or the flange width. Different manufacturing concepts established in different plants can also be visualised with this model, using the same process hull but placing different resource models upon it. Another benefit of this concept arises from the use of standard functionalities of EDM/PDM systems such as versioning, variant management, or configuration handling. Comparisons with other versions

can be performed across the several hulls of the information model, allowing the user to view existing process data with the most actual product versions after a geometry change.
Yet, this concept is much more flexible: it also works the other way round, supporting design for re-tooling. Starting with the outer or inner hull with an empty product model beyond it can be a very efficient way to provide the design engineer with restrictions when developing a new variant for an existing production line.
In order to allow a concurrent working style and decoupled management of information, responsibility for each of the shell model's hulls is assigned to the relevant organizational group. The designer provides the geometric basis on which production planners can store their information without the need to have write access to product models.

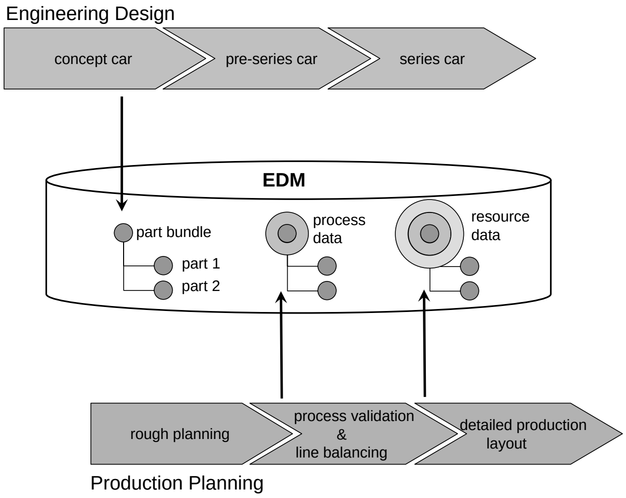

Figure 2. Interaction of the shell model's hulls

Further, this model also allows description of the manufacturing steps of the component itself, as mentioned at the beginning of this section. But this seems relevant only for very complex products. In the case of sheet-metal parts for the body-in-white, the design engineer is responsible not only for the final geometry but also for the different stamping steps in between, thus storing this model in the product description in several layers.

4. Implementation into a heterogeneous data management environment

Within process chains in product development, a variety of CA applications are used, each of them supporting a special engineering discipline. Some of these applications have a proprietary data management. They are so called team data management systems, which are specially designed for the kind of information handled in a certain software tool. Others still have file-based working styles which are still quite common in industry; yet they are being tightened more and more as the full exploitation of the existing functionalities in CA tools is only possible when using the corresponding TDM system (if it exists at all), mostly sold by the same system provider.
This heterogeneous architecture is the result of growing IT support within the last decades. It is not easy to implement new archiving concepts such as the described shell model due to the fact that the existing IT landscape and also some of its processes have to be taken into account. Figure 3 portrays the situation of cross-domain data management along the product lifecycle, leading to the authors' attempt to answer some important questions.
In [Burr 2005], the authors discussed different possibilities for data integration in a CAx context, coming to the conclusion that a hybrid system environment would be the preferred solution in favour of a monolithic approach. Trying to set up an integration on the basis of a single database would lead to a very inflexible and rigid system, resulting as well in very long testing cycles for each new

software release or for data model extensions. Of course, the coupling of different databases calls for interfaces between them, leading to both technical and organisational questions.

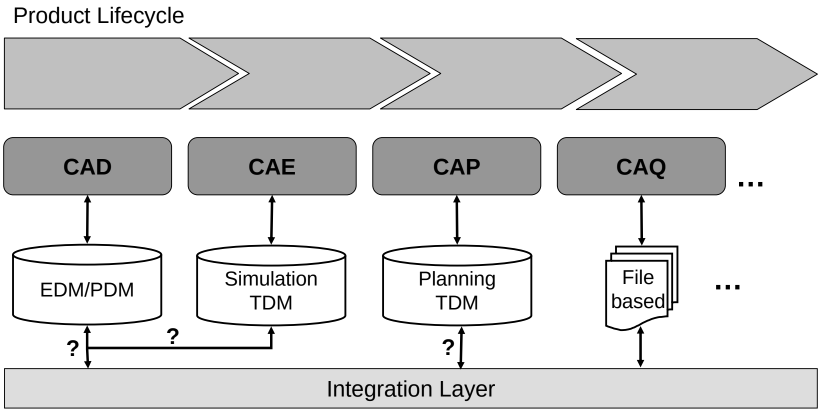

Figure 3. Cross-domain data management along the lifecycle

One of the most crucial technical questions is the realisation of interfaces. In [Doblies 2000], the authors distinguish between five different levels for interfaces in a heterogeneous architecture, ranging from a “biological interface”, e.g., one person that transfers the data manually between the systems (“copy-and-paste”), to a federated solution with harmonised systems using the same kernel with identical data models. The advantages and disadvantages of the different levels of interfaces depend on the amount of data that would have to be transferred as well as on the frequency of data exchanges between the systems. In any case, a mapping between different structures is required, since each application has its own way of structuring information. And even the translation of attributes and metadata is necessary. A further key technical question could be the relevant format for a certain process. Is it necessary for development to provide fully detailed models to downstream processes or are these also viable with tessellated data formats such as JT or CGR? Thus, an in-depth analysis of dataflows in such reference scenarios as body-shell development must be carried out in order to establish a sustainable system integration.

The organisational challenges deal with issues such as the master role in processes and the responsibility for the data managed in different systems at different times. The application example in section 5 shows that sometimes the responsible area changes over the time. The distribution of data is an important aspect, since it can be passed on to other process participants at predefined times or on demand, or when reaching a required degree of maturity. In some cases, the application of a workflow system could be helpful to support the data exchange, representing a kind of coordination layer. On the other hand, such an integration brings with it a higher level of transparency between the departments, which is not always welcome. In this context, overcoming user bias is a research topic of its own, requiring the inclusion of pilot users in very early phases or even the involvement of work psychologists. This challenge is probably one of the most important ones, since, in the end, the human factor decides whether a concept is realised successfully or not.

5. Application example

Within the authors' research work, body-shell development was chosen as a reference scenario. As mentioned in the introduction, many relevant and important characteristics are bundled within this process. Developing the body-in-white of a car means an interaction of design engineering, die development, various CAE departments, and, of course, production planning. And the body shell runs through different manifestations, beginning with early prototypes in order to show the suitability of new concepts, and continuing with the pre-series and series cars that are applied for the validation and optimisation of the production engineering. Thus it is in early phases of the process that the interaction of the different disciplines must be very close, as multiple iterations are necessary to achieve a steady improvement of the required properties, making the time factor crucial. Different product variants have to be covered, and the layout of different plants for these products can result in various manufacturing concepts and alternatives.

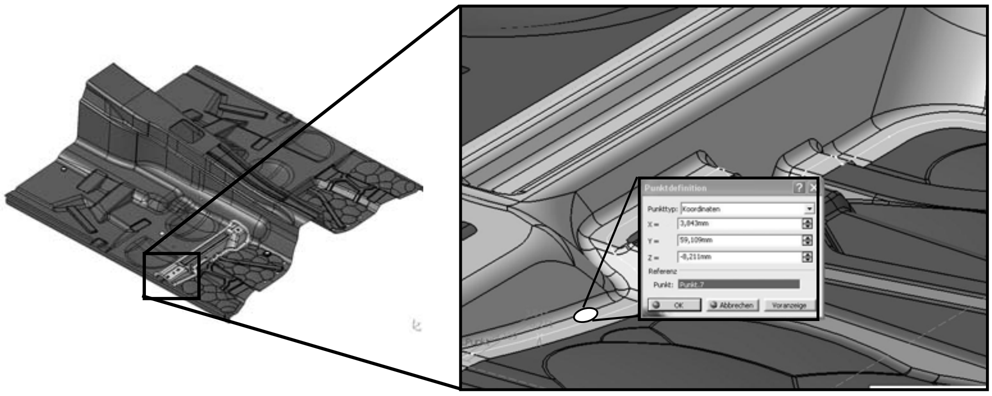

Figure 4. A connection point in design engineering

To the same degree that the product is being optimised, the amount of data managed between these different departments grows and grows. In figures 4 and 5, the application of the shell model is shown taking the example of an inter-part connection of two metal sheets belonging to the main floor of a compact class car.

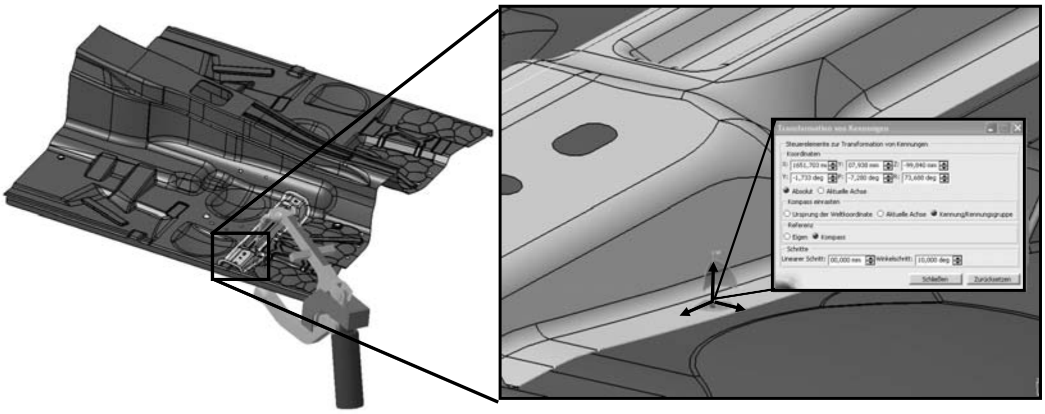

Figure 5. Additional information for the connection point

The design engineer starts with the exact position of the connecting point on the components, based on results coming from the crash analysis department, for example. In order to avoid the phenomenon of front loading, the design engineer need only determine the exact X, Y, and Z coordinates of the point and the required rigidity of the connection. When the product geometry for a certain prototype has reached a high level of maturity, the product-describing data are passed on to production planning. The planning engineer is now able to add information in the process hull regarding the assembly process for these parts. In the example shown here, the planner has decided to make the connection between the parts using resistance welding. Alternatives could be laser welding, clinching, or gluing. The required tool, a weld gun, needs other information in addition to the spatial coordinates: the so-called Euler angles that determine the gesture the tool must during welding. These angles are stored in the process hull, on the framework that the design engineer delivered. The information bundled in the core and the process hull could now be applied for reachability analysis and weld gun selection. In a third stage, the information for the layout of the device is defined in the resource hull. This includes,

for example, the selected weld gun or the clamping and fixture points for this components, which can vary with the selected process type. If the body shell is built in several plants, this resource hull can also have several versions, with each of them representing a manufacturing variant.
Thus, each discipline is able to add the necessary information in its own data containers. The management of variants—in this scenario between resistance and laser welding—is effected with standard link functionality in the EDM system.

6. Summary and outlook

This work illustrates that the development processes of today are faced with a variety of different requirements coming from many engineering disciplines. And data management of the relevant information is one of the most important factors when coping with this complex situation. For most of the participating engineering domains, an integrated view of the information must be established in order to create efficient and transparent process chains that allow a seamless cooperation in product and production development.
The shell model presented is one approach for the desired integration, located in the transition between engineering design and production planning. Both prototypical realisations and the improvement of productive processes in body-in-white development have shown the feasibility of the concept. Further research work will aim at the optimisation of the shell model, dealing with structuring concepts for bills-of-material as well as with the efficient coupling of heterogeneous data domains. A further focus is the transfer of the results to the final assembly processes in automotive production lines.

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Dipl.-Ing. Holger Burr
DaimlerChrysler AG
Wilhelm-Runge-Str. 11, 89081 Ulm, Germany
Tel.: +49 731 505 4847
Email: holger.burr@daimlerchrysler.com