

End-to-end Virtualization of the Development and Production of Vehicles

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ABSTRACT

The automotive industry is characterized by short product lifecycles, complex products and an increasing number of variants. Global competition demands reduction of development costs and prototype manufacturing. Hence, interest in simulation of the overall process chain has risen. Until now data exchange between simulation programs is mostly done by manual transfer. The specific simulation tools do not have any open data exchange formats. The objectives of the publicly supported project, called VIPROF, are to specify the necessary interfaces between simulation programs, to integrate simulation data into product data management systems and to develop reference processes. The influence of the stamping, welding and painting processes on the product properties should be considered during the whole period of product development. This can be achieved by a virtual validation of the feasibility of the manufacturing processes. The paper shows how to connect the simulations of forming, welding, painting and crash for an automotive reference part.

Keywords: mapping, process chain, simulation, stamping, welding, painting, crash

1. INTRODUCTION

The situation of producing industry in the global competition is characterised by increasing customer requirements and stagnating or falling prices. To hold market shares more product variants are developed and brought to market in a short time. The interval between model changes has been reduced steadily while the complexity of products has been increased. Hence, prototype design is more and more moved over into the phase of part design. As a result design of parts is partly done without considering boundary conditions caused by the deployed production process. Occurring errors in production cause high follow-up cost for changes. While great cost cuttings could be achieved by automation of production in the past the remaining cost cutting potential lies in shortened product cycles gained by flexible development tools and an optimal virtual process validation.

In most areas of product development CAE technologies are established for single applications. However, these are mostly isolated applications and not a continuous planning instrument. The industry is driven by a strong interest in simulating the entire production process due to the effort of reducing the required time and cost for prototype development and design.

2. PROCESS CHAIN

One target of the project VIPROF is to establish a virtual process chain from forming to crash simulation. Doing that connections between simulation tools should be provided as shown in Figure 1 and open interfaces for integration of further simulation tools should be created. The virtual process chain simulation will be examined on the example of the process chain forming, welding and painting which often appears in frame-and-body construction.

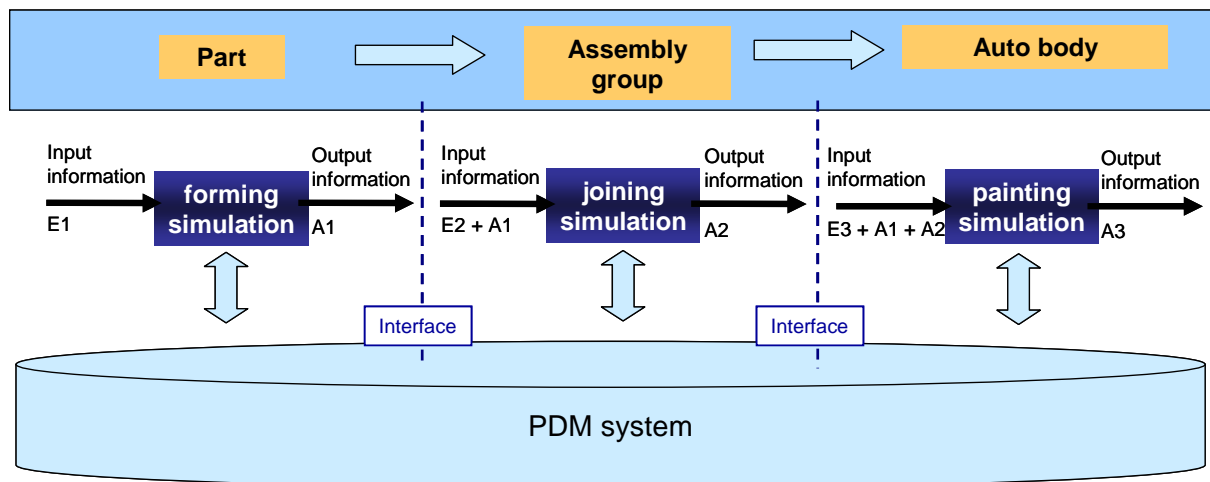


Figure 1: Overview VIPROF

Between these single simulation processes exemplary the scalar blank thickness as well as the stress tensor and plastic strain tensor should be transferred. Additional sensitivity analyses are carried out to identify the relevant parameters and to avoid passing of not sensitive parameters through the whole process chain.

2.1. FORMING

The Forming simulation is performed by an incremental solver (*PAM-STAMP 2G*) which is well established in the automotive industry. The incremental forming simulation is time consuming due to the necessity of designing the tool components of each forming step and the long time of calculation process (FEA). Therefore, it is hardly used before development has reached a high level of maturity. Hence, forming simulation results are not available in the early product development process when the design of product properties takes place through early crash calculations. For that reason the VIPROF project examines the accuracy of results of one-step solvers as an alternative simulation method to use in the early stage of development. For this purpose the sheet thicknesses of different automobile body side parts

are calculated with one-step finite element analysis (*FormingSuite*). These results are compared to the serial components and the results of incremental finite element analysis. The benchmark has shown that one-step simulation is able to achieve high outcome accuracy of the calculated blank thicknesses [4, 5]. Additionally, one step calculation quality of stress and plastic stain should be examined.

For this reason both simulation methods are used to perform forming simulations in VIPROF project. The results blank thickness, stress and plastic strain are evaluated and mapped into the following simulation steps.

2.2. WELDING

In the area of welding simulations welding distortions are calculated. Simulations are performed with a tool called *Weld Planner* that uses the *Systus Solver* for calculation. Figure 2 shows the examined structural component with all its parts. Additionally, it illustrates the simulated welding seams. The used kinds of welding processes are MAG welding, resistance spot welding (RSW) and laser beam welding. The numbers indicate the sequence of assembly done by laser beam welding.

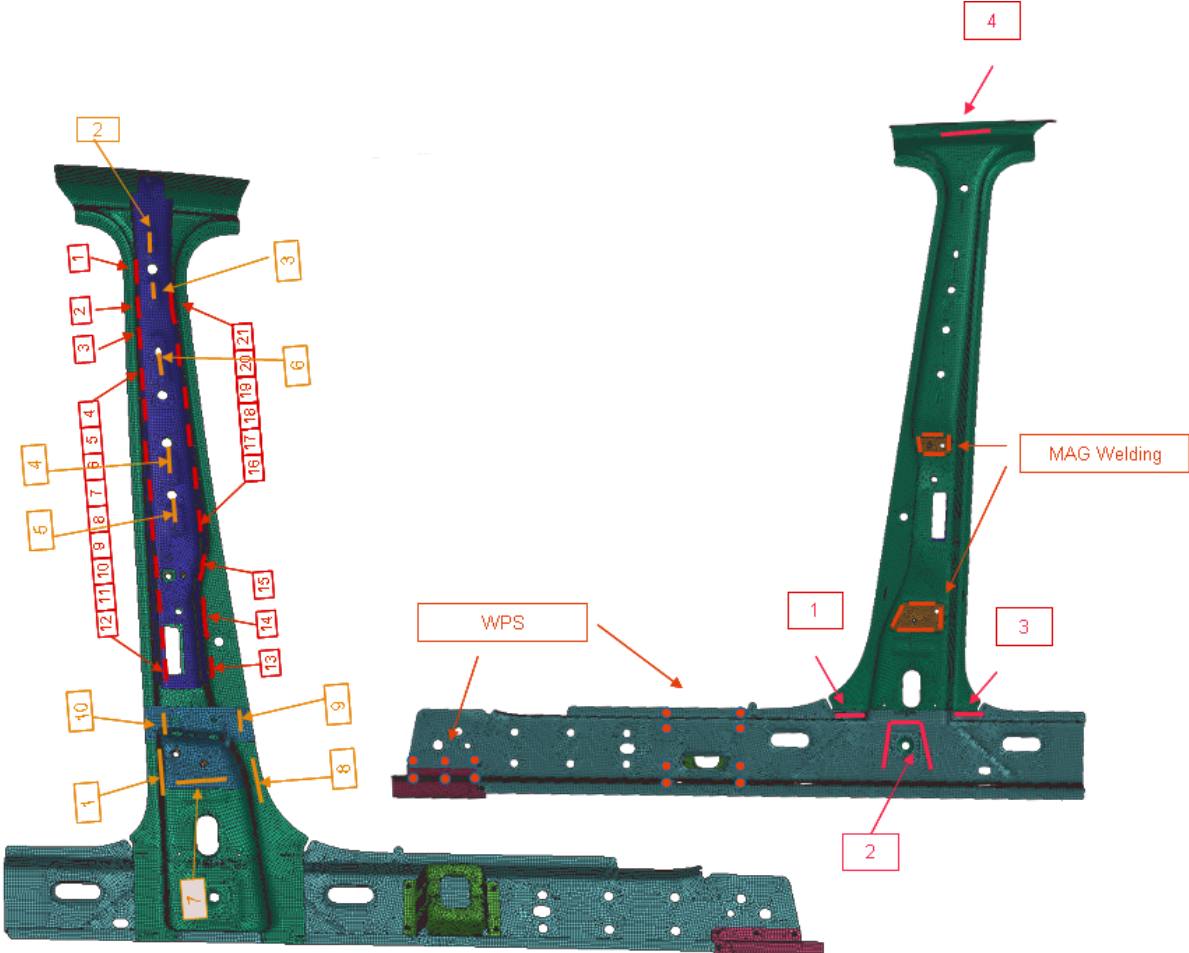


Figure 2: Assembly group for welding simulation with sequence of assembly

The welding simulation is performed with different input parameter sets. The first simulation (Figure 3a) uses only the ordinary input for welding simulations. The second (Figure 3b) includes the thickness distribution of forming simulation. The third simulation (Figure 3c) includes the plastic stain results of forming simulation. The fourth simulation (Figure 3d) is performed with both results from forming simulation.

These different input sets are examples of work of VIPROF project, where the influence of different input parameters should be explored through sensitivity analyses. Figure 3 shows the welding distortion of the joined assembly after the calculation with the mentioned input sets. The shown displacements refer to the deviation from CAD geometry.

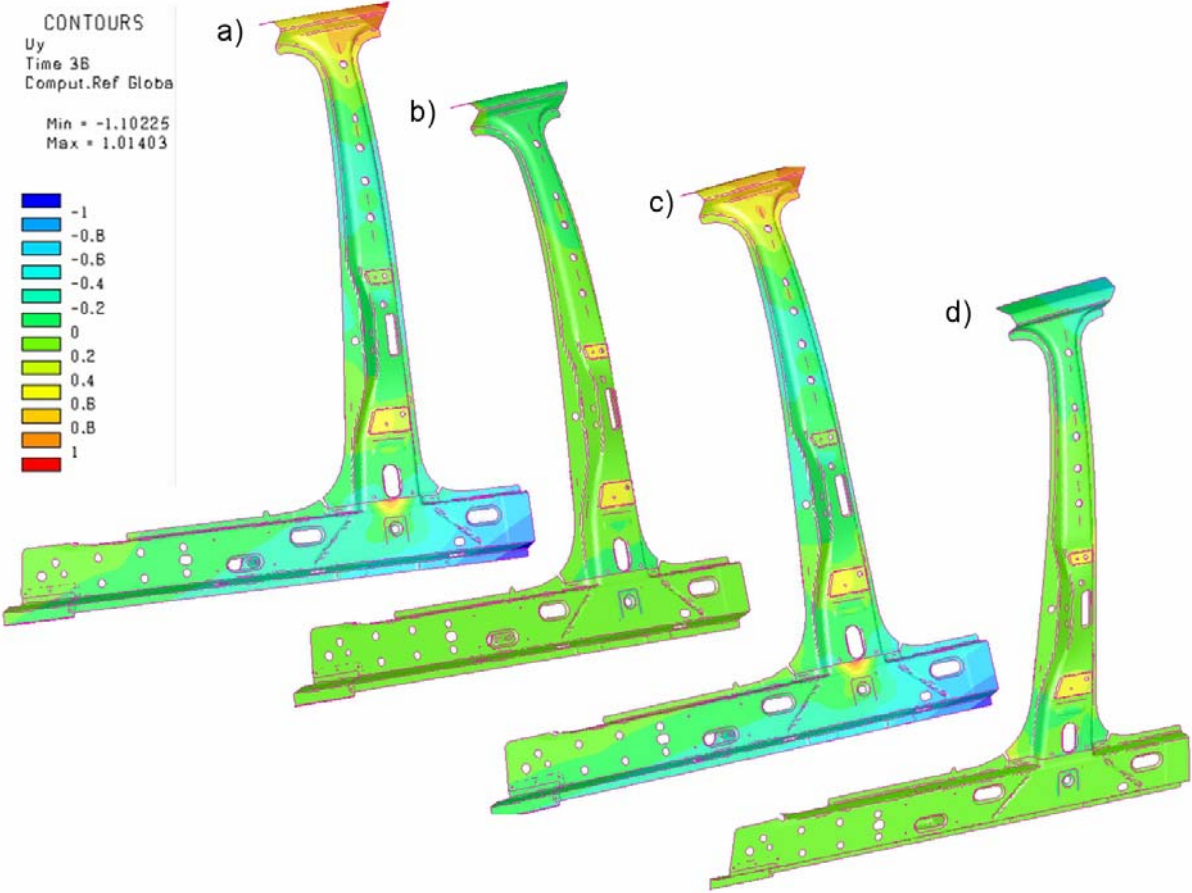


Figure 3: Welding distortion of joint assembly (Picture: ESI GmbH)

2.3. CAR BODY DRYING

The thermal heating of car bodies is used at several stages of the automotive fabrication process: for curing of paint or adhesives, for metallurgic purpose or for evaporating moisture after cleaning steps. The precise characteristics of the heat-up, sustain and cool-down cycles are relevant for all the afore mentioned processes. *VPS/DRY* is used to compute the detailed temperature vs. time history at any location of the body-in-white in the drying process. It takes into account the energy transport from the heat sources of the oven to arbitrary parts of the car body. As a result, it is possible to identify cold spots or critical locations in terms of

the temperature slope in an early design stage. Based on primary temperature vs. time results additional secondary examinations can be performed:

- Dwell time within a selected temperature range
- Hardening state of paint and adhesives
- Bake hardening state
- Thermal deformation and stress.

Figure 4a shows a schematic illustration of the different oven zones. In Figure 4b an oven cross section is shown. On the left side the hot air nozzles can be seen. The right side depicts the thermal radiation applied to the car body by the oven walls (red arrows). Figure 4c shows the simulation results of a temperature distribution for a specified time.

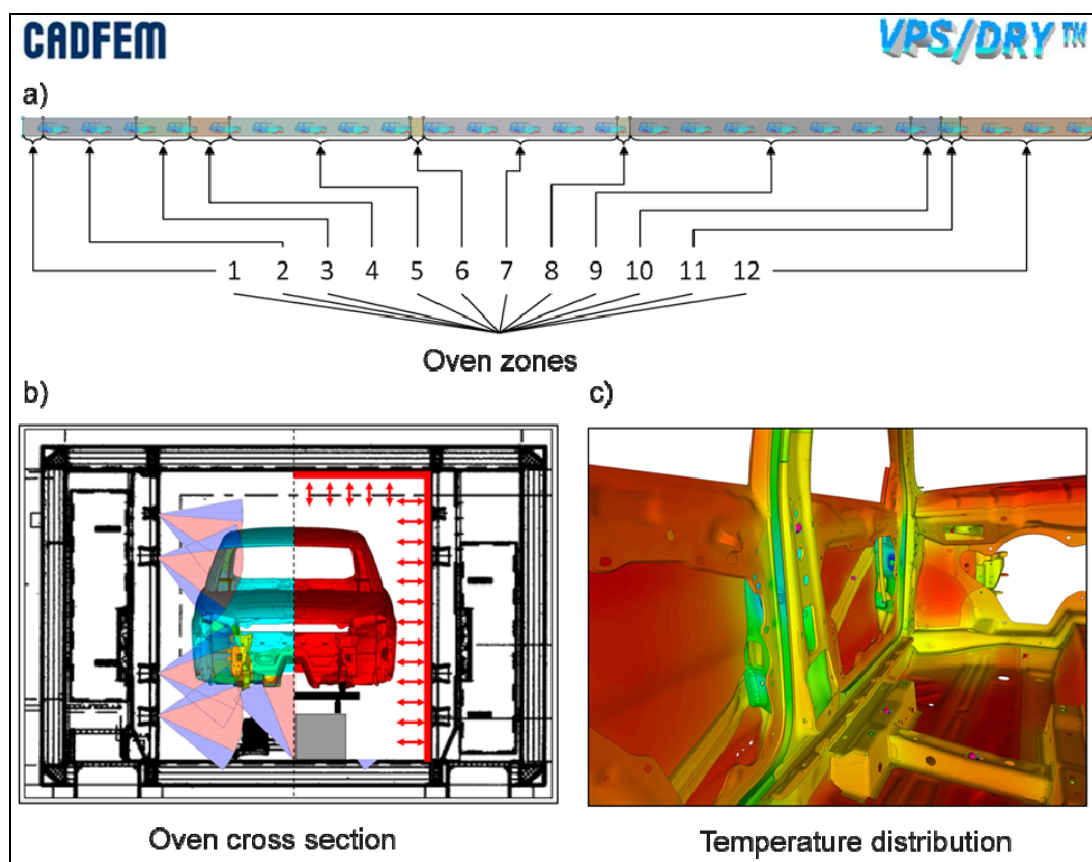


Figure 4: Simulation of the paint drying process

2.4. CRASH SIMULATION

The entire virtual process chain is validated by the results of crash calculations. Thereby, the linking of different process simulations is analyzed in its sensitivity on the crash behaviour of the car body which is an important product feature of cars. That way the effect of different influences on the results of crash simulation is detectable. Additionally, the benefit-cost ratio of the inclusion of different process simulations into the process chain can be evaluated.

As the calculation of process simulations for the entire car body is extensive, the verification is carried out on the basis of a relevant module for side impact. Some structural body parts in the area of B-Pillar and sillboard are selected for the calculation as shown in figure 5a. The crash simulations are performed according to Euro NCAP pole- and barrier impact, as shown in figure 5b and 5c.

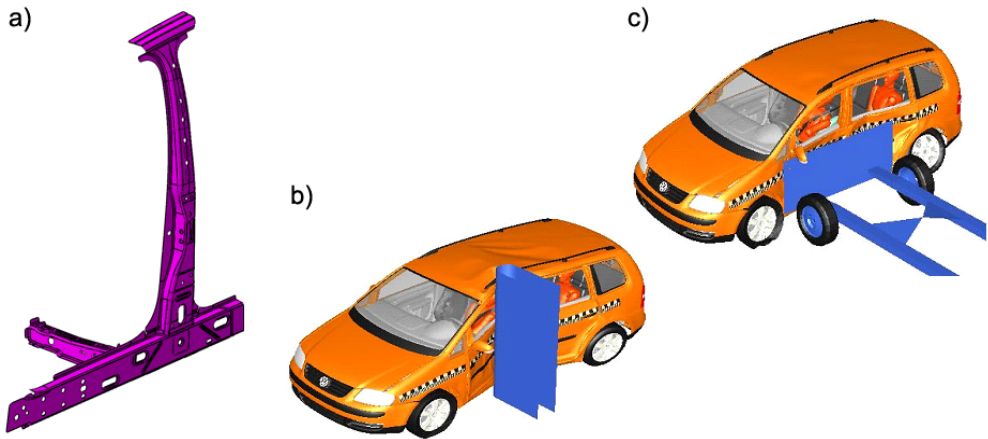


Figure 5: a) Group of components; Crash model: b) pole impact; c) barrier impact

Similar to the sensitivity analysis in welding simulation crash simulations were performed under consideration of different forming results. The results show that for this kind of structural components the mapping of plastic strain has a larger influence on crash performance than the mapping of blank thicknesses. Figure 6b shows the deformation of a passenger compartment after a pole impact. By consideration of plastic strain (shown in figure 6a) as forming result the survival space could be increased by 10 mm. The positive influence of linking forming results to crash simulation is also described by Peetz [2], Scholl [6] and Zöllner [3].

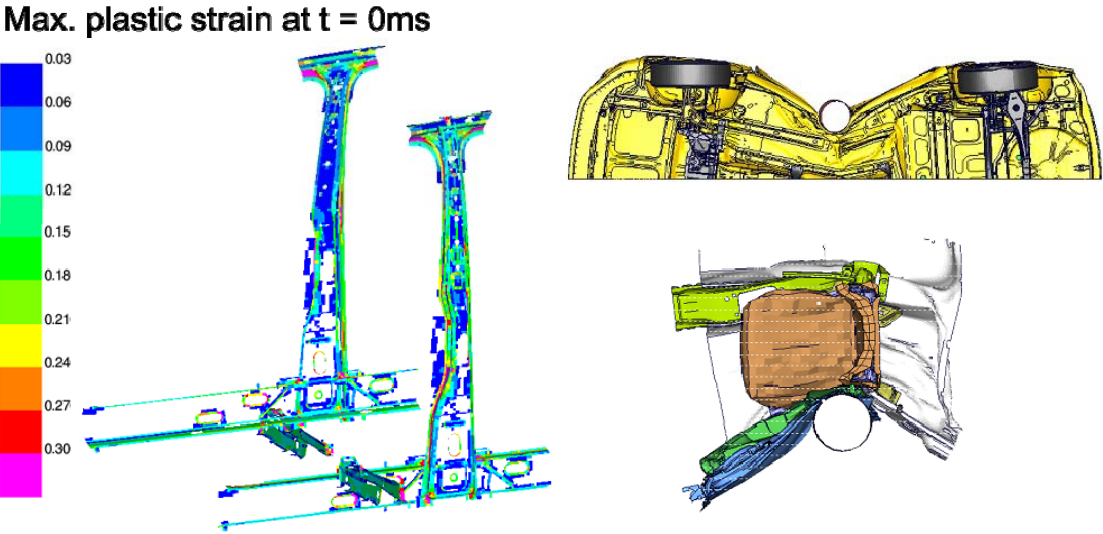


Figure 6: a) Mapped plastic strain

b) Maximal intrusion after pole impact

2.5. MAPPING

To get an entire process chain two simulation steps were initially linked together. First step is to analyze and record import and export interfaces of simulation tools. It was found, that there are no standardized interfaces for simulation data transfer provided by any software producers. Therefore, a direct transfer of simulation data into the next simulation tool is hardly feasible without further intermediate steps, especially when using simulation tools of different producers. Furthermore, the finite element meshes and coordinate systems differ between the simulation tools. For example incremental forming simulation is performed in the tool coordinate system. In contrast the one-step and crash simulations are performed in the vehicle coordinate system. Therefore, the meshes have to be transformed into a shared coordinate system before mapping process can be performed. Forming simulation meshes have to be refined adaptively during calculation at radii whereas joining simulation meshes have to be refined in the area of the weld zone and the meshes for the paint drying and crash simulations have uniform elements.

The shell elements that are used in the simulations do not vary just in the number of nodes (triangle or rectangle elements) but also in the number of integration and Gauss points. Figure 7 shows exemplarily the differences in Gauss and integration points between forming (*PAM-STAMP 2G*) and welding (*Weld Planner*) simulation. Additionally, some export formats give their results per element but other formats give them per node.

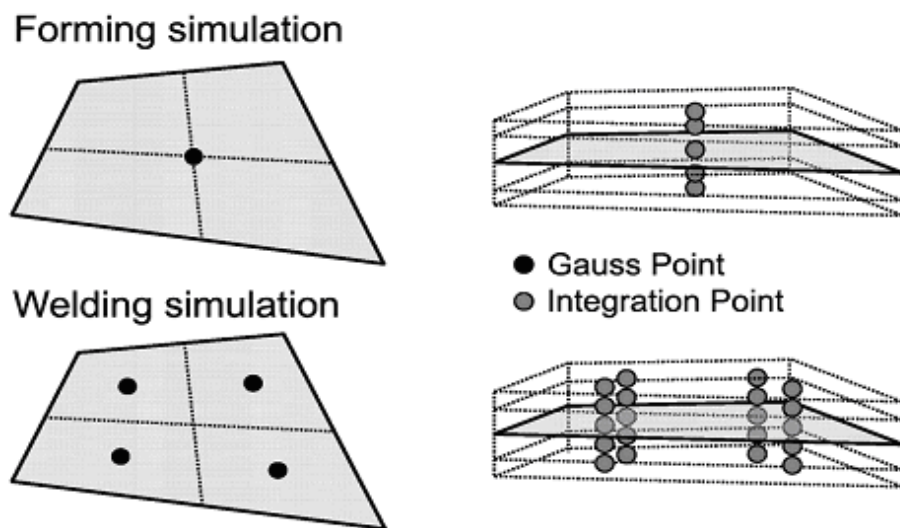


Figure 7: Gauss and integration points in forming and welding simulation (Picture: ESI GmbH)

Due to incompatibilities between the processes as well as differences in mesh discretization the use of mapping tools is necessary to transfer output quantities between the process simulations [3]. Fraunhofer Institute SCAI and the University Stuttgart have developed a mapping tool called *SCAIMapper* within the framework of VDA/FAT Working Group 27. The *SCAIMapper* is able to import and map a wide range of file formats and is therefore used to link the simulation tools in the process chain [6]. The graphical user interface and the

included validation tool of the *SCAIMapper* facilitate the execution of the single mapping steps as well as the evaluation of mapping quality.

The results of incremental and inverse forming simulation were transferred in the subsequent simulation steps with the *SCAIMapper*. Figure 8 exemplifies the thickness distribution of a B-pillar after forming (8a) and after mapping on the mesh of welding simulation (8b), on the mesh of paint drying simulation (8c) and on the mesh of crash simulation (8d). These mapping results show a good consistency with the original results of forming simulation in a wide range. Nevertheless, areas with a high gradient in the forming mesh show a discrepancy up to 6 %.

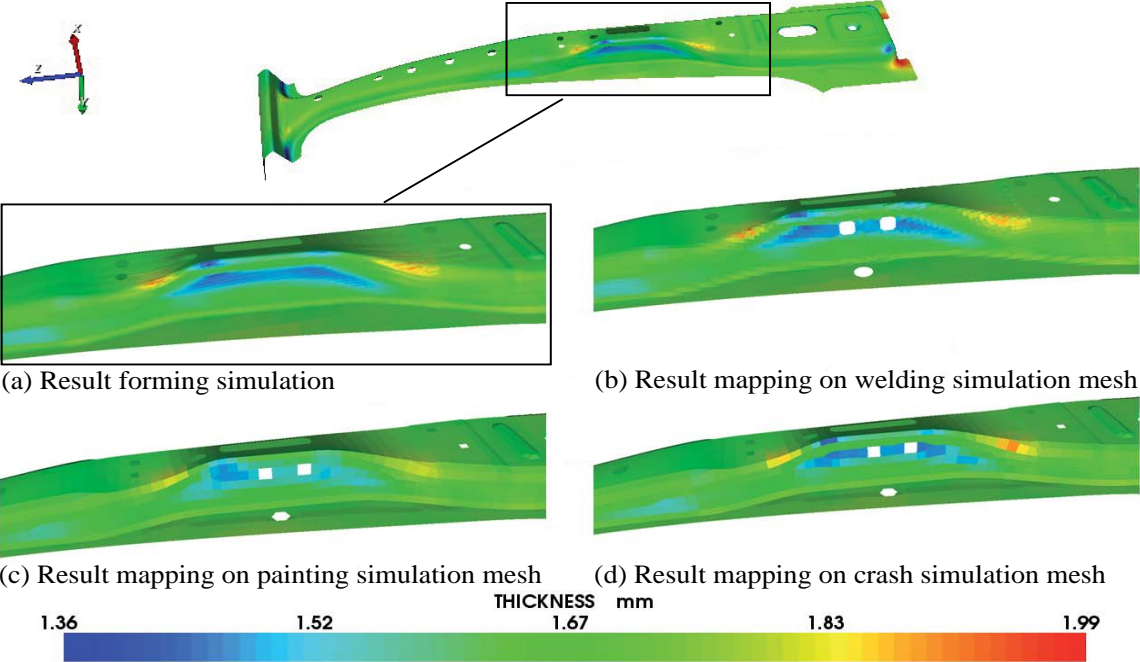


Figure 8: Sheet thicknesses after forming simulation and mapping on meshes of subsequent process simulations

By now it is difficult to accurately map data between joined assembly groups with adjoining parts. In doing so it was found that data from one part is not only mapped on the part itself but also partially on parts close-by. This is caused by the deployed kind of mapping algorithm which was not designed for mapping joint assembly groups like they were used in process chain simulation in VIPROF project. Hence, further work will have to deal with this challenge. Additionally, the inclusion of mapping of stresses and entrainment of deformations into the process chain will be expedited.

2.6. PROCESS PLANNING

A modular cockpit is implemented to achieve transparency along the process chain. Figure 9 shows a schematic view of the aimed module cockpit. It will represent the degree of maturity of production planning by maturity indicators. Each single process has to be ensured and each part must be producible before it is released for the next manufacturing process by a

green status light. At the next level components will be made from the parts produced by forming. These components have to be checked for joinability. Subsequently the components are assembled to become a car body. Paint curing in the dryer may not leave any plastic deformation in the car body. The finished product is available when all status lights are green.

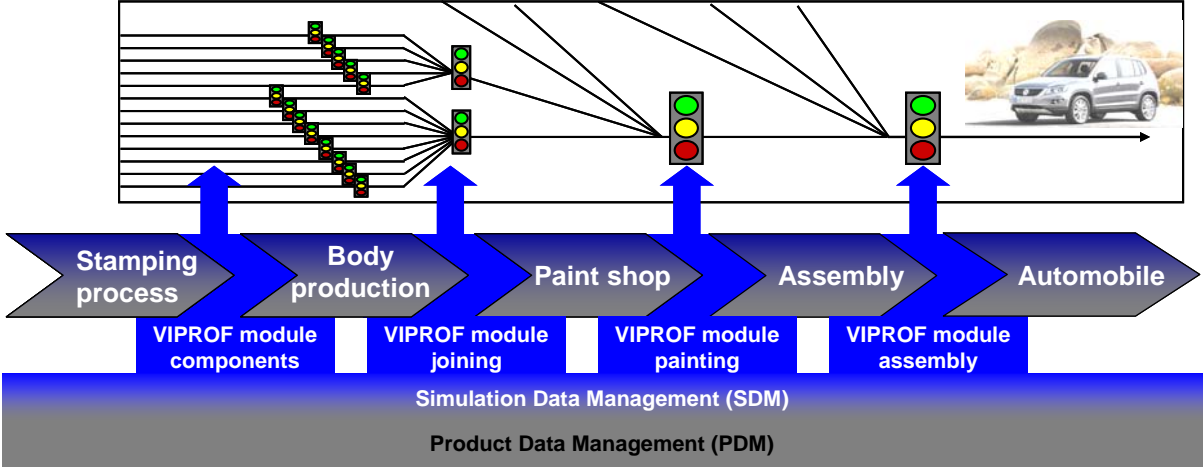


Figure 9: Module cockpit - Status of process planning along the process chain

3. CONCLUSION

The global competition and increasing quality standards to a modern car as well as shortening of product development cycles enforce the validation of manufacturing process at an early stage. Furthermore, the influence on products from the sight of manufacturing is necessitated. Close coordination at the interface between component development and production planning is the basis for early validation of product design. Thereby, it is possible to avoid cost intensive modification efforts after conclusion of product design. For this purpose a paradigm change from discipline orientated operation to an integrated approach is essential. Through virtual validation of producibility along the entire process chain (press plant – body construction – paint shop) and cross-process result transfer recording of production orientated product properties and their consideration in product development should be facilitated.

The challenge of this project is to link product development and manufacturing technology to a continuous, digitalized and cooperative planning of development and production. To achieve this aim two strategies of resolution are pursued. It is intended to integrate all data which is generated by CAD systems and simulation tools, etc. into a PDM system. This allows for a consistent storage, administration and supply of data that is generated during the product life cycle [7]. Additional development of fast and flexible direct interfaces is purposed to connect all simulation tools involved in the manufacturing chain.

The present paper shows that simulation data exchange across the entire process chain pose a challenge because of different data formats, varying mesh definitions and lack of interface standardisation. Until now blank thickness and plastic strain were mapped within

the process chain with the *SCAIMapper* receiving an adequate mapping quality for parts. Nevertheless discrepancies due to geometry differences and interpolation inaccuracies occur. Remaining work is the mapping of stresses and entrainment of discrepancies to reference geometry that should be included into the process chain.

Moreover, it will be possible to query the production planning status at any time in a module cockpit using maturity indicators, thus achieving the highest possible levels of transparency for all those involved.

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Further information can be found on the VIPROF project at <http://www.projekt-viprof.de>.

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