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# Approach for a standardized database regarding tolerance analysis in automotive industry

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**Abstract**
The focus of this paper is an approach which ensures that all the necessary information to build-up a tolerance analysis model is digitally available in the development process. Since tolerance management is a cross functional discipline, the data sources for tolerance simulation models are often inhomogeneous. In large-scaled enterprises like automotive industries the information is normally created, used and stored by several departments in the company. In order to grant accessibility, large-scaled industries are advised to install PDM-systems. Yet these systems are often focused on storing product information and do not provide satisfying solutions for production development information. This approach specifically focuses on the storage of information relevant for production. It considers other disciplines and aims at fitting smoothly into all disciplines involved in the development process like production development, change management or quality management.

***Keywords: Tolerance analysis, automation, development process***

## 1 Introduction

Manufacturers are committed to provide the highest possible product quality to the final consumer at acceptable costs. This drives beyond rigorous quality management to specifying product tolerances in the right manner at an early stage of the development process, where no physical data exists. Tight tolerances lead to high costs, whereas large tolerances can decrease the final product quality right up to a total loss on functionality. Therefore, statistical 3D-tolerance analysis tools offer possibilities to find a reasonable compromise in order to fulfil the functional aspects as well as the manufacturing requirements.
To create tolerance analysis models, different information is used. The information can be distinguished between product related information (such as component parts and tolerance information) and manufacturing process related product information (such as assembly graphs, fixture and clamp concepts, joining locations and measurement points). The storage of this information is fulfilled by several systems in different formats due to various

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requirements towards the data and also various responsibilities of the data producers. Due to this, there is yet no possibility to automate the tolerance simulation model build-up process. Hence the key component of the proposed approach in this paper is to provide a solution for dataflow between the two development processes of product-/ and production-development in the operative business (e.g. automotive industries) to successfully establish cross functional disciplines like tolerance management.

## 2 State of the art

In large scaled enterprises, PDM-systems are usually used to ensure a centralized data management for the product related development information [1]. The PDM-system is an indispensable tool to enable a cross enterprise engineering solution [2]. This chapter shows the current state of the art of storing product related information in PDM-systems. Furtheremore the approaches of storing manufacturing process related data (production development data) in PLM-systems are shown, which are broadly based, taking the whole product lifecycle into account [3]. Additional the builp-up process of tolerance simulation models is shown based on examples out of the automotive industry. This indicates the relationship of the different development information out of PDM-/ PLM-systems to create a tolerance analysis model.

### 2.1 Storage of product relevant data in PDM-systems

Today the PDM-system usually forms the backbone of data management in product development process. There is meanwhile a very extensive literature for the usage of PDM-systems in development-/ and designing-tasks [1, 4-7]. Looking at the available PDM-systems on the market the orientation for these tasks is getting more obvious. The focus of these systems lies in organizing product master data, documents for product development data and on categorizing data (1 in figure 1) [8]. The implementation of configuration-/ and project-management, publishing data and also backup functionality is an exception in today's systems [4]. The main reason is the PDM-systems history. With the implementation of 3D-product development in CAD environment it was getting inevitable to enable a global accessibility for the product development data in an enterprise spanning database [1]. Figure 1 shows the PDM-system (interlinked with CAx-systems which provide product related information to build-up CAT-simulation) in context of the product development process (3 in figure 1) [9].

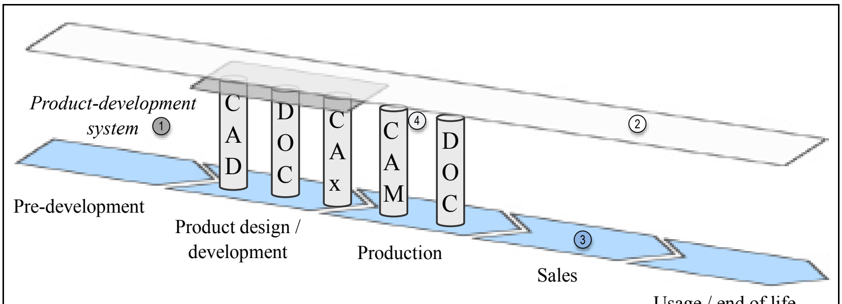


Figure 1 PDM in context of the product development process based on [9]

The missing storage of e.g. production relevant product data in this PDM-backbone approach can be detected (4 in figure 1). That is one reason why more domain spanning approaches are existing (PLM-approach).

### 2.2 Storage of production relevant product data in PLM-systems

To successfully launch a product in todays' market situation it is getting more and more necessary to decrease the product development time, this is the only way to increase cost-efficiency and remain competitive. Therefore simulation tools are an indispensable tool [10, 11]. These simulation tools are not only regarding the product itself (e.g. FEM, CFD), but also the product production process (e.g. CAM, CAT, etc.). As a consequence the amount of data which is used in- or as a simulation result is getting bigger and bigger. As mentioned in [1, 4] more domain spanning approaches are coming up especially in automotive and aeronautic industries to ensure a smooth interlinking (2 in figure 1). The term „product development" (which focuses mainly on the product) is getting more and more replaced by „product lifecycle management" (PLM) (taking the whole product development process into account). Figure 1 also shows the PLM approach in context of the product development process [9].

### 2.3 Production system development in context of PDM-systems

To be competitive on the market it is inevitable to grant a domain spanning accessibility of product-/ and production-development information in all fields of activities in a company over the whole lifecycle [3, 12]. Today the usage of a PDM-backbone with regards to production development is more or less pronounced. This is motivated by the different approaches regarding the development of production systems. Partly the development information for these production system is directly stored in the OEM's PDM-system by the supplier. Normally this is the case, if it is a requirement by the client (OEM) [7]. At the same time there are cases without a report / storage of the development information in the OEM's PDM-system [13]. Often the suppliers' widespread contract portfolio would require massive investments (e.g. licensing costs) to ensure the support of different OEM specific PDM-systems.

Figure 2 shows the implementation of PDM-/, PLM-solutions in context of the production lifecycle.

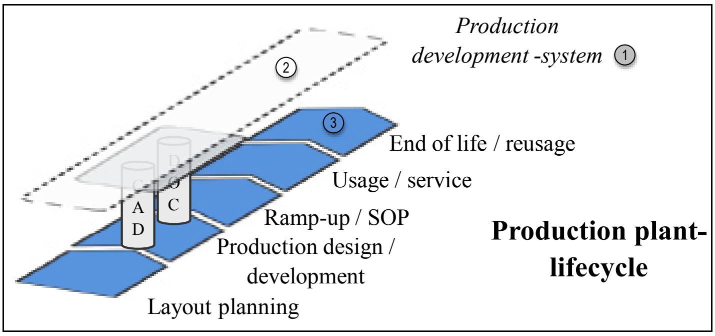


Figure 2 Production development in context of the production lifecycle

### 2.4 CAT-specific data

To build-up a tolerance analysis model a multitude of information is required. The process to set up a specific tolerance simulation is the following [14, 15]. At first the scope of data to be verified has to be brought to the CAT-software. The next step is to define the correct assembly graph of parts among each other, as well as the production plant (fixture of the parts). Furthermore faces, holes, etc. of parts being part of the created tolerance chain have to be specified with datum targets or tolerance information. The final step to set up the tolerance simulation is to define the quality feature (e.g. a gap measurement in automotive industries). To run the simulation, it is necessary to set several parameters in the tolerance simulation software (e.g. GD&T standard, cycle of runs, etc.).

By analyzing the different types of information, one can distinguish between product development information and product related production development information. [16] summarizes the dependencies and relations between the different data in one graph and can be extended as depicted in figure 3.

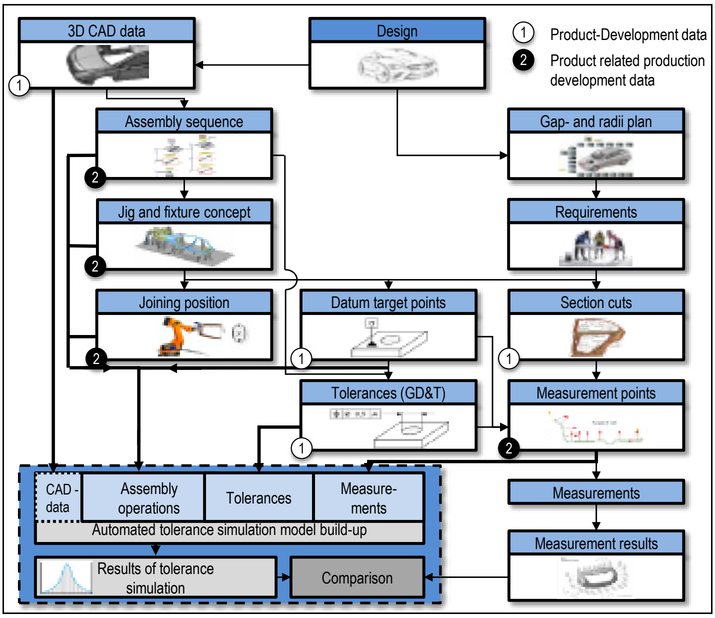


Figure 3 Dependencies and relations of classified input data for tolerance simulation model based on [16]

Based on the results of the tolerance analysis the different kind of data can be optimized (tolerance simulation in the loop) to fulfill the multilayered requirements.

# 3 Deficits in the operative business

As mentioned before, in order to build-up a tolerance analysis model a multitude of different information is needed. For domain-spanning development tasks (e.g. tolerance management, change management) this means that information from both processes has to be provided. Currently the technical literature on this topic draws solutions to grant a dataflow between the two processes and approaches to successfully establish cross domain development tasks (chapter 2.1-2.3). Also the software available on the market ensures a linkage of the development processes. Yet, in practice it remains difficult to install enterprise spanning PDM-solutions. This is due to several reasons which are discussed as organizational / methodical and technical aspects.

## 3.1 Deficits due to organizational / methodical aspects

The development of a product in comparison with the development of the production plant behooves in large scaled enterprises like automotive, aeronautic industries several departments. This results in various efforts in installing a common database across all cooperation departments. Rather, the organizational cut of departments leads to self-contained partial solutions. These solutions suggest, when regarded isolated, a well-running process. There is also the fact that over the years a domain specific software solution has been grown. These well implemented solutions often cause a lot of effort to adapt them on commercially available PDM-solutions. Furthermore the adaption of an “out of the box” PDM-solution requires investments and results in interferences in well-running processes. This bears a serious risk on current ongoing projects.

### 3.2 Technical deficits caused by the PDM-systems history

As mentioned in chapter 2.1 the focus of PDM-systems is the storage and provision of development data. Thus, development specific requirements are often mapped insufficient and data is provided in a format, which can hardly be used in follow-up processes. The implementation of different views in PDM-systems provides an example for this (product view, assembly graph view, etc.) [17].

Transferring data between different CAx-tools in PDM-systems always leads to a loss of information. Standardized data-formats like STEP or JT enable a transfer with minimal loss of information between common CAx-tools [18, 19]. For specific CAx-tools like CAT current software solutions do not provide a system independent exchange format [16].

Management of documents is well-implemented in current PDM-solutions. Information stored in these documents often is not available in follow-up processes, due to documents' format (PDF, etc.). As a consequence these data sinks lead to additional expenses.

### 3.3 Derived deficits for tolerance management issues

Concerning tolerance management there are several deficits which are often related to organizational / methodical and technical aspects. Today the automated build-up process for tolerance analysis models is complicated due to missing interfaces from CAD-systems to specific CAT-systems allowing the exchange of data in a platform independent solution (e.g. XML) [16]. Furthermore for a correct build-up of the tolerance simulation model the assembly sequence of the parts in the manufacturing plant is needed. As mentioned before todays' PDM-systems do not provide satisfactory solutions to organize different kind of views. Hence the required manufacturing sequence is often stored in documents (e.g. PDF) which cannot be integrated in follow-up processes, contributing to complicating an automized simulation model build-up process. Additional, for quality management issues the assembly graph is required. Measurement points for specific assembly levels (containing the specific tolerance values of the assembly level) are stored in separate "measurement"-databases which are more or less similar to the assembly graph. Regarding quality management the requirements for an assembly graph does come up in a proceeded product development stage (hardware prototype phase). This means the reconstructed manufacturing view in specific "measurement"-database cannot be used in an early development stage where tolerance simulation normally is performed.

## 4 Approach to stamp out the deficits in the operative business

In the operative business a domain spanning PLM-solution combining product-/ and production development can hardly be implemented. Thus a solution is drawn, to adapt existing PDM-solutions to requirements derived from domain-spanning development tasks like tolerance management.

### 4.1 General approach

On the one hand, the cut down of development time leads to a more and more pronounced simultaneous engineering between product-/ and production development. As a result the usage of common databases can be increased. These databases are accessible for product development engineers as well as production development engineers (see step 1 in figure 4). On the other hand, product related production development information has to be stored in the product development PDM-system. This shifting of production development data is caused by the strong dependency to the product development data (e.g. joining elements, assembly

graph, measurement points, etc.) (see step 2 in figure 4). It must be ensured, that the information is completely interchangeable between the development environments (see step 3 in figure 4). The shifting of data may also require a modeling of additional information early in the development process in the domain foreign development environment. Then at the appropriated time these information are downstreamed to the production development process.
By implementing specific interfaces for domain specific development tasks (e.g. tolerance management, change management), furthermore a smooth data exchange can be guaranteed. Figure 4 summarizes the explained approaches.

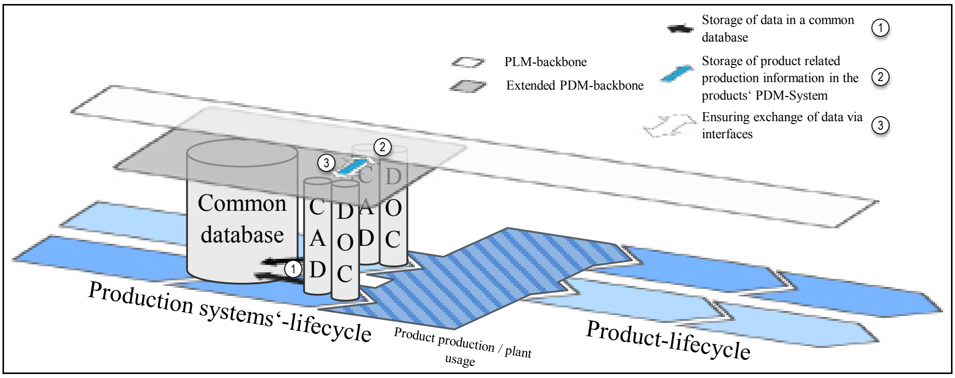


Figure 4 Domain spanning approach for product-7 and production development in context of the product, production lifecycle

### 4.2 Requirements for the product related production development data regarding tolerance management development tasks

The majority of targets concerning tolerance management are product-related (narrow gaps, enabling functionality of components). Thus, organizational the domain-spanning development task is often attached to the product development process. In operative business this alignment leads to requirement affecting product-related production information.
The assembly graph is the fundament for storing production development data in PDM-systems (chapter 4.1.1). On this basis further production development data can be stored (chapter 4.1.2).

#### *4.2.1 Approach to store the assembly graph in the product development environment*

The problem for an implementation of the assembly graph often is a very deep nesting (containing lots of development data). Handling these structures leads to performance problems. The product view avoids these performance issues by organizing the content in specific modules (see 1 in figure 5). In addition the top level assemblies are often not related to the sublevel parts and assemblies (see 2 in figure 5). Thus the product view is not able to be transferred into the assembly graph view.
The solution for storing the assembly graph based on the manageable product view is to insert jig- and fixture data[1] in assemblies of the product development environment (e.g. as a separate part; see 3 in figure 5). Beside the product related production development information (of the jig- and fixture concept) an additional attribute has to be implemented. This attribute stores parts and subassemblies which are assembled in a specific manufacturing step (jig- and fixture scope) to a higher level assembly (see 4 in figure 5). Furthermore an attribute is

[1] Jig- and fixture concept: contains the description of fixture, alignment and orientation of parts in a specific manufacturing station

needed to manage the hierarchy of several jig- and fixture parts in a specific assembly scope (see 5 in figure 5). Based on this additional information it is possible to create a rooted tree structure which corresponds to the assembly graph. To stamp out performance issues in handling this structure, it is possible to save the assembly graph (for a specific product configuration) separately in an XML-file. Figure 5 shows the considered approach for creating the assembly graph based on the product view (using additional attributes in the CAD-environment).

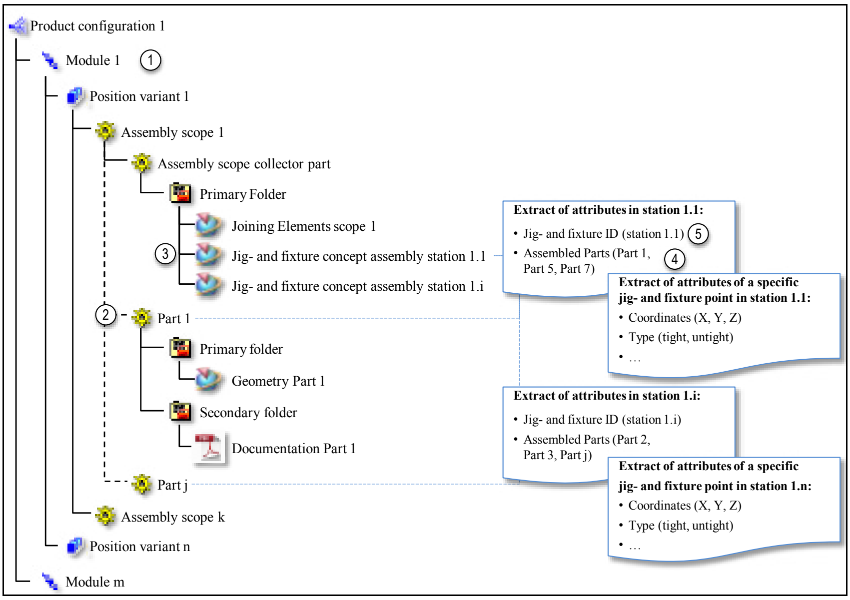

Figure 5 Approach for storing the assembly graph in PDM-systems

### *4.2.2 Approach to store further product related production development data in the product development environment*

*Requirements concerning the jig- and fixture concept:*
Based on the assembly graph stored in the product view there are several opportunities to store further development data. Regarding tolerance simulation it is necessary to know the order of parts and subassemblies assembled in the specific scope. Thus a further attribute has to be stored in the jig- and fixture concept (Attribute: *Part order*).

*Requirements concerning the joining elements:*
To ensure correct assembling of the parts in tolerance simulation software, it is necessary to store a further attribute "*joining partner*" in the joining elements. Based on this attribute it is also possible to detect the number of joining elements in each manufacturing step (specific jig- and fixture scope)[2].
Along with this information the following information is typically stored in joining elements:

- Joining ID
- Operating direction of the joining element
- Coordinates of the joining element

[2] The assembly graph is known. Thus the single parts (and subassemblies) are linked to a specific jig-and fixture scope. Having the additional attribute "*joining partner*" the joining elements are linked to the single parts. Thus the joining elements are also linked to the specific jig- and fixture scope.

*Requirements concerning measurement points:*
For measurement points tolerance analysis software also requires some additional information beside the simple point information (*coordinates*, *direction, etc.*). For example the measurement point should carry an attribute like *"tolerance information"*. This attribute stores the tolerance ranges for the specific assembly level which the measurement point is valid for. Furthermore the "*methodology of measurement*" (tangent, curvature, grid-parallel) has to be stored in an additional attribute.

Figure 6 summarizes the requirements to store product related production development information in the products' PDM-system to successfully handle tolerance management development tasks.

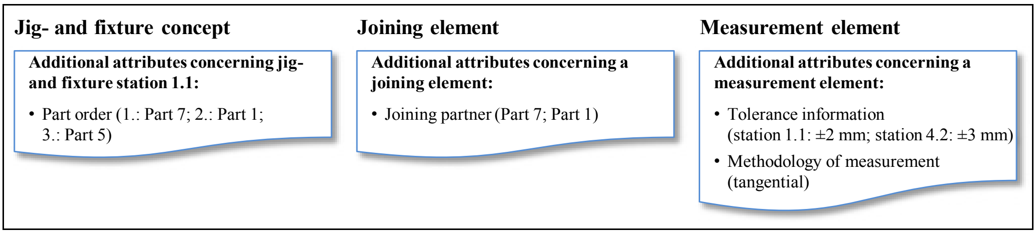

Figure 6 Requirements for additional attributes to store product related production development information

## 5 Integration into other disciplines besides tolerance management

The discussed approach enables documentation of the assembly sequence in PDM-systems for product development, allowing to create automated CAT, consequently affecting other domain spanning technologies. In order to ensure the implementation of the approach, the impacts of two examples, change management and quality management, are shown.

### 5.1 Change management

Considering product change management the approach does not really affect product development since there are no depending constructive processes. However taking a look at production development, there are a lot of opportunities considering change management and few open questions.
On the one hand documentation of relevant production development data in product PDM-systems and their availability for other users, e.g. external suppliers has to be regulated. To avoid further data sinks direct data-access is inevitable.
On the other hand the approach simplifies the determination of changes in the assembly graph. In addition, the assembly graph in combination with the available number of joining elements on each manufacturing steps (jig- and fixture scope) offers a major simplification. A statement can be derived, how e.g. changes in the number of joining element impacts on the manufacturing plant or the cycle time. The result could be a cut down of evaluation time concerning changes.

### 5.2 Quality management

Regarding quality management the storage of the assembly sequence in product view offers several opportunities. As mentioned before quality management reconstructs the assembly sequence in a separate database to store their measurement results in the right order. The considered approach for the storage of the assembly sequence now enables the storage of measurement results directly in the related assembly scope e.g. an excel report in the

secondary folder. Thus measurement results for series production process would be centrally available in the development environment.
Taking again tolerance management tasks into account the build-up process of tolerance simulation models based on measurement data could easily be implemented.
Furthermore the additional attribute "*methodology of measurement*" allows for a simplification of the determination of required measurement machines.

## 6 Conclusion and Outlook

This paper presented a novel approach to store tolerance management relevant production development information in the product development environment. Especially the fundament of the production development information (the assembly graph) is considered. In conclusion the approach shows a simple way to implement the assembly graph in the existing product view of the products' PDM-system. Only few changes are required (jig- and fixture attribute: assembled parts) to ensure the feasibility. The approach enables furthermore the storage of additional product related production development information. Thus other cross domain spanning departments like change management or quality management benefit from the effort. Future work allows considering the whole development process (starting with conceptual models up till product production process) with regards to tolerance management targets. For example an automated tolerance analysis model build-up process which includes measurement result data for deviating single parts (instead of random numbers for permitted single parts tolerance ranges).

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