Efficient preparation of digital production validation

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Abstract
In automotive industry, digital production validation promises efficiency and quality improvements that are comparable to those of product validation. However, several departments with different views and objectives have to be involved. In this work, a methodology for preparing production validations is proposed. It classifies operations and assigns validation objectives and methods to each class. Model requirements are derived from each validation method. Thereby, one holistic digital validation model with differently detailed operations is generated. The methodology is applied to power-train assembly. While it is efficient for requirement definition, a validation tool independent data base is required for full modeling advantage.

Keywords:
Factory and production planning, Digital planning validation, Cross-functional planning validation

1 INTRODUCTION

Digital methods for validation of product and production are well established in automotive industry [1]. Digital validation methods increase product quality and improve process model quality.

In product engineering, many validation tasks, such as digital mock-up (DMU), mixed mock-up [2] or digital screw-validation [3] employ digital models for efficiency [4] and improve product quality.

Digital production validation promises similar effects for the production process.

For complex production processes such as automobile assembly, integration of several planning departments such as production logistics is required for increasing efficiency by production validation [5]. Additional benefits such as reduced commissioning and quality cost may be realized by this integration. Therefore, it is necessary to identify all relevant criteria in product and production.

In this work, a methodology for preparation of cross-functional digital production planning validation tasks is proposed. An application presented for an example of power train assembly is presented.

Power train assembly is part of the car production process. Normally, car production is described as starting in press shops, where basic sheet metals are formed. Next, those parts are welded together in body shops to create car bodies that subsequently reach paint shops. After painting, the car bodies run through assembly lines, where interior and exterior parts are installed. While the just illustrated assembly actions take place in one location, the assembly of power trains is usually situated in a separate area. The power train assemblies join the main process at the so-called marriage of vehicle body and power train.

Figure 1 illustrates a general overview of the different manufacturing areas in automotive industry. Each production planning process is a cross-functional discipline, for example the logistic department is involved in all manufacturing processes.

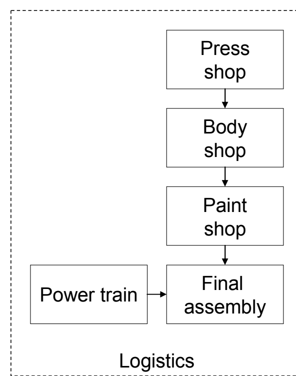

Figure 1: Manufacturing areas in automotive industry.

Therefore, the following departments have to be involved in cross-functional digital production validation:

- Product development
- Body in White planning
- Factory Layout planning
- Logistics
- Assembly planning

2 DIGITAL PRODUCTION PLANNING VALIDATION

In general, digital production planning validation assumes that a planned process meets a set of criteria. Improving planning processes by means of validation results increases the level of confidence in the planned process for being successfully implementable in reality. In comparison to conventional production validation, that is based on physical prototypes, digital production validation employs digital models and simulations. These digital models can be made available earlier in the planning process. This procedure is called front loading. Early availability of validation results allows implementing process changes at lower cost and with a less challenging time frame. Therefore, digital validation of production processes and planning states can lead to higher planning quality, better product quality and less errors during ramp up.

In literature, there is a rich variety of validation methodologies for specific process aspects such as automation of robot cells, material flow, validation of assembly processes, assessment of ergonomic aspects based on digital methods for human operations [6], production oriented product validation [7] or virtual commissioning [8]. While these methodologies focus on single validation tasks, possibilities and limits of digital production validation for assembly ramp up are described in [9]. Thereafter, production validation tasks are more heterogeneous in functionally organized planning departments. Each planning department has specific views on validation tasks, which are expressed by different validation objectives, criteria, methods and tools.

While substantial effort is put into validation of each department's planning results, cross-functional interfaces lead to planning errors that cannot be systematically addressed using digital models for front-loading. In order to early unveil these planning errors at the interfaces between departments, validation results have to be made comparable. An essential prerequisite for this task is to gain a common understanding, which validation objectives have to be validated at which level of detail by whom at which point in time [10]. For this organizational synchronization, a common digital model of the process would be beneficial. However, increasing model complexity for the whole process is still prohibitive considering both computational limitations and model generation effort.

In order to reduce model complexity, the digital model that is used for process validation is proposed to be detailed only where processes are present, which justify the effort. Since different views form the basis for validation objectives and methodologies, they form the first step for the digital production validation methodology that is presented in this work.

2.1 Specific views on validation tasks

As mentioned in the previous chapter, production planning is a heterogeneous and cross-functional discipline. Each planning department has specific points of view on planning tasks and their validation results (Figure 2).

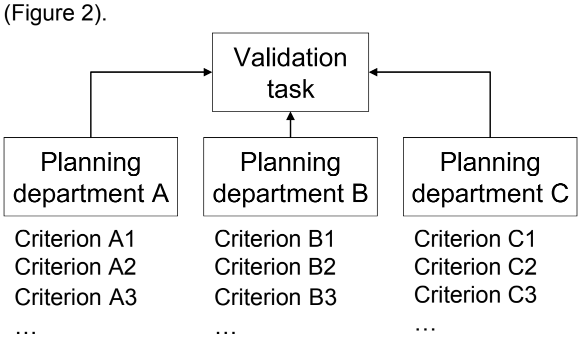

Figure 2: Specific points of view on validation tasks.

The challenges of preparing cross-functional validation tasks are to indentify relevant criteria that should be validated as well as to select the best adequate validation methods. An additional point is that the departments are normally each responsible for their own validations. Therefore, reconciliation of interests on validation tasks is necessary to avoid extra work and to use synergies.

There is a considerable number of criteria in production planning. Wack *et al.* propose a shell model for identifying criteria for validation of the ramp-up process [8]. The following list introduces general criteria in relation to validation tasks and planning results grouped by planning department. Note that the body shop is out of scope of this work and therefore has not been addressed.

Product development:

- Assemblability of product
- Collision free product
- Process adequacy of tolerance model

Factory layout planning:

- Available space
- Routes
- Infrastructure

Logistics:

- Material provisioning
- Cargo carriers
- Supply processes

Assembly planning:

- Sequence of assembly
- Cycle time
- Assembly time
- Ergonomic aspects
- Assembly line balancing
- Worker paths

The general aspects on the above-stated validation tasks in production planning will be detailed in case of digital screw-validation (Figure 3).

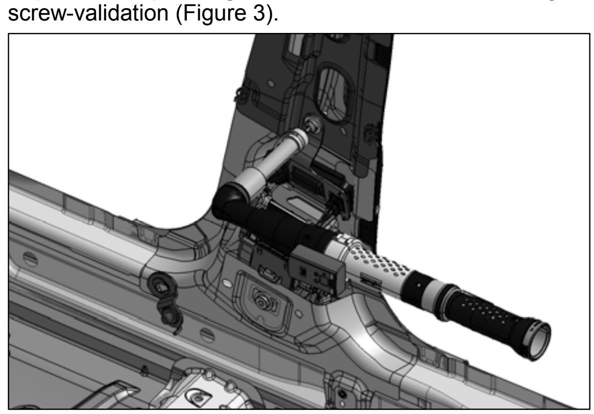

Figure 3: Accessibility of screw tools.

Screw validation contains different criteria of planning departments (Figure 4). The assembly department is interested in assuring accessibility of screwing locations for workers, fast and faultless pick up of screws via Poka-Yoke solutions and an easy access with standardized tools.

In logistics, questions such as kind of material provisioning and cargo carriers have to be answered. The product development wants to validate the type of screws, torque and finally collision free parts and assemblability of the whole product.

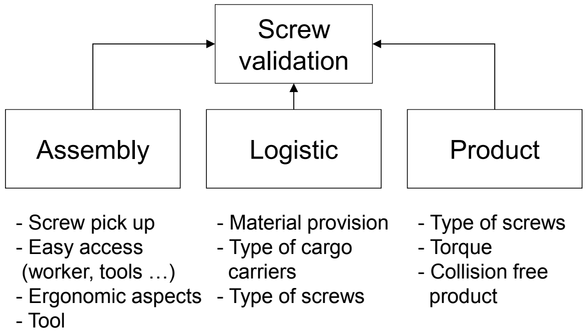

Figure 4: Specific points of view on validation task screw-validation.

2.2 Operation List

A complete list of all assembly operations is created during the production planning process. An excerpt of an operation list is illustrated in Table 1. The assembly operations are described concisely, aiming at a common understanding for all planning departments listed in chapter 2.1.

It is the duty of the assembly planning department to detail out the so-called operation list on basis of an assembly sequence and a bill of material.

Each operation is assigned to a station of the prospective assembly line. In an iterative procedure, the assembly operations are reallocated until an optimal plan is found. The most common term used for this assignment is assembly line balancing (ALB). It is also executed by the assembly planning department.

The product planning department examines the operation list to evaluate production-oriented product design.

The logistic planning department derives material requirements of each station from the operation list in order to work out a concept of material provisioning. Physical mock-up (PMU) as well as digital mock-up (DMU) workshops use the operation list. The operation list is checked point by point to assure efficiency of the current planning state.

Throughout those procedures, specific planning validations of the planning departments are conducted.

In summary, the operation list describes the whole assembly line and is indispensable for the planning departments.

STATION	NO.	OPERATION
5	1	Push engine block along roller conveyor to detent
5	⋮	⋮
5	5	Lock engine block at front side with pin
5	⋮	⋮
5	10	Release engine block at front side
5	⋮	⋮
5	19	Pre-screw four M14-screws at adaptor
5	20	Tighten four screws with impact wrench
5	⋮	⋮
5	32	Make entry in route sheet
5	⋮	⋮
5	34	Press release button
5	⋮	⋮
5	36	Go back to beginning of station

Table 1: Excerpt of an operation list of one station.

Figure 5 shows the assembly operation no. 20 “Tightening of screws“ of the operation list which is illustrated in Table 1. Using an impact wrench, four screws are tightened in order to mount an adaptor to an engine block.

Figure 5: Assembly operation “tightening of screws”.

3 PREPERATION OF DIGITAL PRODUCTION VALIDATION

Preparing cross-functional digital production validation tasks is a time consuming undertaking. Considerable efforts are needed for data collection and building simulation models. Cross-functional planning validation tasks have to be identified and prepared. Normally, the planning departments meet in workshops at defined points in the process for holistic validation of the current planning state.

In contrast to physical production validation, which is based on prototypes, digital production validation employs digital models of the manufacturing process for validation of production plans. However, modeling each process step in a way that is sufficiently comprehensive and detailed for each possible validation method has proven too time consuming for efficient digital production validation. Therefore, the degree of model detail has to be minimized for each operation.

In order to determine a minimum level of model detail, validation objectives and validation methods have to be derived systematically. The methodology that is proposed in this work is based on the fact that in most cases validation objectives are dependent on the production method that is employed in the operation. These production methods are categorised. Each category is mapped on a set of validation objectives (s. Figure 6) which easily can be associated with adequate validation methods.

In a first step, each operation that contains more than one verb (task) is split up into one-verb operations. Next, similar activities are mapped onto a classification scheme. This classification scheme follows DIN 8580 ff. [11] (s. Figure 8) for value-adding operations and DIN-EN 1005-5 Appendix A [12] for material handling operations. These standardized operation categories are accompanied by the two auxiliary in-process operation categories “Testing” and “Documenting” (c. Figure 7).

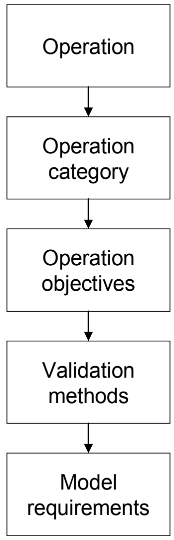

Figure 6: Methodology for determining model requirements.

A set of validation objectives is defined for each operation class that contains at least one operation. For each objective, a set of validation methodologies and validation tools is established. These validation methodology sets constitute model requirements for the assembly operations. Since the operation classes form a hierarchy, different levels of planning detail can be identified. DIN 8580 defines a production method hierarchy, which the operation classes follow (Figure 8).

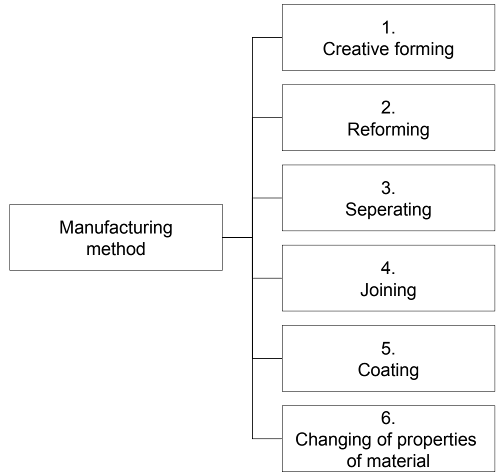

Figure 8: DIN 8580 classification of manufacturing methods [11].

In this tree, operation class "4. Joining" is on a higher level and therefore more abstract than operation class "4.3.1 Screwing". Validation objectives on higher levels always comprise questioning if the planning level of the operation is detailed enough for the current stage of the planning process. Detail validation objectives such as tool collision freeness appear only for low level operation classes.

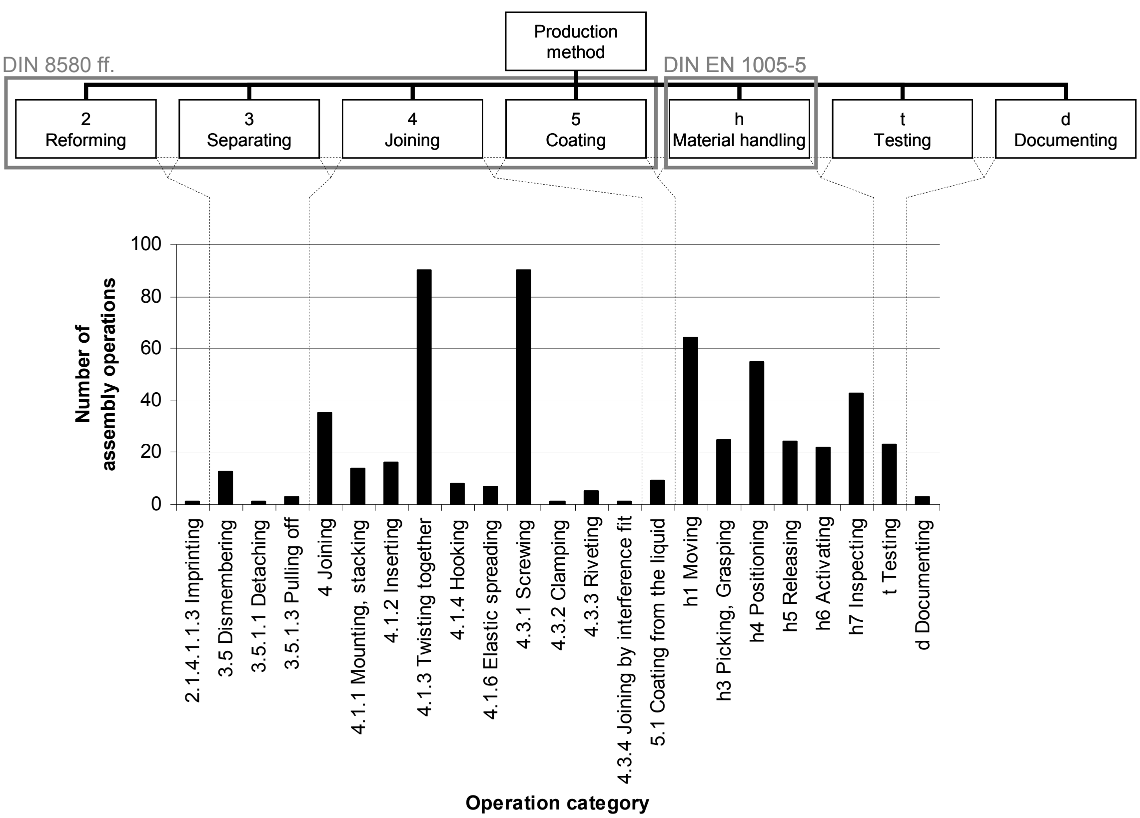

Figure 7: Operation classes and their frequency in the power train assembly use case.

4 PRODUCTION VALIDATION PREPARATION FOR FINAL ASSEMBLY OF POWER TRAINS

The preparation methodology has been applied to a newly planned line in final assembly of power trains.

The operation list comprises 501 operations with 81 different verbs and verb combinations. After splitting up the combined verbs and joining synonyms, 52 verbs are identified. These verbs are categorized into 15 value-adding categories, 6 material handling categories and the two auxiliary operation categories testing and documenting (compare Figure 7).

Considering the frequency of operation type classes, “4.1.3 Twisting together” and “4.3.1 Screwing” predominate with 90 operations each. Considering value adding tasks, they are followed by the more abstract class “4. Joining” with 35 occurrences. Material handling task classes sum up to 233 occurrences. Auxiliary operations are planned in 26 operations.

In order to illustrate the process of objective forming, methodology derivation and model requirement setup, the category “4.3.1 Screwing” is presented in more detail.

4.1 Detailed description of objectives and related validation methods

After grouping operations in operation classes, objectives from different planning departments can be defined. Figure 9 illustrates four objectives of assembly department, product development and logistic department for the operation class “screwing”. The four presented objectives can be assured by three validation methods: Digital screw validation, assembly process simulation and material flow simulation.

4.2 Validation model requirements

Requirements of validation models differ from criteria that should be validated. The required level of detail of the model increases with depth of the category tree.

The operation “Tightening of screws” for example can be placed in the category “screwing” which has the four following criteria: Accessibility of tools, collision free product, provision of material and ergonomic aspects.

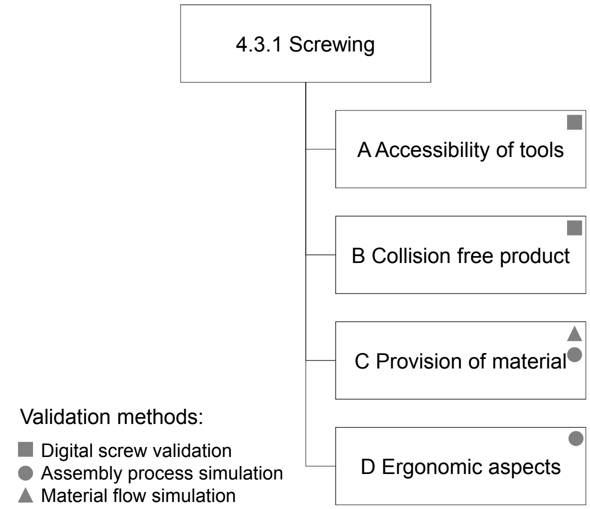

Figure 9: Mapping validation criteria and validation method.

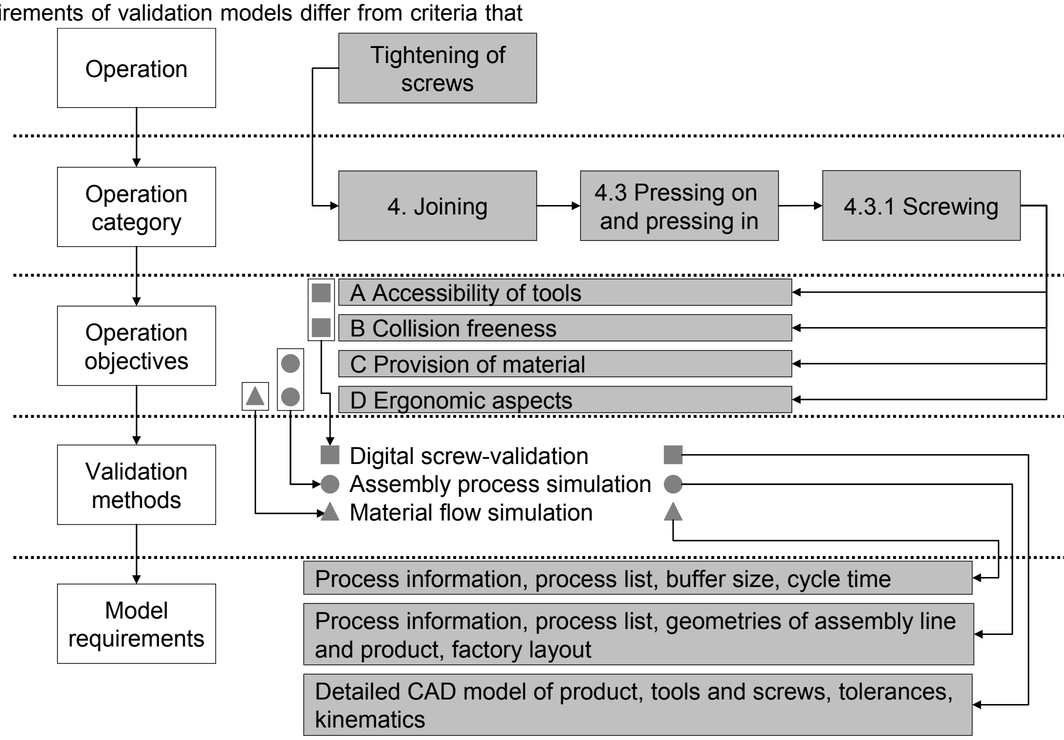

Figure 10: Detailed use case “tightening of screws“.

These four criteria require a detailed model for validation. In case of accessibility of tools, Computer Aided Design (CAD) data of product, tools and information about tolerance are required. An exemplary application of the proposed methodology is shown for the operation “tightening of screws” in Figure 10.

5 DISCUSSION

The application of the proposed methodology shows, that “Twisting together” and “screwing” are the most frequently operations in the operation list. About 180 operations have detailed objectives and also need a validation model with high level of detail.

However, nearly 40% of operations are affected by detailed model requirements. Automating the preparation of these validation models as well as automating the validation itself is expected to further reduce modeling time.

Derivation of operation verbs remains a difficult and time consuming manual process. Difficulties are caused by different naming conventions for operations, different languages and typographical errors in operation descriptions. These issues are being counteracted by standardizing operation descriptions.

Furthermore, the quality of digital validation models depends on which time in the planning process the validation should be performed. In early planning phases, detail information is not available. The point in time is an important aspect by planning validation. Adapting the methodology under consideration of time aspects will be part of future work.

6 SUMMARY

The presented methodology for preparing cross-functional production planning validations has been proven to be practically applicable for power train assembly. The use case clarifies that there is additional efficiency potential. The employed classification enables grouping most actions and makes cross-functional definitions of validation tasks and model requirements possible. Criteria of involved departments can be easily identified and assigned to modeling effort.

There is a lot of efficiency potential by combining modeling efforts across different parts of the tool-chain. Additional benefits can be gained by automating frequent validation tasks such as screw accessibility. Such integration requires one holistic data base that provides the data for at least most of the validation tools.

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