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IMPACT OF MODULARISED PRODUCTION ON PRODUCT DESIGN IN AUTOMOTIVE INDUSTRY

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ABSTRACT
During the last decades, the product life cycle in the automotive industry decreased from 10 to 6 years or even less. At the same time the demand for individualized and configurable cars has increased. This has led to new challenges in product development and production planning. One key factor in order to gain important time and cost potentials in the different project phases is a standardised production.
This contribution deals with the influences of a standardised and modularised production on the product design and presents the most important requirements and restrictions which have to be taken into account already in an early phase of the development process. Furthermore, a new approach is introduced which supports the designer in consideration of this requirements and influences the product design from a production point of view. Afterwards the introduced methodology is demonstrated with the help of a body-in-white welding cell. Finally this contribution ends with a summary and a short outlook towards future activities.

Keywords: Modularised production, production requirements, production oriented product validation

1 INTRODUCTION AND MOTIVATION
The challenges for automotive manufacturers have changed a lot in the past decades and will change even further in the coming years. Companies in the automotive industry are currently faced with the following challenges [1]:

- A soaring number of product variants with many product derivates
- Decreasing innovation and model cycles
- Accelerated market launches of new products and product variants
- Longer production lifecycles with highly flexible and agile manufacturing systems
- Uncertainty related to future powertrain systems (diesel engine, hybrid, fuel cell, e-drive)

Due to the changing boundary conditions described above the automotive industry is motivated to think about new ways of developing, producing and distributing products. The increasing number of personal car models and variants caused a need for new ways how to design new products. In the product development new concepts like design templates, platform and module strategy are introduced in the process. On the one side this requires an adjustment of the production strategies, but on the other side it opens new possibilities that were not imaginable in the past where this kind of standardisation was not the rule. Indeed standardisation in the product design leads to standardisation in the production, which enables certain flexibility (ability to produce several products on the same production line) [2].
Conventional methods are no longer sufficient to speed up the planning and development processes, to reach budget targets and to manage the increasing complexity of new products. One of the generally accepted solutions to the problem of increasing production complexity is a standardised and modularised production. A key issue towards such a modularised production is an early consideration of requirements and constrains coming from the standardised production modules during the product design phase. The production of new products has to be possible with the standardised production equipment; otherwise the advantages of standardisation can not be reached. Hence, an overall approach for the product development and the production planning is necessary.
The solution introduced in this contribution is dedicated to the just mentioned challenge of product validation based on production requirements in order to achieve the goal of a modularised production.

2 RELATED WORKS

Design for manufacturing, design for assembly or design for logistics are guidelines which were developed in order to consider the production requirements already in the product development phase. On a single part's level, the part's geometry, material, and respective manufacturing technology determine quality and cost of manufacturing (e.g. stamping of sheet metal body parts or injection moulding of polyamide) [3]. A detailed collection of respective design guidelines can be found e.g. in [4]. On a sub-assembly or complete vehicle level, the determining factors for quality, cost and time are parts handling, joining, and fastening. Design for manufacturing and assembly is not only supported by design guidelines, but also by elaborate methodologies and software-tools that focus on the reduction of costs [3], [5]. Production oriented design checks have been established in the whole product development process. Using the common Digital Factory tools the production engineer is able to check the vehicle's compliance with the production requirements in a virtual scene [6].

Production tools, fixtures, containers and man-models can be integrated into the virtual scenes which allow a realistic evaluation of tool accessibility, fixing processes, and ergonomics. Examples for virtual validation of production processes performed during the product development processes are shown in Figure 1.

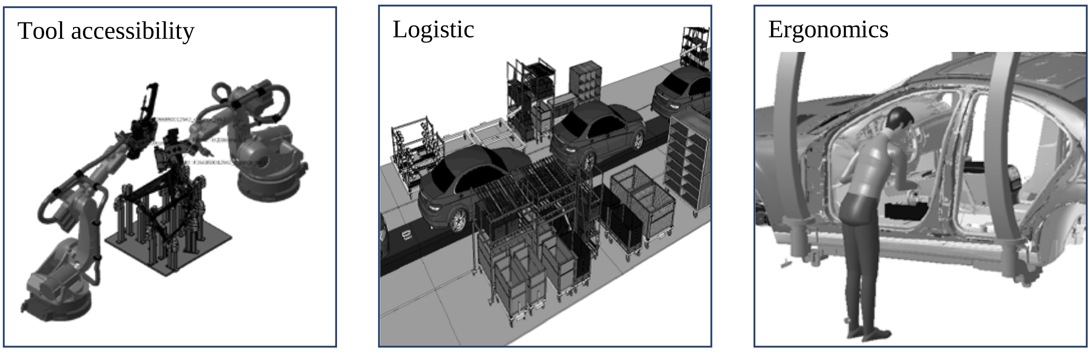

Figure 1. Examples for digital production validation

The results of production oriented design checks have to be discussed in interdisciplinary meetings with product designers, production planners, plant representatives as well as members of the management. In the automotive industry such meetings take place roughly every six months at defined milestones of a car project [7].

A supporting approach for a continuous and structured product validation process is introduced by Stanev et al. This work presents an integrated method for validation whether a product component can be manufactured on a given production line. This is performed by modelling and evaluating the respective product, resource and process information based on knowledge engineering techniques [8].The core of the framework is the validation method that is executed in the frame of a validation procedure. If the result of the validation is positive, the new developed product can be manufactured on the existing production line. If the result is negative, an engineer needs to change either the product design or the production resources [9].

Requirements from manufacturing should be taken into account as early as possible in the development process. Brockmeyer introduces a computer-aided methodology which influences and validates the product design regarding production requirements [10]. The basis of this approach is the availability of manufacturing knowledge to the development engineer's assistance. Geometrically oriented knowledge about the influence of tools, fixtures and grippers is applied to product design [11].

Summing up, production oriented design checks and early product design influence regarding production requirements help to reduce production problems, but they can not assure a standardised and modularised production. The following issues have to be taken into account:

- Production oriented design checks detect problems often too late in the product development process. Hence it is not possible to change the product design anymore. So the production system has to be re-designed. This is contrary to a standardised and modularised production system.
- The presented approaches, like Design for Manufacturing, support the product designer in such a way that the products are easy to manufacture. Nevertheless requirements coming from the standardised and modularised production are not taken into account.

3 FROM A STANDARDISED PRODUCTION TO MODULAR PRODUCTS

This chapter introduces a new approach which supports the product developer to consider production requirements in order to achieve the advantages of a standardised and modularised production. Coming from the conventional production planning the new approach will be developed step by step.

3.1 Production Planning

Figure 2 shows how a production planner develops a production system beginning with the engineering bill of material (EBOM). The EBOM is a list of parts and sub-assemblies, representing the product as it is designed by the engineering. First of all the hierarchical engineering bill of material has to be transformed into a manufacturing bill of material (MBOM) according to the relevant priorities like production rate per day, cycle time etc.. A MBOM reflects the product as it is planned by the manufacturing engineer. Each knot of the MBOM represents an assembly and contains the information of associated parts, corresponding fasteners (e.g. welding spots) and necessary value-adding and non value-adding processes. Furthermore, a knot of the MBOM describes at least one station of the whole production line.

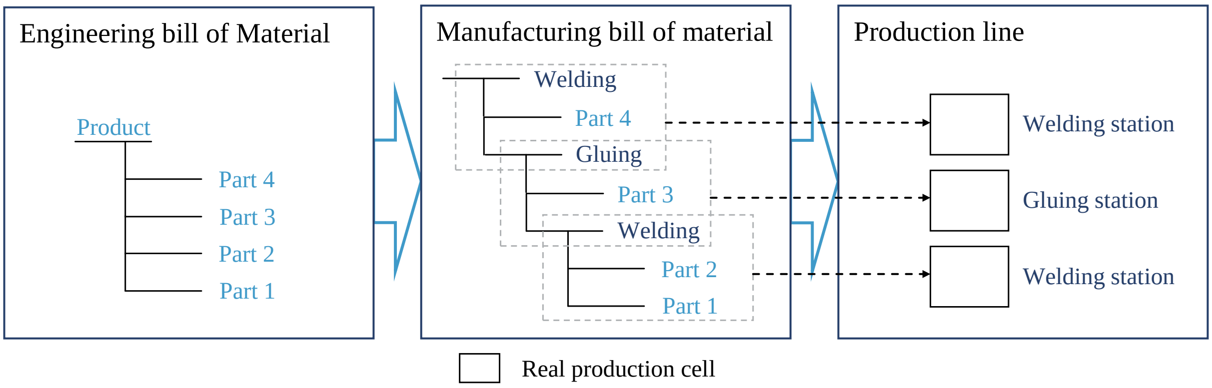

Figure 2. Production planning process

One station consists of several resource components for performing specific operations like handling, gluing, welding etc.. Finally, as mentioned above, a digital validation of the system is essential.

3.2 Modular manufacturing

The operating experience and the know how of the production planning leads to standardisation and modularisation of the production system according to the “best practise”-solution. Reusing knowledge and experience of previous production systems offers industry opportunities to improve planning quality and standardisation while enabling decrease of costs [12]. Figure 3 describes the planning process with production modules. Firstly, basing on the previous production lines, robots, tools and other manufacturing equipment are summarised in units called modules. Designing a new production system the production planner can use these modules. The new manufacturing system is constructed and reconstructed by combining these building blocks.

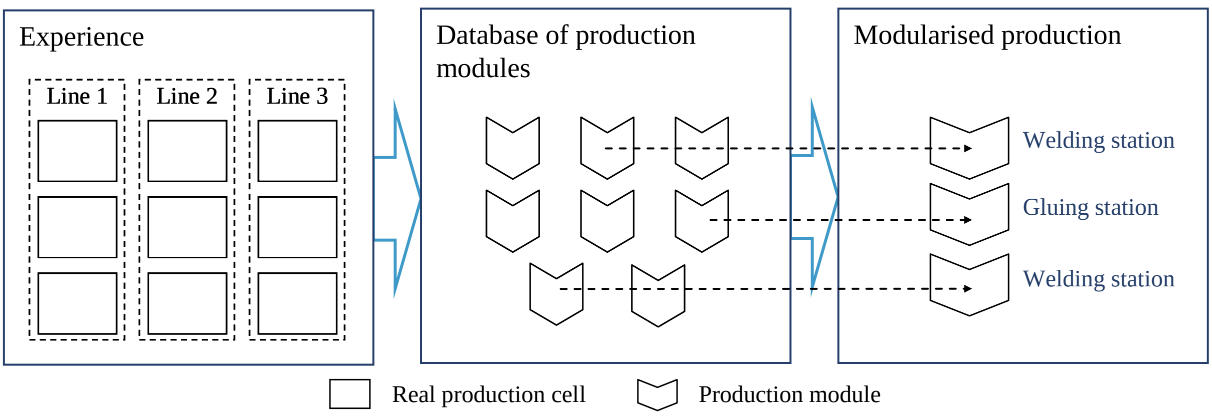

Figure 3. Modularised Production

A modular construction of new production systems enables “standardized diversity” by using different combinations of standard components. A modularized production has the following advantages [13]:

- The planning time gets shorter.
- New design is realized by using and combining existing modules.
- Reuse of production equipment is possible.
- Using the same parts helps to reduce costs.
- Maintenance becomes easier.
- Standardised production modules help to eliminate islands of automation.

However, the following restrictions have to be taken into account during the development process of the product in order to reach the advantages of a modularized production line:

- The materials of the new product have to be processable with the standardised production equipment.
- The product structure has to fit to the modularised production. The maximum number of parts which can be handled by the each production module has also to be considered in the product design.
- Assuring the accessibility of the fasteners makes the product design suitable to production tools (e.g. welding gun).
- The number of manufacturing operations must not exceed the cycle time. Therefore the number of fasteners (e.g. welding spots) has to be limited for one production module.

A support of the product designers is necessary; otherwise the advantages of a modularized production can not be reached.

3.3 Support of the early stage of the product design

The advantages of standardised production modules can just be reached if the production system is planned with the standardised modules predominantly. Therefore, as mentioned in the previous chapter, some restrictions have to be taken into account during the early product design phase. This chapter introduces an approach which supports the designer to consider the mentioned restrictions.
Before designing the product geometry restrictions and requirements of the standardised production modules are summarised in the so called production environment and are provided to the designer (Figure 4).

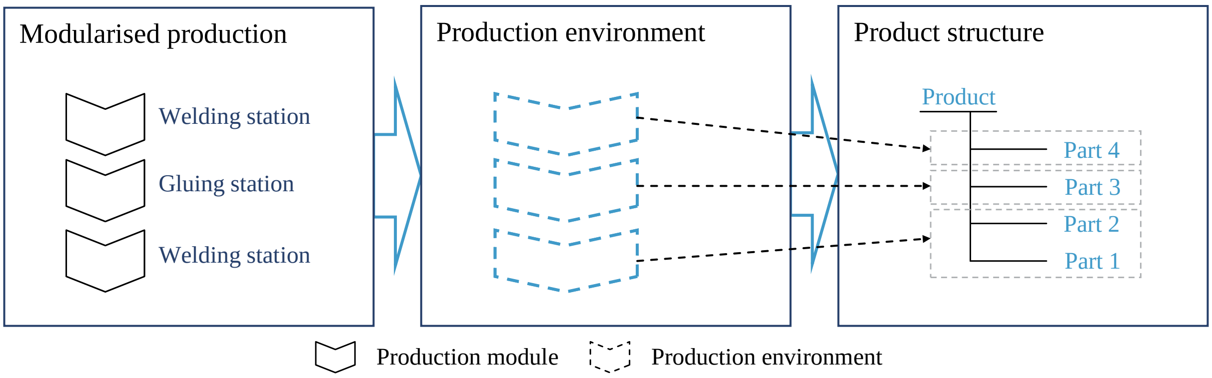

Figure 4. Production environment

The production environment can be accessed in the CAD system and collects all requirements relevant for the modularised production:

- Tool Geometry: The product design has to fit the tool geometry.
- Sequence Time: Time is an important requirement. All value adding and non value adding processes of a certain production module must not exceed the cycle time. Hence, a maximum number of production operations like welding spots or clinches are limited.
- Product Structure: The particular product subassemblies are already allocated to the corresponded production modules. Therefore the production environment offers a pre-structure of the product. In addition the production environment contains interfaces to other CAx-tools for a further use of the data.
- Grippers: The new product geometry has to be fitted to the grippers which are part of the

production module.

- Fixing and clamping concept: The new product geometry has to be suitable to the fixing and clamping devices which are part of the production module.
- Tolerances: The production tolerances have to be in regard of the product design.

Figure 5 summarises the requirement needed to be taken into account during the design phase of the new product.

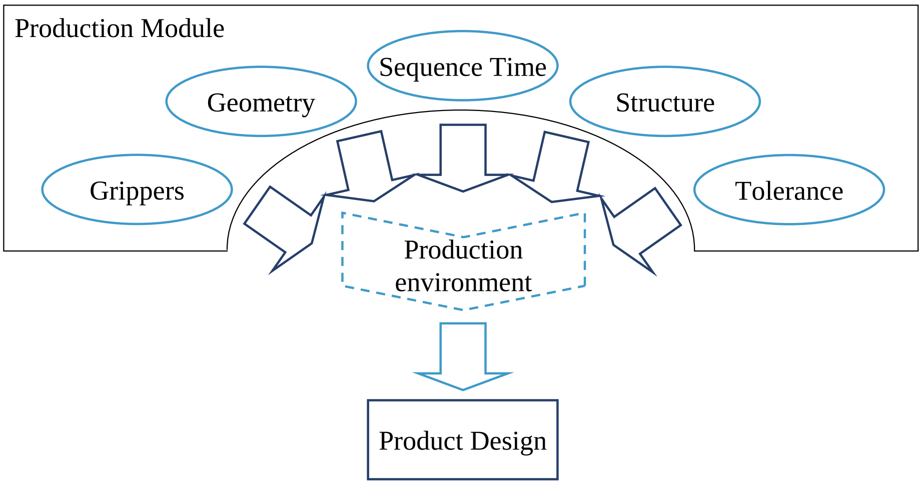

Figure 5. Production requirements

Creating a new product the developer has to design it inside of the production environment which provides the necessary information about the production module. Afterwards the single product components are transferred to the product structure (Figure 4). In this manner the freedom of the designer is limited, but the advantages of a modularised production can be easily reached.
A further advantage of this approach is avoiding problems regarding production requirements. Figure 6 describes the validation process during the product development based on the production environment.

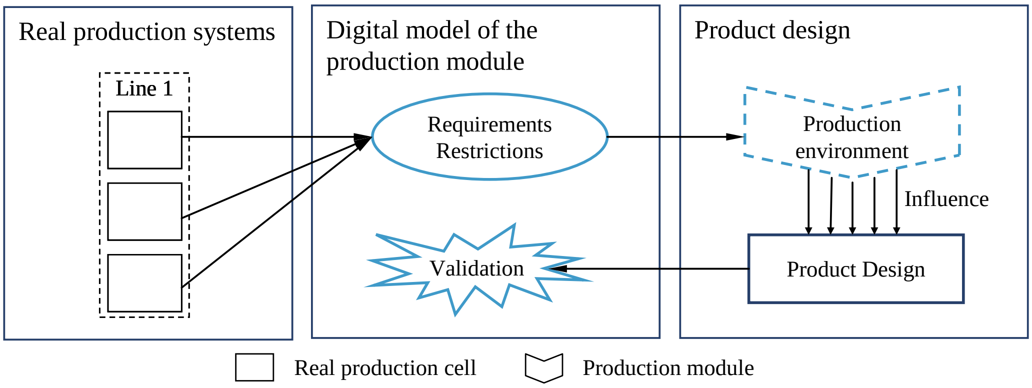

Figure 6. Validation process

As mentioned in the previous chapter, the basis of the production environment is a digital model of a proved production system. In this manner the possibilities as well as the limitations of the production system are provided to the product designer. Considering most of the production requirements already in the beginning of the design phase, many production relevant problems can be avoided. However, a detailed product validation regarding production requirements is still necessary and can be performed with the common Digital Factory tools. If the production module has not to be changed, the number of detected problems will be smaller compared to a traditional designing process, because the most important requirements have already been taken into account during the designing phase.
In an ideal case the production planning process is very simple because the planner just has to combine predefined modules. But in reality the modules have to be modified in order to fit in the real factory layout. Nevertheless, the planning effort of the production system is quite low in comparison to a traditional one.

3.4. Discussion of the approach

The presented approach has several advantages but also some disadvantages which are summarised in this chapter:

- The effort for initial creation of the production environments is quite big.
- The production modules with their production environments have to be modified when new production technologies are used (e.g. laser welding instead of spot welding).
- The product structure and the number of single parts have to be changed often because of stiffness problems.

Nevertheless, the introduced approach has the following advantages:

- The product design is influenced by the production requirements at an early stage of the product development process.
- The production oriented validation which is performed at later time during the development process detects fewer problems.
- The introduced approach supports the designer and production planner in reusing production equipment.

4 APLICATION AREA

In this chapter the introduced approach is demonstrated using an example of a body-in-white production cell. The body-in-white production is one of the main phases in the car manufacturing process, where standardisation is widespread.

In this example the welding spots of an engine bonnet are defined with the help of the introduced production environment. Two strengthening parts have to be fastened on the inner part of the bonnet. The structure of the bonnet is illustrated on the left hand side of Figure 7. The corresponding production module is shown on the right hand side of the same figure.

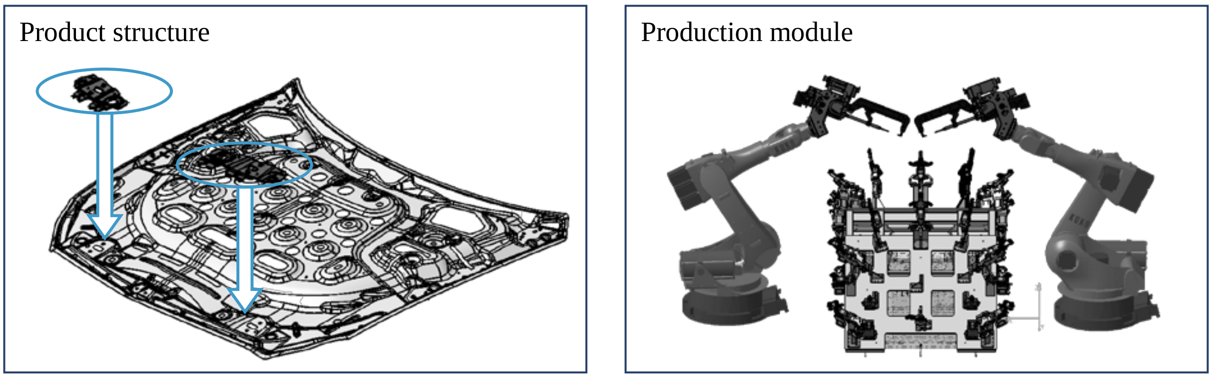

Figure 7. Engine bonnet and the corresponding production module

The production module contains a fixing and clamping device and two robots with welding guns. The production resources in this module constrict the designing freedom of the product developer. For example the two robots are not able to perform an unlimited number of welding operations. The product designer has to be aware of this. Hence the production environment provides the maximum number of welding spots (Figure 8).

Production environment

Max. cycle time:	61s
Time for part feeding:	12s
Time for one weld spot:	7s
Max. number of weld spots:	2 x ((61s - 12s) / 7s) = **14**

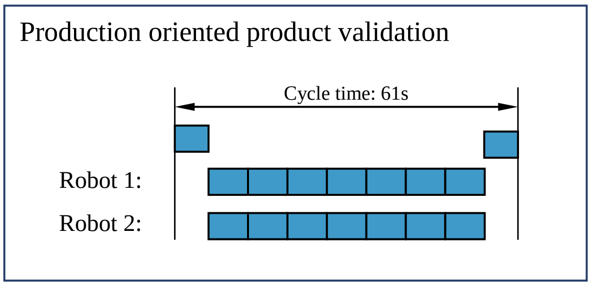

Figure 8. Consideration and validation of cycle time

If the product developer keeps to the restrictions and constrains provided by the production environment, the production oriented product validation will not discover cycle time problems and the production module will have not to be changed.
Not only the maximal cycle time but also the accessibility of the production module has to be taken into account in order to fit the new product into the standardised module. Therefore an automated approach has been developed which visualises the accessible areas on the product surface (Figure 9 left hand side). The accessible areas are coloured green whereas the not accessible areas are red. Before defining the welding spots the product developer can see where the production module is able to spot-weld.

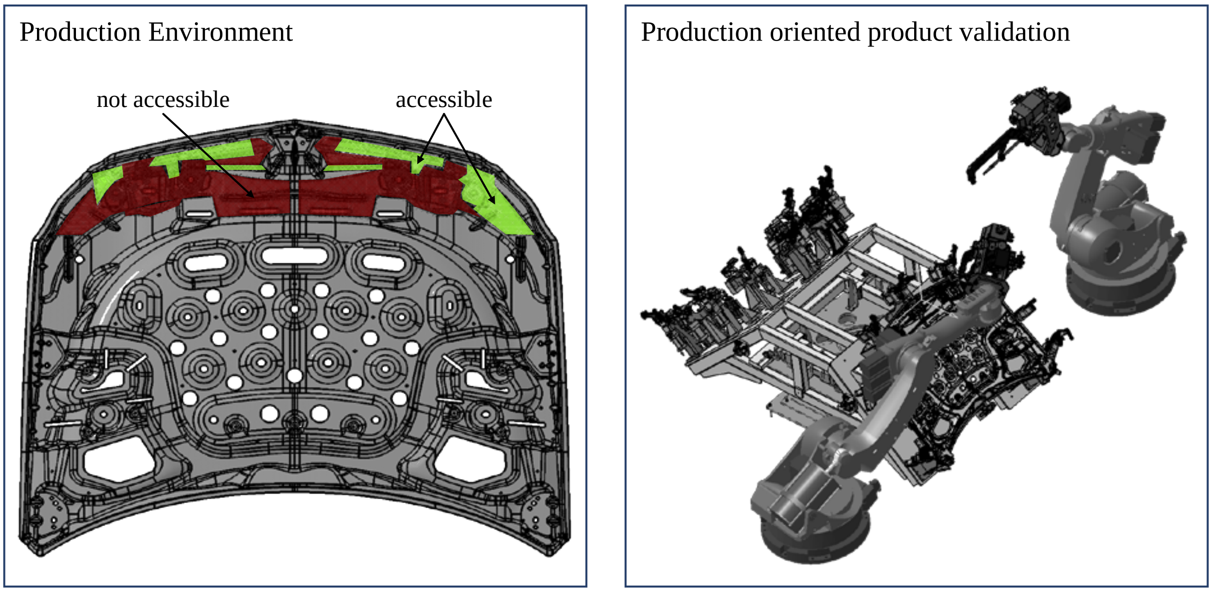

Figure 9. Consideration and validation of tool accessibility

If the product developer defines all weld spots inside of the accessible areas, the accessibility check will not fail (Figure 9 right hand side) and the production module can be used without any modifications. Inaccessible welding spots trigger a modification of the production module. In our example an additional weld gun would be necessary. Consequently the maximum number of weld spots would decline because of the processing time needed for tool changing.
The presented application area demonstrates the benefits of the introduced approach:

- Identification of production related problems and taking requirements of standardised production equipment into account in a very early stage of the product development process
- Decrease of production related problems (cycle time, accessibility) which can appear during the production planning phase or even during the real production ramp-up
- Reducing investment and maintenance costs by realisation of a standardised and modularised production system

Summing up, the advantages of a standardised and modularised production can just be reached by consideration of production requirements early in the product development process.

5 CONCLUSION AND OUTLOOK

Due to an increasing customer-individualisation, the growing complexity of the production systems and the even faster changing business environment, the automotive industry is facing a new kind of challenges. The standardisation and modularisation of production systems is getting more and more important.
In this contribution a novel approach was presented how the product developer can be supported in order to realise a modularised production system. The presented method generally differs from the common validation processes. The early consideration of requirements and restrictions coming from the production modules avoids production-related problems and ensures the advantages of standardised production. Finally the results were demonstrated with the help of a body-in-white welding cell.

Much progress has been made in this topic, but the following questions still remain to be addressed:

- Which further production requirements have to be taken into account during the product development process?
- How can further requirements (e.g. tolerances, fixing and clamping concept, etc.) be integrated into the production environment?
- How can production modules be automatically transferred to production environments?
- How does a modularised production and the product development process change when new manufacturing technologies are introduced?

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