Virtual validation of material provisioning in assembly in the automotive industry

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Abstract

The competitive situation in automotive industry and increasing market demands necessarily lead to higher complexity in product development, production planning and production ramp-up processes.
One key challenge for mobilising important time and cost resources in production engineering projects is a virtual validation of the ramp-up. Especially in cross-functional cases where many planning departments are involved using simulation models instead of physical prototypes for a complete validation of production ramp-up is a new approach. This work presents requirements and solutions of virtual ramp-up validation focussed on material provisioning in automotive assembly.

Keywords:
Factory and production planning, Material provisioning, Virtual ramp-up validation

1 INTRODUCTION

Dynamics of markets and their demands result in an increasing competition in automotive industry with shorter product lifecycles will finally lead to obsolescent products.

Furthermore, the number of product variants and derivates has tripled in the last 20 years. Longer production lifecycles based on flexible manufacturing systems [1], [2] with a rising number of integration processes during the running production lead to new challenges, especially in the field of production engineering [3].

Empirical studies clarify that about 40 percent of necessary modifications take place after the late advanced prototype phase. Hence, lots of modifications are performed during start of production and after finalizing tools for series manufacturing. For this reason, an efficient production ramp-up has an increased significance and offers big cost-savings for the companies

To ensure efficient production ramp-up in final assembly in the automotive industry, physical prototypes are used. In so-called station preparation workshops, physical prototypes are assembled to improve processes of assembly and logistics and make them ready for series manufacturing. Physical prototypes are very cost-intensive.

Several approaches deal with methods for optimization of the capacity of physical prototypes or substitution of physical validations with virtual validations in order to reduce the number of required physical prototypes. Since a long time, the vision of virtual validation of product and production under the premise to reduce physical prototypes exists. But until now, the implementation in practise is still not or just partially realized.

Virtual validation methods focus on early discovery of planning errors. So, a huge potential to improve quality of product and production lies in using virtual validation methods. Virtual validation methods in product engineering are state of the art and well established [4]. For example, simulation of crash behaviour and virtual validation of vehicle functions are performed. However, in case of production engineering, a complete virtual validation of ramp-up in assembly is still not completely possible [5].

This paper presents an approach for virtual validation of production ramp-up criteria in assembly by avoiding physical prototypes in the phase of production preparation. Especially the area of conflict between assembly and logistics will be described. Finally, this specific conflict will be introduced in a use case.

2 VIRTUAL PLANNIG VALIDATION

About 10 years ago almost every German car manufacturer started some kind of Digital Factory initiative. Similar approaches can be found in car manufacturing in other countries although they are sometimes described by other terms like digital manufacturing [4].

The main goal of these initiatives was to introduce virtual planning methods for designing new production facilities and methods for validating the planning results, e.g. by means of different simulation methods.

From a historical perspective, the Digital Factory initiatives also intended to close the gap between the very sophisticated IT support for product development (3D-CAD, CAE, etc.) and the rather rudimentary IT support in the area of process development [6].

Quite significant achievements have been made so far: Process design tools allow the virtual development of production processes and provide 3D-enabled design environments. Following the promise of product lifecycle management philosophies, these tools are even integrated with product development tools and their databases.

The question at hand to be discussed in this paper is the extent to which the validation of the designed processes is possible today and which effort has to be made for performing the validation.

Virtual planning validation in general can be defined as the process of verifying that a planned process meets a set of criteria. A successful planning validation increases the level of confidence that the planned process can be successfully implemented in reality.
According to this definition, validation can address different criteria and cover a multitude of validation aspects. It can even look at the planned processes at different levels of planning detail, requiring models of different resolution and adequate simulation methods.

As an example, there are well established simulation methods validating the kinematic aspects of the processes taking place in a robot cell. They require detailed 3D models of the product and of the resources (robots, fixtures, transport facilities) and their kinematic properties. The validation criteria that can be verified by these methods include questions like avoidance of collisions, cycle times and efficient resource usage.

A different validation method is material flow simulation. Here, we require models of a higher level of abstraction. In this type of simulation, the focus is on stochastic influences on the planned production process and the validation of control strategies (buffer strategies, allocation of resources and workers, etc.). The operation of a robot cell may here just be represented as a simple cycle time value – requiring of course, that this time value has been validated by a different validation method. The validation criteria that can be verified through material flow simulations [7], [8] include classical performance factors (how many vehicles can be produced in a time period), efficient resource usage, bottleneck detection and avoidance, etc.

In summary, there are many different aspects of virtual planning validation which can already today be performed. The standard repertoire includes the validation of automated robot cells, material flow aspects including line balancing and resource allocation [9]. Also possible today is the validation of ergonomic aspects by using simulation methods for humans operations [10].

A main drawback can be seen in the fact that many different tools are required to validate all individual aspects of a planned process. This holds the danger of potentially ignoring dependencies between individually validated criteria.

This heterogeneity of the IT tools supporting virtual process validation also results in heterogeneity of data formats and sources for representing the planning process. Many conversion steps may be needed to provide each tool with its required input formats. This can easily lead to inconsistent validation results. A contribution to attenuate these effects is made by extensible standardized and neutral data exchange formats like AutomationML [3], [11], [12].

Problems in the practical application of the existing validation methods can also arise from the different perspectives of the involved stakeholders. A logistic planner may very likely have a very different perspective than an assembly planner, even though they will have to plan a certain process cooperatively in order to make it work. The virtual validation of material provisioning and material zones discussed in the next sections is a typical example for this.

3 PRODUCTION PREPERATION

In general, production planning in the automotive industry is a collaborative issue. Many different planning departments are involved. Product development, Body in White planning, Factory layout planning, Logistics and Assembly planning are typical planning departments in the automotive industry. Process planning and material planning are very sophisticated jobs, which have to be performed in the manner of concurrent and collaborative engineering.

In comparison to the Body in White where a high degree of automation can be found, the main part of operations in final assembly is done by workers manually.

The phase production preparation is part of the series production launch process at Daimler (see Figure 1). In order to assure an efficient production ramp-up, validations of relevant criteria of an assembly-line take place. The production preparation process is an iterative process where many planning departments come together to improve processes for series manufacturing.

In so called station preparation workshops, the physical prototypes are assembled step by step, station by station. Basis for the assembly is the current planning state of an operation list. The operation list is a complete list of all necessary assembly operations.

The use of physical prototypes is very expensive. For that reason several approaches deal with the usage of virtual methods instead of physical validations. However, it suggests itself that virtual validation methods may replace physical validations (see Figure 2 and Figure 3).

Figure 2: Physical validation.

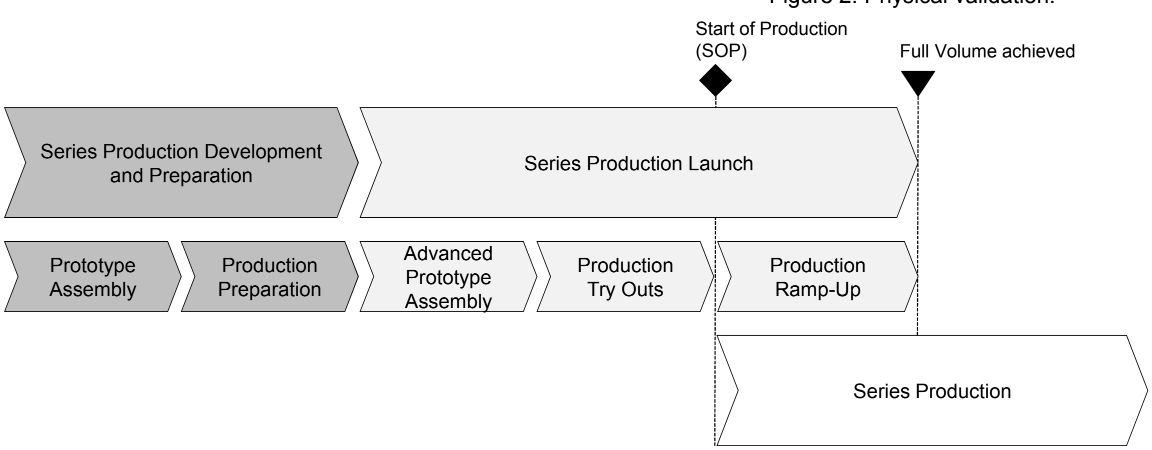

Figure 1: Phases of series production launch.

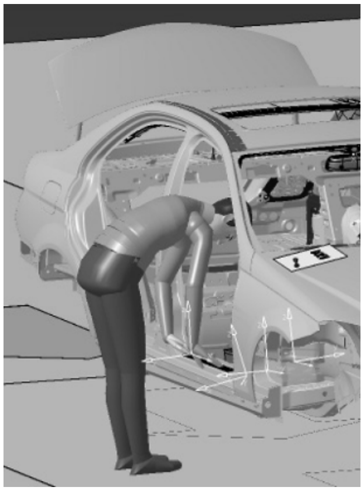

Figure 3: Virtual validation.

An objective is to reduce physical prototypes in production preparation phase using virtual models and virtual validation methods. Hence, the physical production preparation will be shifted from the real phase in the virtual phase of the production planning process. Doing so implicates, that virtual models qualify as a decision platform for production preparation. Figure 4 visualizes this approach.

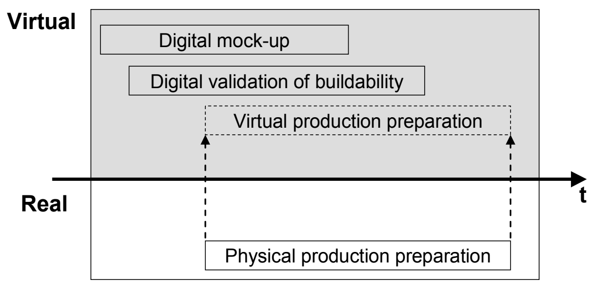

Figure 4: Shifting production preparation from real in virtual phase [5].

In [5] four main topics for validation criteria of production ramp-up in assembly are defined:

- Production oriented product validation
- Product oriented process validation
- Production oriented process validation
- Validation of resources

The production oriented product validation describes the validation of product from the point of view of production. Validation of assemblability is one example.

Product oriented process validation is related to value adding processes which have a direct affect to the product, like screwing or twisting together.

The validation of production oriented processes ensures that production-relevant processes are efficient. For example, worker paths have to be as short as possible and logistic routes should be optimized.

Finally, the validation of resources focuses on used tools, cargo carriers etc.

The validation of these partially interdependent aspects is done in the production preparation phase to ensure an efficient production ramp-up in assembly.

4 ASSEMBLY VERSUS LOGISTICS

In literature several models can be found for simulating production ramp-up and increasing its transparency. Lots of publications neither deal explicitly with the interface between assembly and logistics [13], [14], [15] nor they focus the production ramp-up phase. In comparison, Heins & Nyhuis [16] for example addressed changeable production ramp-up in assembly.

As already mentioned in the previous chapter, there is an area of conflict in production planning and production operating between assembly and logistic.

On the one hand the assembly department wants each needed part as near as possible at the assembly line to realize short worker paths.

Driven from the customer value [17], the Hours-Per-Vehicle (HPV) factor is a key indicator for personnel productivity analysis of a production plant. This indicator can be optimized by avoiding waste (Muda), i.e. long or unnecessary worker paths in assembly. Moreover, parts have to be provided sorted as required by the assembly sequence.

On the other hand the logistic department wants to carry as much parts as possible with one route to the assembly line.

Depending on different points of view, interests, objectives and finally contrasting planning premises, both planning departments have to reach an agreeable planning result. During production preparation and ramp-up phase, assembly and logistics have to comply with the philosophy of lean production [18].

Detailed criteria for both departments with focus on production preparation phase will be introduced in the following chapters, after defining the term material zone in conjunction with final assembly in the automotive industry.

4.1 Defining Material Zone

Material zone in the automotive industry is an important issue and more than just a kind of storage. The efficiency of a series production also depends on optimized material provisioning. Therefore, the area of material provisioning in the final assembly will be defined:

The material zone describes the physical location of material provisioning. Exactly at this location the worker picks up parts for assembly and the logistics resupplies them.

Planning the material zone is a collaborative issue. The assembly department and the logistics have to coordinate the planning of the material zone together. Figure 5 illustrates the material zone of an assembly line in the automotive industry.

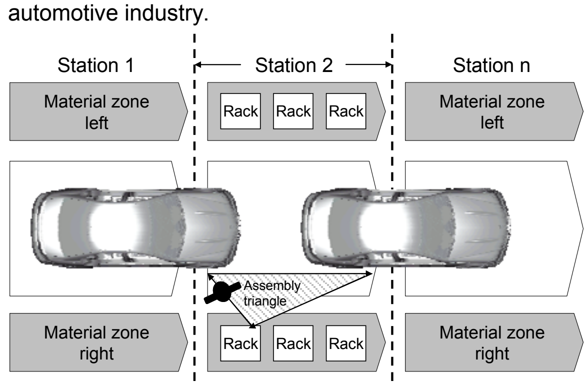

Figure 5: Material zone in final assembly.

Several criteria have to be assured by planning a material zone. For example, the material provisioning in automotive assembly has to take place exactly within the station where the parts are needed.

Further boundary conditions are short worker paths, ergonomic orientation of material for picking up parts, exactly one pick-up point for one part family and finally support the assembly triangle. The assembly triangle shown in Figure 5 represents the idealized worker path within an assembly station.

Beyond those general criteria, there are further specific criteria of assembly and logistics.

4.2 Requirements of Assembly and Logistics

Planning the material zone has lots of constraints resulting from the planning departments and processes.

In general, the assembly planning department generates an operation list on basis of the assembly sequence and the bill of material. In an iterative procedure the assembly operations are assigned to stations until an optimal plan is found. The assembly department is interested in efficient assembly of the product. For that reason the following criteria have to be assured:

- Optimized assembly sequence
- Short worker paths
- Easy and defined pick up of parts
- Faultless pick up (Poka Yoke)
- Ergonomic worker movements and postures
- Short cycle time
- Production oriented product design

The logistic planning department derives material requirements for each station from the operation list in order to work out a supply process. A main aspect is to deliver material to the assembly line in a way that supports the assembly process:

- Pick up-optimized cargo carrier
- Minimal access times
- Optimized space of the material zone
- Short routes
- No packaging materials in the assembly area
- Optimized storage size
- Quantity of transportation
- Minimizing inventories
- Adequate supply process (Just in Time, Just in Sequence)

These criteria will be assured during the phase of production preparation workshops. For virtual validation, models and simulations are needed to assure these criteria in the same way as the phase of physical production preparation does.

5 VIRTUAL VALIDATION OF MATERIAL PROVISIONING IN ASSEMBLY

In case of production preparation, the validation and optimization of material provisioning is only one aspect of many others. The four main topics proposed in chapter 3 also have to be represented in simulation models.

But the material provisioning is not less important because the material zone is one of the most valuable places of an assembly line.

However, during the planning process, different tools are used at different points in time for planning and optimizing the material zone and validating the different specific criteria.

In an iterative process, the assembly department assigns operations to stations of the assembly line. This is the basis for further planning steps in the production planning process. Step by step the plan is detailed out until finally a complete assembly process using models with a high level of detail is developed.

During each planning phase several aspects have to be validated by different models. Starting with 2D planning, the material zone will be more and more detailed.

For the use case production preparation, a workflow for virtual validation is proposed (Figure 6)

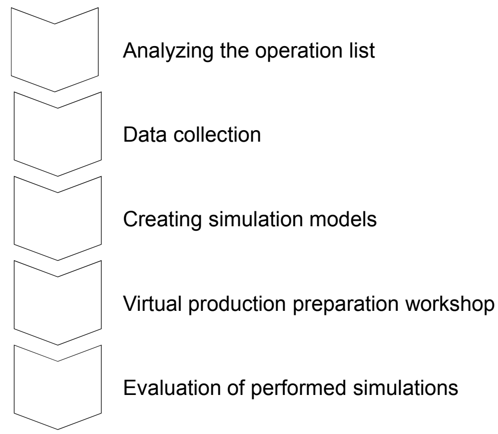

Figure 6: Workflow for validation of virtual production preparation.

Beginning with analysing the operation list, required simulation models will be defined. After that, the data collection takes place. The collected data will be used to create required simulation models, which are necessary to perform a virtual preparation workshop. Finally, the results of the simulations have to be evaluated.

The biggest effort for generating such simulations is the creation of simulation model. The following steps introduce the process of virtual validation of material provisioning in assembly.

5.1 Analyzing the operation list

During each planning phase several aspects have to be validated by different models. Starting with 2D planning, the material zone will be more and more detailed. For the use case production preparation, a model with a high level of detail is needed. To optimize the assembly processes, assembly process simulation is needed. Using assembly process simulation for validation of assembly processes or ergonomic aspects offers the possibility to validate aspects of material zone, as well. To validate assembly operations where flexible parts are used, a simulation model for the simulation of flexible parts is needed. To optimize logistic processes, material flow simulation is required.

The current state of the operation list clarifies, which parts are needed at which station and which tasks have to be performed by the worker. Additionally, parts are linked with cargo carriers. This are required information to set up the right simulation models.

5.2 Data collection

After determining required simulation models, necessary data has to be collected. Starting from the operation list, CAD data of product and factory layout, cargo carriers to human models are needed.

All data will be integrated in different kind of simulations, which have to be prepared. For that, interfaces between used tools are needed, that can handle all relevant information.

5.3 Creating simulation models

Planning a material zone is a cross functional undertaking. Therefore, the simulation models have to support different planning aspects. Additionally the simulation models have to qualify as a decision platform for assembly and logistics.

Creating simulation models is time consuming. Each pick-up, each worker path, each assembly operation has to be modelled. After transforming the collected data in simulation models, the process simulations can be optimized.

For validation of material provisioning, a variety of sequences are needed. Because of different possible locations for cargo carriers within a material zone, worker paths can differ. Hence, various time consuming simulation models have to be prepared. Figure 7 illustrates this point exemplary.

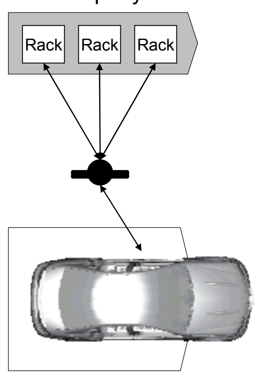

Figure 7: Interface in simulation model of assembly and logistics.

As the Figure 7 shows, there can be lots of possible worker path, depending on which point the cargo carrier is located. Another aspect with numerous possible variants is the pick-up of material (see Figure 8). Each possibility has to be modelled in order to be simulated.

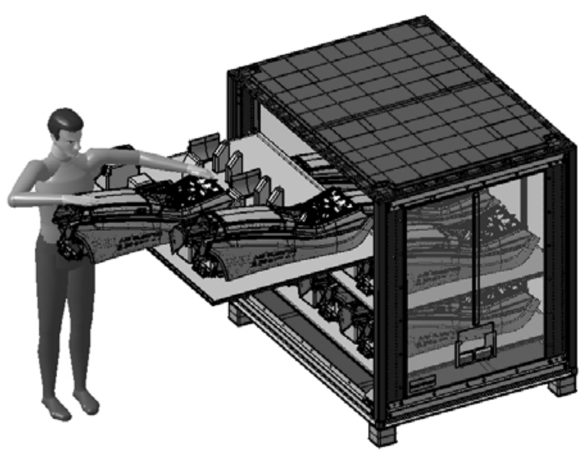

Figure 8: Virtual validation of picking up material.

5.4 Virtual production preparation workshop

The planning departments meet in a workshop for virtual validation of the production ramp-up as well as in real production preparation workshops. Basis for decision making are the different simulation models. This cross-functional approach leads to validate ramp-up criteria virtually.

5.5 Evaluation of performed simulations

The performed simulations have to be evaluated. Each planning department has specific points of view on validation tasks. Defined check lists are used to evaluate the performed simulations. If any criteria cannot be validated through existing simulation models, the models have to be adapted. Furthermore, if any criteria are critical, the planning states have to be updated. This is a iterative procedure.

In case of material provisioning the result is an agreeable material zone for both, assembly and logistic planning departments.

6 CONCLUSION AND OUTLOOK

For virtual validation of material provisioning, several models are needed. Some criteria, e.g. storage sizes, can be validated with low detailed models by using 2D factory layout. Validation tasks with these model requirements are executed without time consuming preparation of models. Other validation tasks like picking up material from cargo carriers need a high level of detail. Therefore lots of model requirements exist. Additionally there is a big effort in generating simulation models.

As the use case illustrates, planning the material zone is a cooperative task of the assembly and logistics planning departments. The interface between these two departments needs a higher level of transparency. Virtual validation of material provisioning seems to be a good approach for improvements in that direction. Virtual models can be used as a decision platform for production planning like Digital Mock-Up (DMU) is used by product engineering.

In summary, the simulation of assembly processes and logistics aspects on material zone is time consuming, but possible. A lot of potential for efficient simulation model preparing is given in partial modelling. Segmenting models in a modular way can lead to efficient model preparation. Hence, further research will focus the efficient model generating.

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