

TOWARDS INNOVATIVE ASSEMBLY CONCEPTS: INTEGRAL PRODUCT- AND ASSEMBLY STRUCTURE

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1. Introduction

A significant part of the production costs of industrial products is allotted to the assembly. Considering the link between the causation of costs and the responsibility of costs, a specific correlation of the development of a product and its production can be stated. Though high costs incur in the production, it is the development, an earlier phase of the product emergence process, where these costs are accounted [Gairola, 1981]. These considerable potentials for production cost reductions must be developed in the design of the product. The assembly claims up to 70 percent of the overall production time. Since these thereby occurring costs are determined in the development phase, a high importance to design for assembly (DFA) has to be attached. To accommodate the influence of the product design on the assembly efforts, various tools and methods can be applied in the particular development phases according to the common procedure by e.g. [Pahl and Beitz, 2007].

At the beginning of the paper a short overview of the established proceedings for design for assembly is given. Afterwards methods for the development of modularized product structures and procedures for assembly planning are presented. On this basis a holistic procedure for the development of products designed for assembly is evolved. In this context the approach of an integral representation of the product structure and the assembly sequence (iPAS) is introduced. Finally the procedure is exemplarily applied to the assembly of the interior components of civil aircrafts.

2. Brief tribute to Design for Assembly

According to Pahl and Beitz the developer does not only influence the costs and quality of the manufacturing of parts to a decisive extent, but also the costs and the quality of the assembly of these parts. The fields of observation for the design for assembly are the product structure, the assembly parts and the joints as well as the assembly system. The superior goals of all DFA measures can be categorized among the following four general aspects:

1. Reduce
2. Standardize
3. Simplify
4. Structure

To implement the measures for the optimization of the ease of assembly various tools are at the developer's disposal. In the design phase a large amount of guidelines can be applied. These guidelines tend to show a universal character. Therefore the provided general information needs to be adapted to the specific task by the user [Pahl and Beitz, 2007], [Andreasen, 1988]. In order to support the practicability, the guidelines are grouped and provided in catalogues.

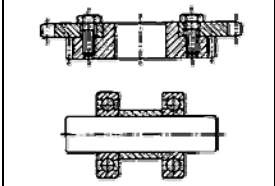
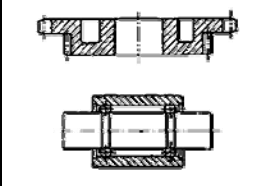
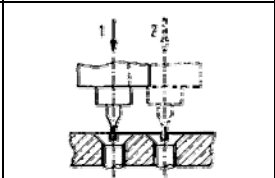
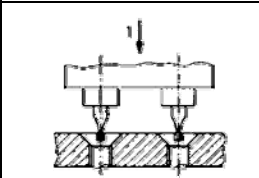
Guidelines	Wrong	Right
Connect parts using integral an composite structures		
Execute assembly operations simultaneously		

Figure 1. Design for Assembly Guidelines [Pahl/Beitz 2007]

For the analysis of the ease of assembly of products several methods exist, which already reached a mature state and are often implemented in computer applications. The most common methods are the Design for Manufacture and Assembly (DFMA) by [Boothroyd, 2002], the Hitachi Assembly Evaluation Method (AEM) by [Ohashi, 2002] or the Design for Production (ProKon) by [MTM, 2006].

These methods are applied in the late design phase, in which more detailed product information is available. In particular the focus is concentrated on the shape and the interfaces of the parts. In order to optimize the assemblability of a part, the interfaces and the shape have to be evaluated regarding their specific implications on the assembly efforts, which are determined by the required handling and joining operations. Different tools like charts and checklists are available for the evaluation. The results range from specific key data up to the detailed generation of assembly times. Based on the results of the evaluation, fields of action are identified and suggestions for design modifications are provided.

Most of the DFA methods and tools have already reached maturity. Their application is widely established in the industrial practice. In particular the method based optimization of parts and joints is considerably supported and widely used. As opposed to this, the support for measures regarding the optimization of the product structure remains on an abstract level. Furthermore the methods show a lack of consistency among the consecutive development phases. The transfer of the results of measures taken in one phase to another is not supported. Due to these identified deficiencies further methods are analyzed for potential contributions to the design for assembly.

3. Further approaches towards design for assembly

Beside the conventional methods presented in the previous chapter further methods exist, which contain various aspects of the design for assembly topic. In the following sections approaches towards the structuring of products and the analysis of assembly sequences are reviewed to which extent and in which way the optimization of the assemblability is supported.

3.1 Perspective-based modularization

Modularization is an established approach for the structuring of products. In general industrial products have to meet the demands of various different interest groups. In order to develop a product architecture regarding all relevant boundary conditions, different business perspectives have to be considered. According to the method developed at the Institute of Product Development and Engineering Design of the Hamburg University of Technology (PKT) the four companies' perspectives 'product strategy', 'purchase', 'after-sales' and 'assembly' are included in the generation of modular product structures [Blees, 2009]. Therefore the components of the decomposed product are clustered into chunks depending on a specific choice of module drivers. In particular the assembly itself is represented by the aspects of 'testing', 'preassembly', 'assembly process' and 'handling'. The

user is supported with questionnaires in the analysis of each component relating to the module drivers. Central element of the method is an adapted Module Indication Matrix (MIM) according to [Erixon, 1999]. The procedure for developing perspective-based product structures is displayed in the following figure.

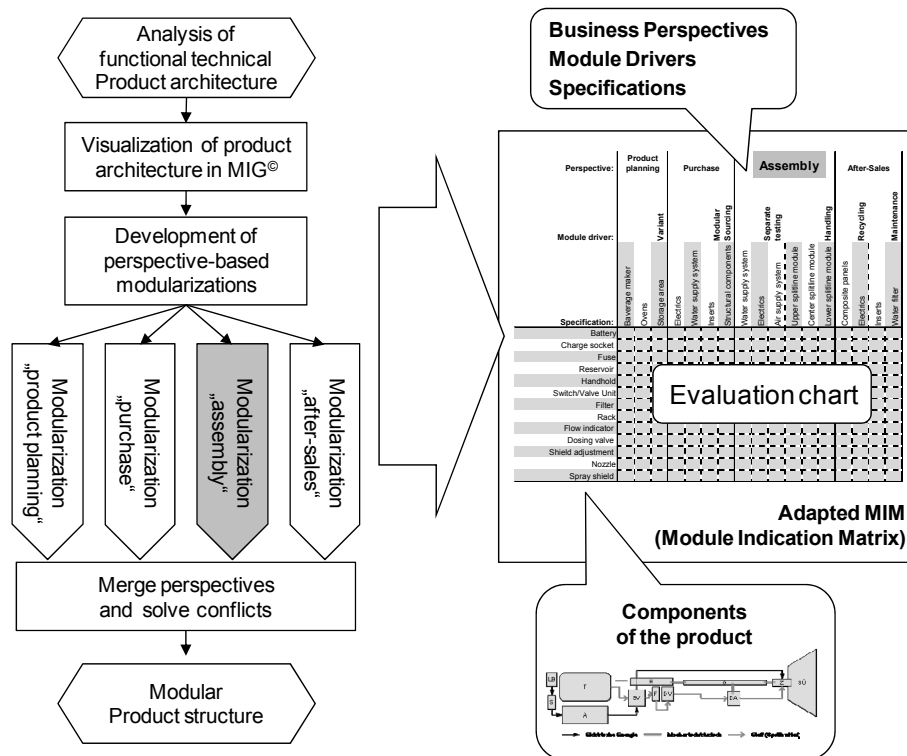


Figure 2. Perspective-based modularization [Blees 2009]

The assembly is considered as one of the four defined company specific perspectives. The generated product structure must therefore be characterized as a compromise between these perspectives. The superior intention of this modularization approach is to support the consideration of the essential requirements in the early development steps of the product. In case of products with a high assembly intensity, that means products that consist of a large amount of single parts, the production assures its position as a directly essential factor for the producing company. In order to meet these specific circumstances, the assembly needs to be considered anew after the conduction of the perspective-based modularization. This individual analysis has to be conducted from an assembly point of view. Nevertheless this product optimization has to comply with the product structure and must not breach the requirements of the other perspectives.

3.2 Methods for assembly sequence analysis

The assembly sequence represents a significant indicator for the assemblability. By breaking down the entire assembly process into single tasks, the relevant efforts, e.g. the required assembly time, claimed resources, capacity utilization, etc., can be identified and directly related to the particular assembly process step. There is a variety of methods to generate assembly sequences. These methods can be subdivided into techniques of artificial intelligence based on algorithms or heuristics, conventional techniques based on analytical methods or techniques resulting from the graph theory. The methods differ in the specific application effort and the quality of the output. In general heuristics are applied quickly and simply, but do not guarantee suitable results. Algorithms, however, promise a certain completeness and accuracy, but tend to be very complex, especially with increasing number of parts of the assembly [Whitney, 2004]. The general intention of the methods is to identify feasible assembly sequences. The range of the output extends from the generation of one feasible sequence up to the generation of all possible sequences. For product development the all-sequence methods are the most

applicable. The generation of alternatives provides the possibility to select the most suitable solution regarding previously defined criteria.

The procedures predominantly support the generation of assembly sequences without regard to any evaluation. Whitney integrated the generation methods into a global process for the identification of good assembly sequences. According to Figure 3, after the generation of all feasible assembly sequences, different analyses of the specific impact of the interaction between the product characteristics and the particular sequence are performed. In this way the particular intermediate subassembly states are evaluated according to e.g. their structural integrity, ability for testing or maintenance, etc.. In case of the assembly operations, the necessity of orientation changes and the risk of damages caused by handling are analyzed. Furthermore any specific constraints are reviewed. Based on specific production factors, quantitative data, like times or costs, are overlaid. The derived information, in combination with specific criteria, provides the basis for identifying good assembly sequences.

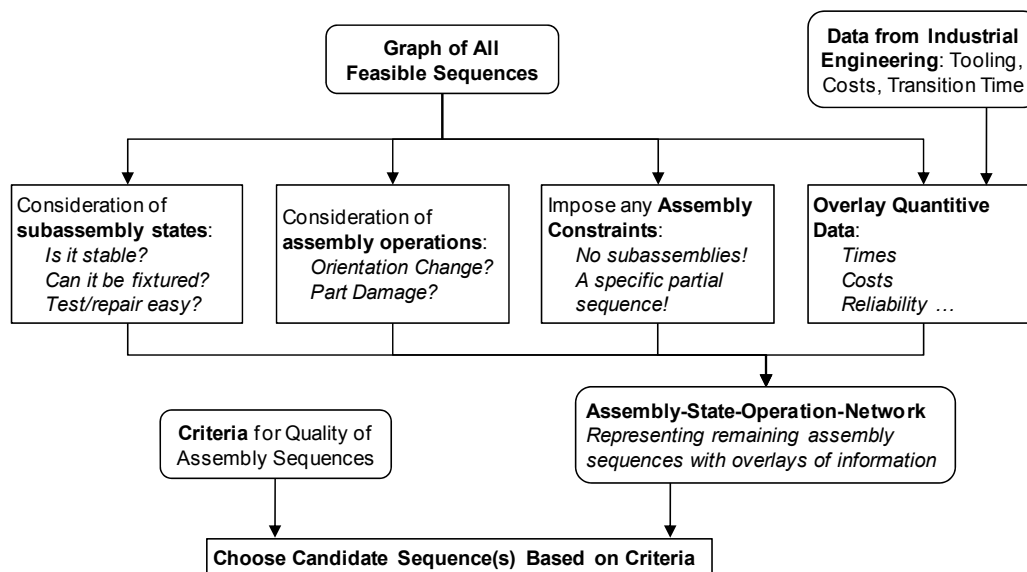


Figure 3. Flowchart of sequence selection process [Whitney 2004]

3.3 Résumé of the presented methods

The previously presented methods, modularization and sequence analysis, are representative for two main types of modifying product characteristics regarding the assembly. The modularization is assigned to the group of determining product characteristics. The application supports the formation of the product structure. The assembly in particular is considered as one of four company's perspectives. An actual analysis of the assemblability using hard facts like assembly time, sequence, etc. is not supported. This aspect is implemented in the group of evaluating product characteristics. This group consists of the DFA Methods as well as the presented procedures for assembly sequencing. In case of these methods the derivation of effects to the design of the product structure is not supported.

The aim is therefore to formulate a methodology, which provides a consistent view of the product structure and the assembly process. Since the product structure determines the assembly sequence, it is necessary to return the results of the evaluation of assemblability to the structuring of the product.

4. Process-based approach to design for assembly

The early consideration of all business perspectives is essential for the development of appropriate product structures within the modularization method described in chapter 3.1. The assembly is thereby included as one perspective among others. Because of the specific constellation of the assembly regarding the causation and the responsibility of costs, a differentiated optimization of the product structure ought to follow up. The entire product optimization process is shown in Figure 4.

The measures for the assembly optimization of the product performed after the modularization is characterized by an iterative procedure. Based on the modular structure, alternative assembly sequences are derived, using the existing methods exemplary described in chapter 3.2. Afterwards the evaluation methods are applied to analyze the different sequences with regard to their particular assembly efforts. Therefore it is essential to adopt the methods to the specific business environment. The results of the analysis are finally returned to the task of product structuring. Based on the obtained information, the product structure is revised. The process is iterated until an optimal solution is achieved.

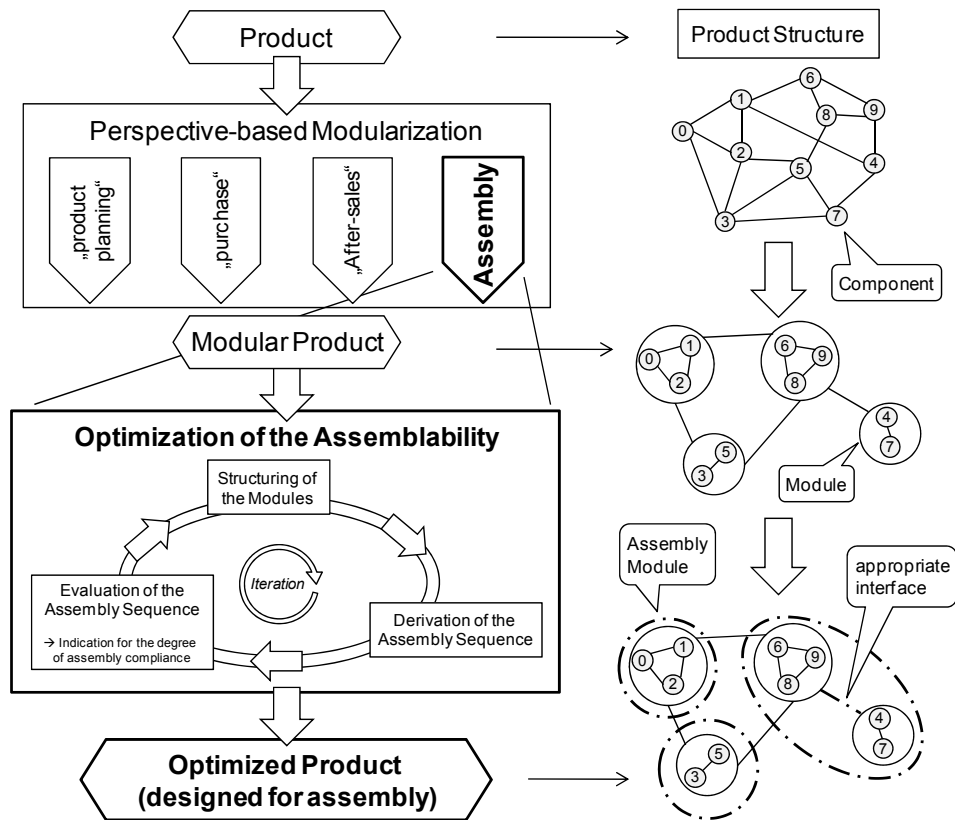


Figure 4. Holistic process to design for assembly

The central element of the approach is the demand for compliance of the assembly optimized product structure with the resulting structure of the modularization. A superior intention of product structuring is to increase the degree of preassembly. Thereby the opportunity is provided to parallelize operations and reduce time in the final assembly. In order to avoid the infraction of requirements, the measures are conducted on different levels. As shown on the right hand side of Figure 4 the modularization proceeds on the level of components. Modules are created by clustering components into chunks. On the level of the modules the assembly optimization of the product is conducted. The modules in turn are grouped into assembly modules. The requirements of other business perspectives, such as the possibility to remove a certain module, are considered by an appropriate design of the structural interfaces, which are added to enable the preassembling.

The procedure shown in Figure 4 establishes a consistent connection between the different DFA methods. The application of this holistic approach offers the possibility for an efficient and early consideration and implementation of the design for assembly topic in product development. But due to the iterative optimization of the assemblability, the procedure turns out to require high application efforts. Various tools and methods of commonly different business units have to be applied in close collaboration.

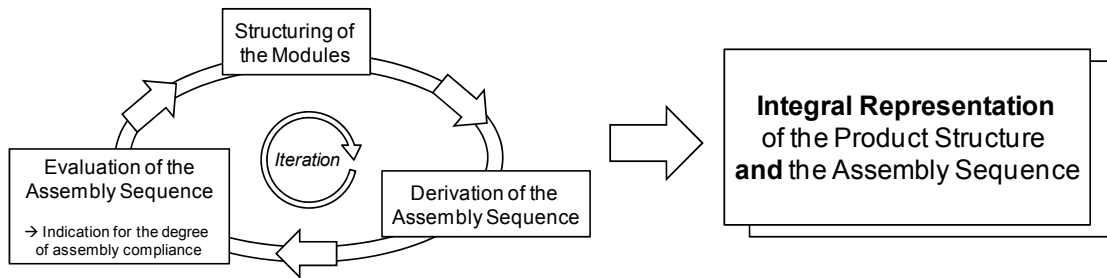


Figure 5. Motivation for an integral optimization process

In the following chapter an approach is presented, which encounters this extensive procedure. According to Figure 5 it is the intention to develop an integral view of the product structure in combination with the assembly sequence in order to improve the optimization process

5. Integral Product and Assembly Structure (iPAS)

The development of a novel approach, based on a first idea presented in [Halfmann 2009], is focused on the avoidance of the conventional iterative procedure to optimize the ease of assembly as described in chapter 4. The concept intends to combine the two aspects of determining and evaluating the assemblability in a combined way of representation. The application of the “integral product and assembly structure (iPAS)” provides the opportunity to support optimizing measures in a single tool. The impact of modifications of the product structure to the assembly sequence and vice versa is directly visualized. To assist the conduction of modifications, specific heuristics and guidelines are formulated.

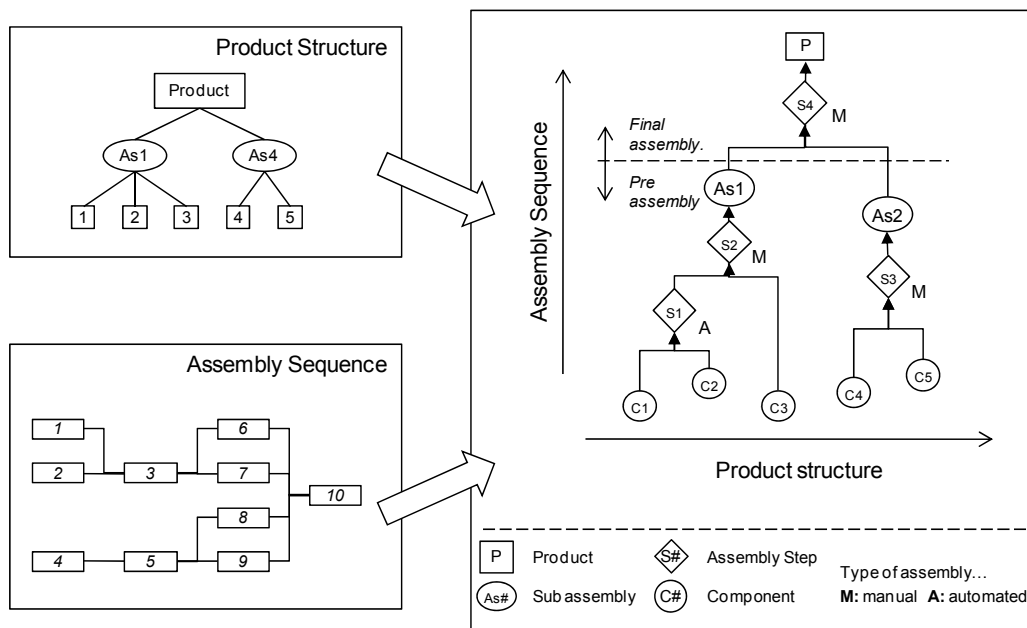


Figure 6. Integral Product and Assembly Structure (iPAS)

An exemplary application of the approach is illustrated in Figure 6. The product is displayed in the integral product and assembly structure. The conventional hierarchical structure is extended by specific information regarding the assembly. The time is represented by the variation of the length of the boxes in the illustration. The precedence of the different assembly tasks is shown by varying the vertical position. In general both dimensions of the illustration are used to display information. While the aspects ‘precedence’ and ‘time of the assembly steps’ are displayed in the vertical direction, the structure of the product, i.e. the number and hierarchy of parts and subassemblies, are attached to the

horizontal axis. To enhance the description, the product specific module interface graph (MIG) is added to the illustration.

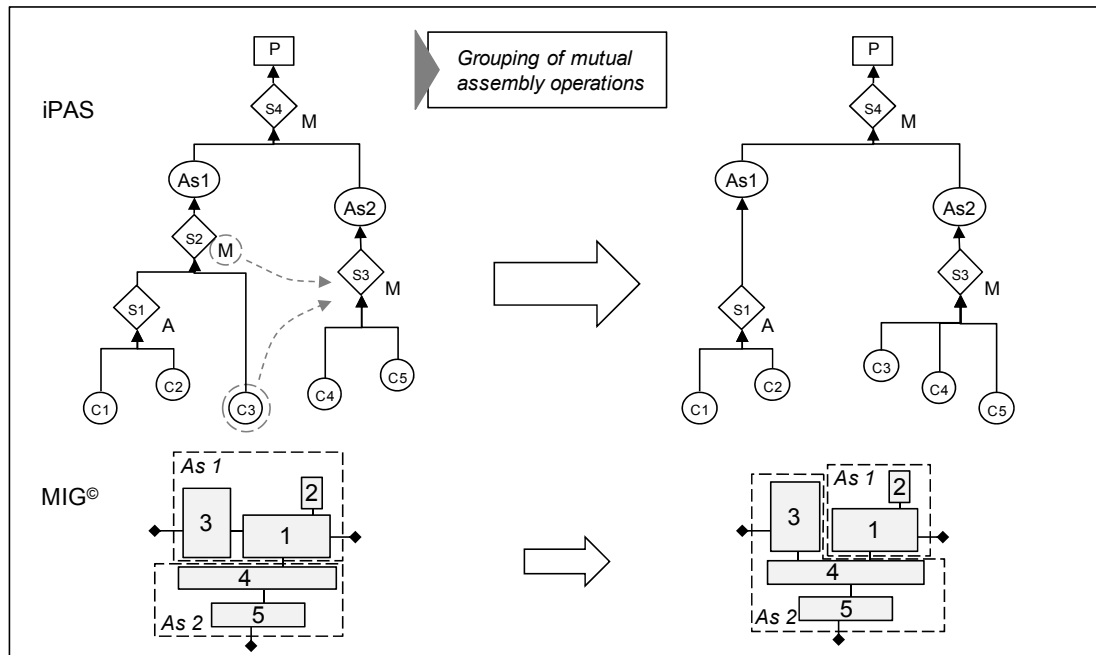


Figure 7. Exemplary application for the iPAS

According to the shown example, the heuristic, as listed in the text box, determines to group assembly operations of the same type, like manual or automated processes. The resulting modification designates a change in the design of the product. In this case, the component C3 is relocated to the group, which currently consists of the components C4 and C5. The implementation of this measure yields to two alternatives. On the one hand side, provided that the conformity with the modularization can be assured, the product structure is changed. On the other hand a preassembly of the particular component with the relevant module ought to be considered.

6. Development of aircraft cabins designed for assembly

For the validation and verification of the presented methodology, the approach was applied to cabin components of civil aircrafts. The interior of conventional aircrafts consists of the passenger seats, toilets and galleys, overhead storage bins (hatracks) and personal service units as well as different lining panels at the ceiling and the walls. An analysis conducted in the final assembly line of the aircraft production process reveals a marginal degree of preassembly. The majority of the assembly tasks has to be performed sequentially. Occasionally specific components need to be partly removed in order to provide access to blocked parts. The whole process is dominated by a large amount of secondary, non value adding tasks. The bottle neck of the cabin installation process is represented by the assembly of the hatracks and the service units. Due to the large number of parts and the complex handling and joining operations the highest expenditure of time is allotted to the assembly of these parts. For this reason the first measures regarding the optimization focus on this specific part of the aircraft cabin.

In the following figure the analyzed assembly process and the product structure is shown. The product structure in particular is represented in the form of a module interface graph (MIG). The MIG shows the approximate size and shape of the parts, their relative location as well as the different interfaces, like spatial, media flow or power. This way of representation offers the opportunity to provide a first impression of the product and its relevant information. As shown in Figure 8, the MIG contains the components of the focused cabin interior section. Relating to the image on the left hand side, the MIG illustrates the cross section of the components, consisting of the hatrack, the personal service unit

underside, lining parts, further adjacent cabin systems, like air outlets, lighting, etc., as well as various supporting parts. On the bottom of Figure 8, a schematic view of the assembly is shown, demonstrating the complexity of the process.

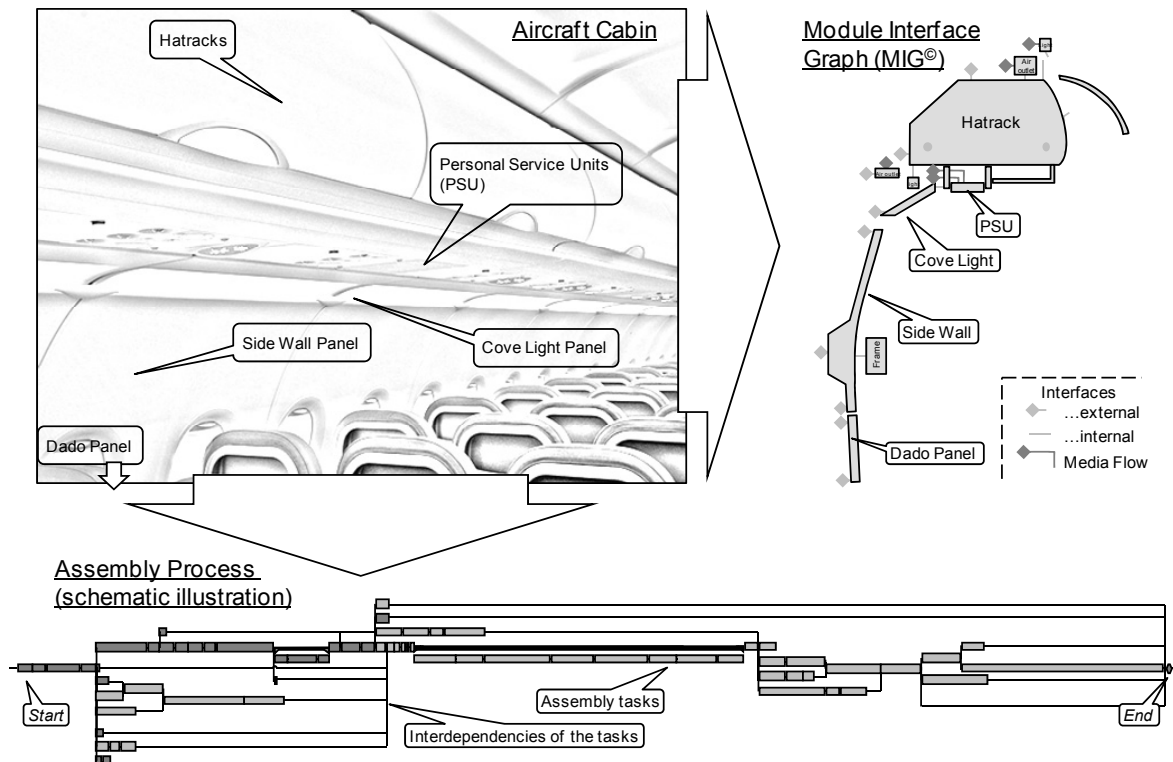


Figure 8. Aircraft interior – product structure (MIG) and assembly sequence

A first measure of optimizing the assemblability is the application of design guidelines. In this context first minor potentials are developed based on the existing design. Furthermore the PKT own developed methodology for modularization is applied to the interior components. The improvements thereby identified imply a reduction of parts by applying integral design to the modules.

According to the systematic procedure presented in chapter 4 the approach for product structuring is applied. Because of the top-level requirement to reduce the lead time in the final assembly, the degree of preassembly of cabin components has to be increased. In this way the possibility is achieved to relocate handling and joining operations into earlier production phases. Since the cabin lining is identified as the main assembly time element, the exemplary application focuses on this part of the aircraft interior.

The modules resulting from the previous modularization procedure are determined to be grouped into one entire preassembly module. The resulting design merges the external structural interfaces of the hatrack and sidewall panels into a single frame part. This frame is the core element of the assembly optimization. As described in chapter 4 the interfaces have to be designed according to the spectrum of requirements, to assure the conformity of the assembly structure with the modularized product architecture. The frame part is therefore designed in a way that it still enables a stable preassembly of a large module, but as well keeps on providing the opportunity to a separate disassembly of single parts, such as required by the after-sales perspective.

The evolution of the design changes of the cabin components is shown in Figure 9. On the left side the original product structure is shown. The entity of components is characterized by a marginal degree of preassembly leading to a high installation time. After the modularization of the components the number of parts and interfaces, that have to be mounted, is significantly reduced. Finally the optimization of the assemblability enabled an extensive preassembly as well as a notable reduction of assembly time.

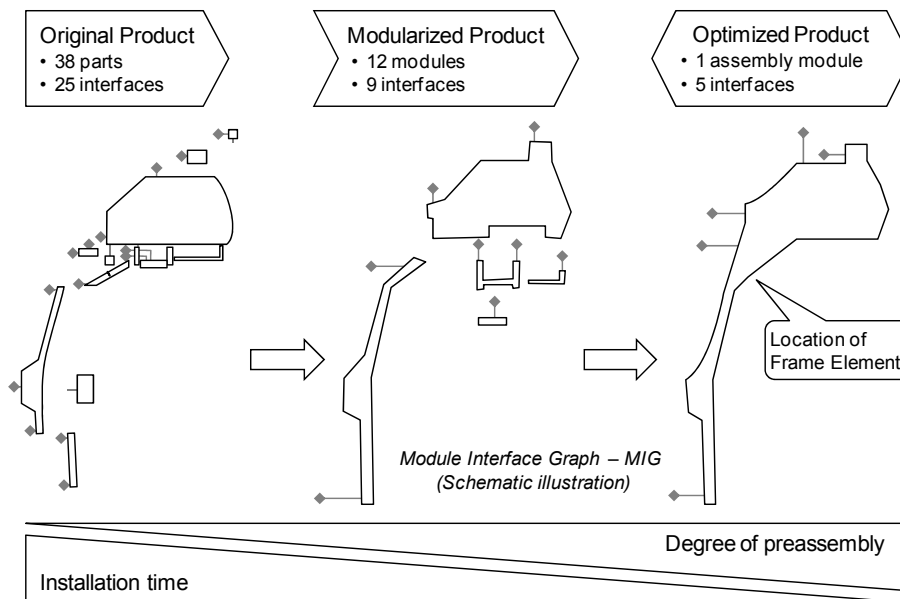


Figure 9. Progress of product optimization

7. Conclusion

The expenses incurred in the late stages of the product emergence process, primarily the production, are predominantly accounted by the early phases of product development. Especially in the case of the assembly early measures are necessary to ensure a high level of assemblability. An analysis of the established DFA-methods showed that a consistency regarding the processing of results as well as the interfaces to other tools of the product development are insufficient. Based on a PKT own developed methodology for product modularization a holistic procedure for the optimization of the assemblability was set up. The approach determines the application of the different methods in the particular development phases and defines the way of processing and transmitting of information relevant for the assembly. As a further step the idea of an integral representation of the product structure and the assembly sequence, which are commonly interdependent but separately considered, was presented. It is essential to avoid the extensive iterative process of changing the product structure and evaluating the assembly sequence. By using the presented method, it becomes possible to directly generate and evaluate the impacts of assembly relevant changes to the product structure.

In the course of a joint research project in cooperation with Airbus Industries, funded by the German Ministry of Economy, the procedure was exemplarily applied to selected components of the aircraft cabin. The aim was to reduce the lead time in the aircraft final assembly line. Therefore the degree of preassembly was significantly increased and the production processes changed. The result is a novel cabin architecture designed for assembly, which only involves the handling of a single final assembly module. Future work contains a detailed elaboration of the approach based on the first results. The interfaces to the different methods have to be designed. In order to achieve a higher level of applicability and performance of the approach, the possibilities of an implementation in a CAX-system are analysed. For a further validation and verification the methodology will be applied to other types of products.

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