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ASSEMBLY TIME ESTIMATION BASED ON PRODUCT ASSEMBLY INFORMATION

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Keywords: product assembly information, assembly time estimation, product design, assembly planning, data exchange

1. Introduction and Motivation

It is not a secret, that globalisation raises competition between companies from different countries. The products from industrial countries must attract customers, because they are not as cheap as products from low-wage countries. To stay competitive, the expensive products from high-wage countries must have better quality, reliability, more functions, must be newer, etc. For this reason the designer needs more time and resources to create such a product, but time as well as resources are rare assets for most companies. In recent years time-to-market became even shorter, e.g. development cycles in the automotive industry used to be about seven years but lately such a cycle is reduced to only five years. This is one of the reasons why products mature at the customer [Drath 2010].

To reduce the product costs and production time it must be analysed where they are determined and arise. In literature the following allocation can often be found: the design department determines about 60-80 % and consumes about 10 % of the costs. Production determines about 10 % and consumes about 70 % of the costs.

The overall production time is divided into 53% for assembly and 47% for the rest [Dudic 2010]. Other departments are responsible for the remaining costs and time [VDI 2235 1987], [Nißl 2006], [Lotter and Wiendahl 2006], [Weber 2011]. This means that the highest potentials for cost optimisation are placed in the development and production departments or between them.

The main challenge is up to the designer who determines the biggest part of theproduction costs and time, although designers are hardly aware of this task. Their main task is to fulfil design requirements like form, fit and function while production relevant properties are rather abstract terms. Specifications require the design of a part or assembly, which costs x € and must be manufactured or assembled in y seconds. Though a designers can rarely satisfy these requirements without experience in production. Designers need more information from other departments, amongst others from process planning, but they often do not get this information. A major reason for this lack of cooperation is the mental and structural “wall” between development and production [Eigner et al. 2013a]. To reduce time-to-market and increase quality it is important that design and production departments work together and share their information during the whole Product Development Process (PDP).

This paper presents a concept and prototype, which improves information exchange between development and assembly planning. It extends our previous concept regarding bimetallic corrosion [Eigner et al. 2013a]. The example of information exchange is based on MTM’s ProKon method, the CAD tool PTC Creo and a CAD model from KHS GmbH, an international manufacturer of filling and packaging equipment for the beverage, food and non-food sectors.

2. State of the Art

The second chapter describes the methodical basis for the paper. At first the methodical gap between engineering and manufacturing is located while the next two sub chapters show the methods which can help to reduce the previously detected gap.

2.1 PDP Models

Most classical product development processes (PDP) as in [VDI 2221 1993], [French 1999] and [Pahl et al. 2006] are linear, because they are made up of different stages and only at the end of the previous stage the next one can start. Iterations are possible, but the main drawback of linear processes remains since the information exchange is placed at the end of each phase. The disadvantage of these PDPs is a late detection of possible design faults, with each detection in a late stage of the PDP causing high change costs [Eigner and Stelzer 2009]. To reduce this disadvantage the PDP-models in [Andreasen and Hein 1987], [Ehrlenspiel 2009] and [Ponn and Lindemann 2011] suggest to place the phases in parallel or overlapping, simultaneous and concurrent engineering being the keywords here. These PDPs allow earlier information exchange between different domains. VDI 2206 [2004] actually goes one step further. The V-model for mechatronic products has a global cycle and each step in this cycle has many further iterative steps. For each function it has to be proved, whether the requirements are fulfilled, but it does not describe any details regarding the amount and time of the data exchange.

As shown, there are some PDP-concepts which allow for an earlier exchange and use of information. Additionally the theoretical concepts mentioned before can be supported by computer aided PDP. The speed advantage through computer aided design in product development is shown in Figure 1. Existing PLM solutions can support PDP through storage and access of product requirements, CAD models, BOMs etc. for every domain. During the design phase the created data should be assessed by their respective domain to find a potential for optimization, preferably in an early phase [Damjanovic 2013].

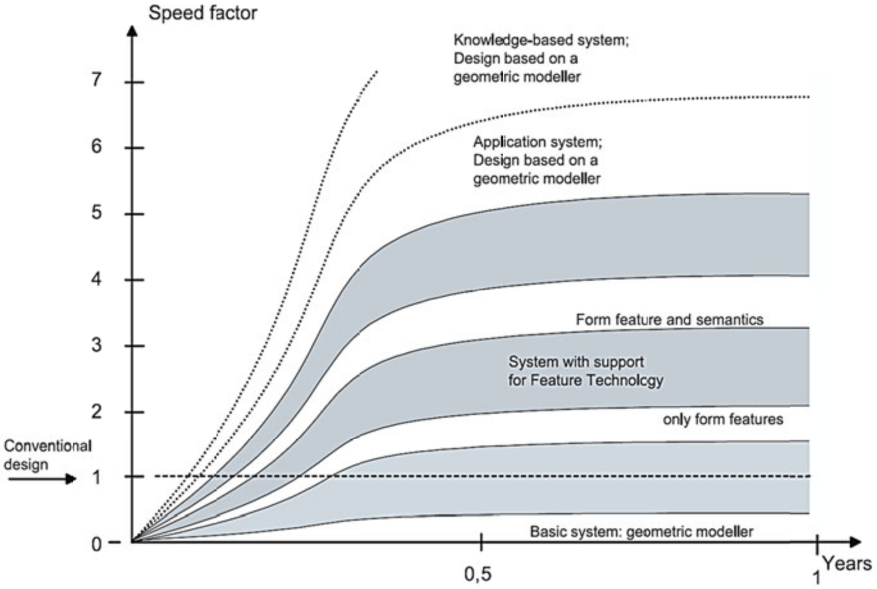


Figure 1. Speed advantage through computer aided design [VDI 2218 2003]

2.2 Design for Assembly

The designer gets part requirements from product planning and can start with part (assembly) creation in a CAD tool. It is important to note, that these requirements describe the functional part of the product but the designer gets no information how the product should be assembled. The design engineer starts developing and creates the assemblies to the best of knowledge and belief but without validation of the created result due to the lack of experience in assembly. This lack of experience is confirmed by Figure 2 where the main reason for barriers to assembly is identified as non assembly-compatible product design. This clearly shows that the design engineer himself is generally not able to create an assembly-compatible product design on his own. For this task the support from a specialist is required, in this case from a process planner.

The design process continues iteratively and with each cycle the model receives new details which can be important for the assembly planner who can assess them and provide feedback to design engineer if exchange of necessary information takes place. The designer can optimize the assemblies earlier and has to make less changes. This can support the design for assembly process, which reduces problems described in Figure 2. Often this potential remains unused, for example because of high license costs as well as systemic separation between domains like development and assembly planning. Companies do not want to use CAD tools as 3D viewers because of unnecessarily high licence costs and assembly planners must wait until the first version of drawings and BOMs are available. The preparation of technical documentation is done quite late in the PDP because the CAD models have to be completed before. The BOMs and CAD models are assessed by the assembly planner and often the designer gets them back for assembly optimization after the review process. At this point in time the CAD model has more attributes and geometrical parameters as in an earlier stage of the PDP and requires more time for the changes. The possible type of changes depends on the type of the product. For example, in certain cases two or more parts could be integrated or replaced by one single new part [Eigner and Stelzer 2009].

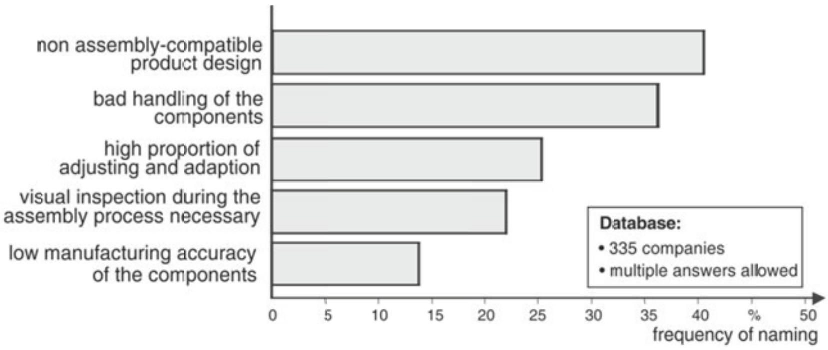


Figure 2. Barriers to automation of assembly [Lotter and Wiendahl 2006]

2.3 Assembly time estimation methods

As soon as development is finished and the part is approved and released, the process planning tasks are started. One of these tasks is the determination of the assembly time. For this task there are only two well-known and relevant companies which created methods for time planning called REFA and MTM. The REFA time-study methods can be efficiently used only at the End of design phase. MTM methods can estimate and predetermine time for assembly tasks in different stages of the PDP and is responsible amongst others for TiCon and ProKon. The first method is used for exact assembly time predetermination and planning of assembly lines. The second one is applied for estimation of assembly time on early phases (s. Figure 3). These methods can be used during assembly planning to predetermine assembly times but the designer rarely gets feedback about those planning results. Next time the designer will most likely create similar parts in the same way because the lack of feedback erroneously suggests that everything was alright. But this is often not the case since the process planner starts a change request only in the worst case, e.g. if the parts cannot be assembled at all. In other cases parts will be assembled with an unnecessarily high time effort.

The in TiCon implemented method is not that useful for time estimation during the design phase because many variables are only known by the process planner. Another point is the need for detailed information about the product which is only given at the late stages of the design process. One of the targets of the ProKon method is to bring designer and process planner closer together to optimize the product for assembly. Therefore ProKon is predestined for connecting the design and the process planning department.

The ProKon method is based on three types of parameters: physical, geometrical and process parameters. For each parameter each component gets product penalty points which are multiplied with the frequency of their occurrence. The multiplied penalty points are summarized to get a total score. The penalty points describe the impact of each ProKon parameter on the assembly time and are based on industrial experience. The fewer points the part gets the better it is for assembly. With their total scores two assembly alternatives can be compared and it is possible to calculate a first estimated assembly time. An example of a ProKon analysis sheet is shown in the Figure 4.

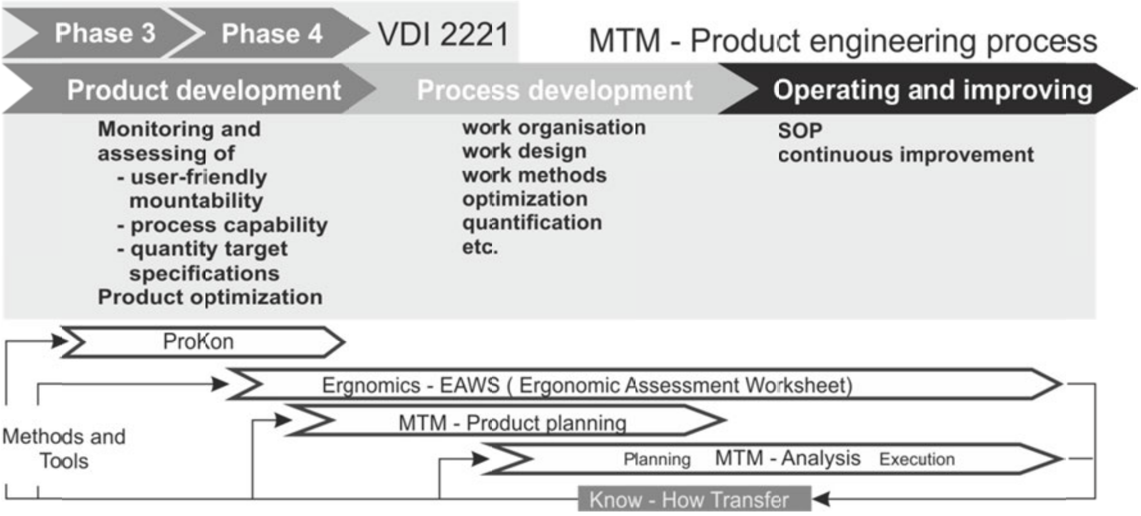
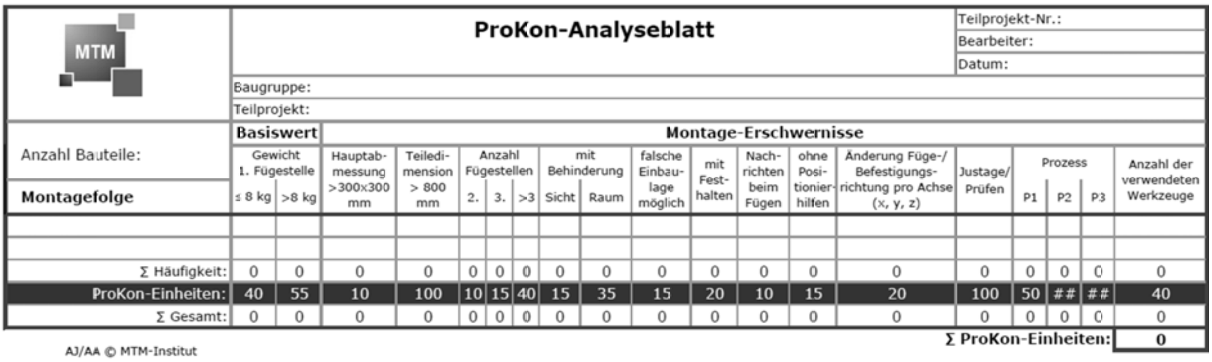


Figure 3. Integration of MTM ProKon in PDP [Deutsche MTM-Vereinigung e.V. 2012]

Almost all columns can be filled by the designer and analysed with ProKon without support from the process planner in an early stage of the PDP. With the support of a ProKon analysis the product can be optimized for assembly and iterations between designer and planner can be reduced. As soon as the designer completes the product, the planner can assess the data to better understand the designer's intensions with respect to design for assembly. Based on this method the product can be optimized for assembly. Until recently ProKon was a pure paper based method but to increase user acceptance the software vendor MTM implemented the method as "ProKon digital". This computer aided version makes the method easier to use, especially when combined with a 3D view of the parts. For this purpose any free viewer is advisable, especially if neutral data exchange formats like JT or STEP are supported.



ProKon-Analyseblatt

Teilprojekt-Nr.:
Bearbeiter:
Datum:
Baugruppe:
Teilprojekt:

	Basiswert		Montage-Erschwernisse																
Anzahl Bauteile:	Gewicht 1. Fügestelle		Hauptabmessung >300x300 mm	Teiledimension > 800 mm	Anzahl Fügestellen			mit Behinderung		falsche Einbaulage möglich	mit Festhalten	Nachrichten beim Fügen	ohne Positionierhilfen	Änderung Füge-/ Befestigungsrichtung pro Achse (x, y, z)	Justage/ Prüfen	Prozess			Anzahl der verwendeten Werkzeuge
Montagefolge	≤ 8 kg	>8 kg			2.	3.	>3	Sicht	Raum							P1	P2	P3	
Σ Häufigkeit:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ProKon-Einheiten:	40	55	10	100	10	15	40	15	35	15	20	10	15	20	100	50	##	##	40
Σ Gesamt:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Σ ProKon-Einheiten: 0

AJ/AA © MTM-Institut

Figure 4. ProKon analysis sheet [Deutsche MTM-Vereinigung e.V. 2012]

3. Concept

The design engineer should be supported regarding the principles of design for assembly already during the design process which includes the automatic analysis of assemblies without leaving the actual CAD environment. By avoiding manual or even paper based work processes are faster, iterations are reduced and assembly planners are provided with templates which are automatically derived from the design phase.

3.1 Concept Requirements

The best concepts and tools are useless if they are not used due to a lack of acceptance. To prevent this it is important to know the following non-functional requirements:

- The design engineer does not want to change the working environment, i.e. the user interface of the design tool should either be integrated or running in parallel but fully synchronized.
- The designer does not want to use additional software tools.
- The usage of a software assistant should not generate more work for the designer. And if it still does, it should at least offer some benefit for the designer.

The functional requirements are:

- The software assistant must use the geometrical information from the CAD model (for example: boundary box, weight, position, assembly order etc.) to reduce unnecessary tasks.
- Assembly elements (screws, rivets etc.) must be structured and should have a data base with classified assembly processes and their rating.
- The assembly planner should be able to use the data without a fully fletched CAD tool.
- For information exchange a neutral format (e.g. STEP, JT, PLMXML etc.) should be used.

3.2 Concept Description

As soon as the designer starts with the detailed design in the CAD tool, a CAD template has to be filled with properties such as material and interface datum planes. These datum planes can be used for part positioning in assemblies. These parameters are known from the concept phase of the PDP. Then the designer creates rough geometries (Figure 5: Stage 1) and interfaces which can be analysed for the assembly process. For this task the **P**roduct **A**ssembly **I**nformation (**PAI**) assistant is started from inside the CAD tool and receives geometrical information directly from the CAD model (Figure 5: Stage 2). The next step is the selection of an assembly element from the drop down menu in the PAI assistant. The assembly elements are typical and predefined connections, which are used in the company by default (Figure 5: Stage 2).

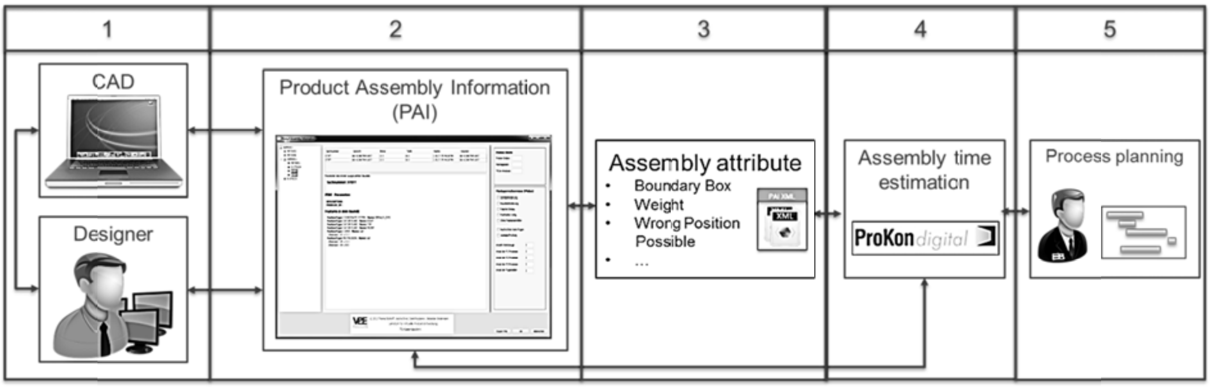


Figure 5. Development and Exchange Process

The connection elements are classified and each connection class is linked to assembly processes. Based on these links the PAI assistant makes a preselection of assembly processes and displays them to the designer who can choose from the preselection. Further important assembly parameters are assembly difficulties like “wrong position is possible”, “the part must be hold” etc. The parameters are typically available in the “design for assembly” guidelines [Pahl et al. 2006], [Ponn and Lindemann 2011]. The designer fills these parameters and the external logic (in our case ProKon) analyses the assembly content (Figure 5: Stage 3 & 4).

At first this seems to be more work for designer but this overhead has two positive aspects. Firstly the designer can critically examine the created parts with respect to design for assembly. Secondly the process planner has more information about the assembly. For the external logic it is possible to use existing solutions (for example ProKon) or to create a new one especially adjusted to the own company.

The feedback from the PAI assistant shows potentials and helps the designer to optimize the parts for assembly. As soon as the designer is satisfied with the model it is send to the process planner or a workshop is organized. In both cases the process planner analyses the 3D representation of the assembly variants with a CAD viewer and the assembly processes which the designer chose through the PAI assistant. Potentials and improvements are discussed and the generated data is saved in an exchangeable format and stored in a PDM system. After this workshop the designer can finalize the parts. (Figure 5: Stage 5) With this method the number of iterations can be reduced.

3.3 Data Exchange and APIs

To accomplish the task of data exchange between designer and assembly planner, various interfaces are required to allow for an appropriate information flow.

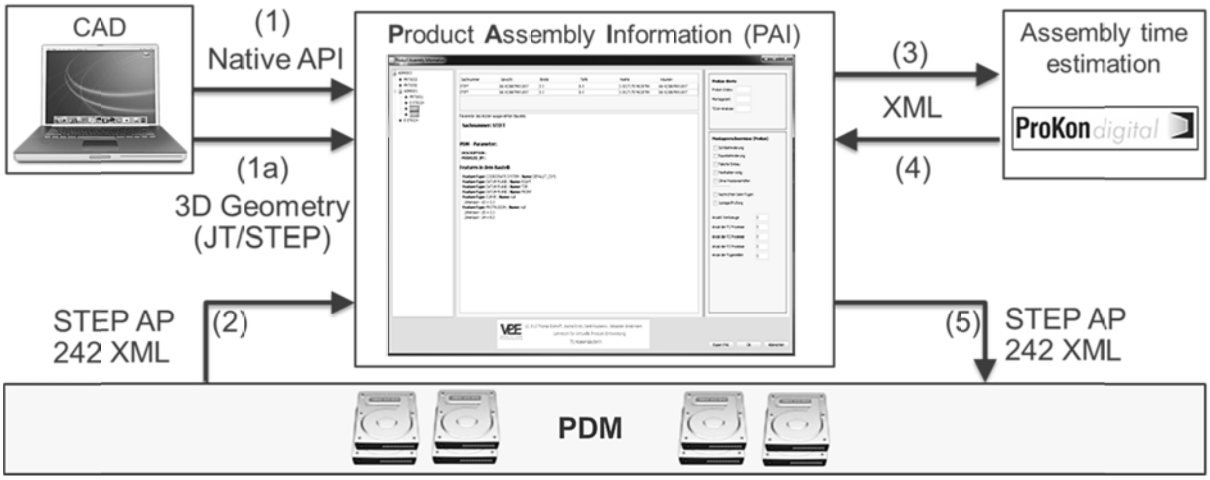


Figure 6. Tools and information exchange processes

Yet during creation or at the latest after the model has been created in the CAD tool, its data which is relevant during assembly is extracted and analysed by a PAI assistant. Best this is done in real time without writing and sending a file containing the model, especially when the assistant is used frequently during the creation of the model. Such a fast or almost real time interface is usually accomplished through the respective API of the CAD tool and therefor a native and proprietary interface (see Figure 6 (1)). In this special case the benefits of direct access providing full model data access in almost real time outweigh the drawbacks of non-standardized interfaces. Standardized data formats are hardly an alternative in this situation because they either lack support for features (e.g. JT) or massively increase the time delay due to format complexity and the resulting process speed and file size (e.g. STEP AP 242). Though during an optional or concurrent step (1a) a standardized 3D geometry file like JT or STEP can be sent to the assistant to provide offline access for geometrical analysis during later design phases (e.g. second use case in chapter 3.4) [Katzenbach et al. 2013]. Once the data is present in the assistant it can be analyzed, altered or enriched. At this point historical data can be integrated into the actually extracted CAD information (2) which is particularly useful for the design process of similar products or design modifications. In the next step the combined package of actual and historical data is handed over to the assembly time analysis tool (3). Again this should be handled by neutral and standardized interfaces because there is significant potential for saving time, work and license costs by avoiding any non-standardized formats [Eigner et al. 2013]. Results of the time analysis are returned to the assistant (4) which can display potential issues or improvement opportunities as immediate feedback to the design process in the CAD tool.

For history and documentation purposes the storage of the result and potential decisions made based on this result is recommended (5) and ideally a neutral and standardized interface is used for the transfer to the PDM system, e.g. STEP AP 242 XML. This PDM system can then serve as source for historical data in previous steps like (2).

3.4 Prototypical Implementation

To evaluate the actual benefits of the concept a prototypical implementation has been created. While the generally positive effect of an enhanced information flow is undisputed, in this case the numerous feasible implementation options require a proof-of-concept which can be tested in a realistic engineering environment. This includes a CAD tool, an assembly time analysis tool and the data exchange between both applications.

The implementation used for this paper consists of PTC Creo 2.0 as CAD tool, MTM ProKon as assembly time analysis tool for the early phase and a Java based graphical user interface (GUI) as PAI assistant in between.

To avoid manual data exchange between Creo and ProKon the assistant is connected with the Creo API to extract all kinds of attributes, features and parameters from the CAD model. The information can be checked and extended in the GUI of the PAI assistant before exporting the appropriate data to a ProKon conform XML file. This can be loaded in the ProKon application to analyse and calculate estimated time and ProKon points which are returned and automatically displayed in the PAI assistant.

This software enhancement is valued as significant improvement to the design process since it provides immediate feedback to the design engineer regarding the quality of the CAD model with respect to the estimated effort of assembly.

Besides the support of the design process in a CAD tool there is a second use case which consists of a specific model version which is discussed between designer and assembly planner during a meeting. This meeting which is usually held at the process planner’s location can be supported by neutral 3D geometry as created in (1a).

A second version of the prototype provides full automation of the assistant and results in a real time feedback system which shows improvement or decline of the CAD model during the whole design process. In this case a screen filling analysis or full report is not appropriate but some sort of colour code can quickly indicate if changes are positive or negative.

For future implementations it is also planned to exchange data between the assistant and a PDM system via STEP AP 242 XML [ISO 2013] to better support design modifications as described in 3.3. The concept of PAI as container for product assembly information is fully explained in [Eigner et al. 2013a] and describes how relevant data is stored in the bill of material of the respective product inside the PDM system.

3.5 Example of Implementation

The designer creates a CAD model or variants of a CAD model (in this case with Creo 2.0) and wants to know which one is better with respect to design for assembly. In this case the girder of a parallel station is analysed which has kindly been provided for this paper by KHS (Figure 7). The first version is created by KHS and the second one by VPE. Both variants consist of a plate and a girder. The first one is easier to manufacture but more difficult to assemble. The second one has contrary properties. The PAI assistant is used to decide which the better one is.

It displays the assembly structure (on the left side in the Figure 8) where at first the fixed part must be chosen before the assembled part can be picked. Finally assembly difficulties like “wrong position possible”, “without position help” etc. and assembly processes (on the right side in the Figure 8) are chosen. The assembly processes are classified in three categories from P1 “easy to assemble” to P3 “hard to assembly”. The process is repeated for each part in the assembly. As soon the designer is ready with the assembled parts data can be exported for analysis in ProKon.

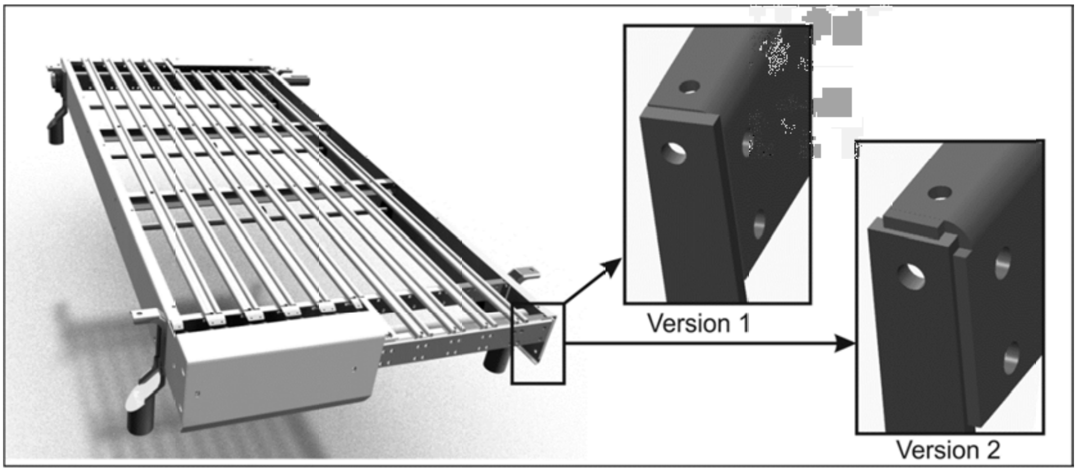
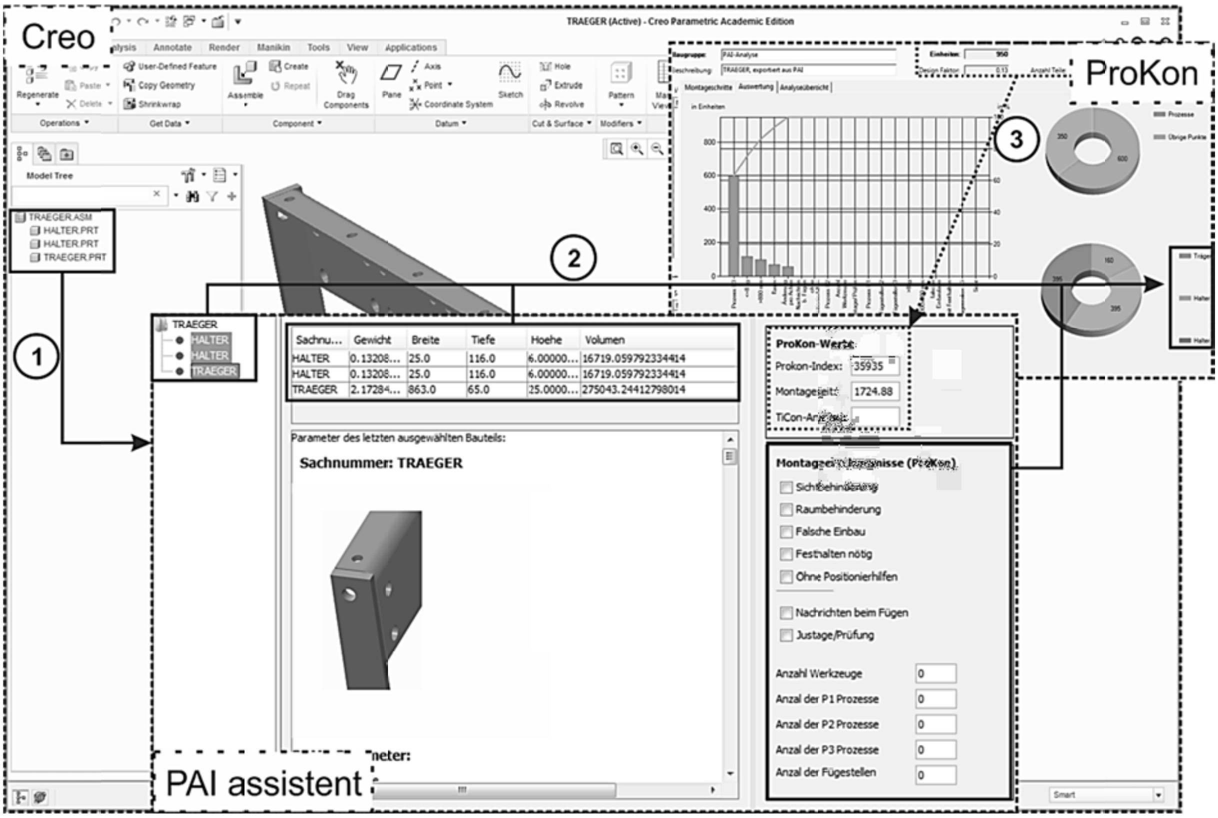


Figure 7. Two possible versions of girder



Baugruppe: PAI-Analyse

Beschreibung: TRAEGER, exportiert aus PAI

Einheiten: 950

Design Faktor: 0.13

Sachnu...	Gewicht	Breite	Tiefe	Hoehe	Volumen
HALTER	0.13208...	25.0	116.0	6.00000...	16719.059792334414
HALTER	0.13208...	25.0	116.0	6.00000...	16719.059792334414
TRAEGER	2.17284...	863.0	65.0	25.0000...	275043.24412798014

Parameter des letzten ausgewählten Bauteils:

Sachnummer: TRAEGER

ProKon-Werte:

Prokon-Index: 35935

Montagezeit: 1724.88

TiCon-An[illegible]:

Montage[illegible]nisse (ProKon)

☐ Sichtbehinderung
☐ Raumbehinderung
☐ Falsche Einbau
☐ Festhalten nötig
☐ Ohne Positionierhilfen
☐ Nachrichten beim Fügen
☐ Justage/Prüfung

Anzahl Werkzeuge: 0
Anzal der P1 Prozesse: 0
Anzal der P2 Prozesse: 0
Anzal der P3 Prozesse: 0
Anzal der Fügestellen: 0

Figure 8. Ideal process and data exchange between IT tools

Based on the assembly time and ProKon points the designer can optimize the parts for assembly or compare solution variants. As soon the assembly is complete designer and process planner organize a workshop to finalize the assembly. The ProKon analysis is the basis for further activities during the workshop.

4. Summary and Outlook

The paper describes communication issues between design and process planning departments and provides a concept to reduce the “wall” between both. For this task time estimation workflows in the early phase of the PDP are suggested to enhance design for assembly.

The concept uses the design information from the CAD model and additional assembly related information of the design engineer. The PAI assistant collects the data to transfer it to a time estimation tool for calculation. The results are presented to the designer to allow for model optimizations regarding design for assembly. The data exchange is accomplished through neutral interfaces and formats. To validate the presented concept a prototypical implementation has been developed which consists of PTC Creo, MTM ProKon and a Java based PAI assistant.

The prototype based on this concept has the potential to reduce the gap between design and process planning departments by improving their information exchange. Though this paper only covers the early phase of product design. Therefor further research can improve the effective range by extending the concept to also cover the more detailed process planning. This includes actual process determination through the use of additional tools of Digital Factory, e.g. MTM TiCon. The final step of further research activities compares estimated, determined and real times of the assembly process while the designer gets the real times as feedback from actual production processes.

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