RESEARCH IN AIRCRAFT PRODUCTION – IDEAS AND CONCEPTS FOR THE CABIN INTERIOR INSTALLATION

Dipl.-Wi.-Ing. S. Umlauft[1],
Dipl.-Ing. N. Halfmann[2], Prof. Dr.-Ing. D. Krause[2]

[1]Airbus
[2]Technische Universität Hamburg-Harburg
Institut für Produktentwicklung und Konstruktionstechnik (PKT)

Abstract

A substantial part of the aircraft production lead time is caused by the interior installation in the final assembly line. Due to the consequential economic impacts for the OEM solutions have to be found to reduce the cabin installation times. In this paper the results of multiple cooperative research projects between the Hamburg University of Technology and Airbus are presented.

1. INTRODUCTION

Rising cost pressure and the intended increase of produced units in the future lead to the necessity for aircraft manufacturers to achieve faster and more efficient aircraft production processes. A schematic overview of the highly complex cabin installation process is shown in Figure 1. The aircraft cabin is mounted in the latest production phase, the so called Final Assembly Line (FAL). In the case of the interior components, a large amount of requirements have to be considered. In general, high degrees of quality, design, functionality and not least safety are expected from the aircraft cabin. Furthermore, the interior is a highly customized product. The customers can choose from a large number of different varieties or in various cases even demand the installation of their own equipment.

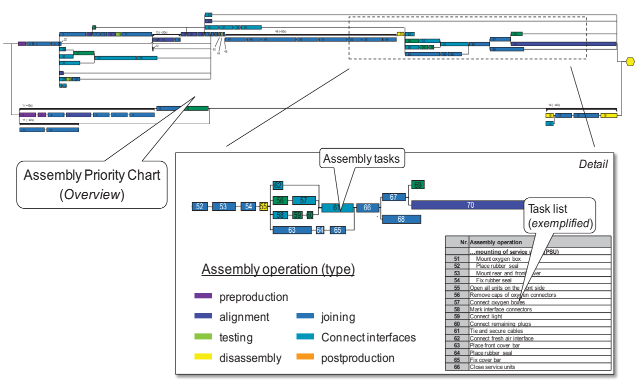

Figure 1. Overview – Assembly priority chart of the aircraft interior installation process

In the course of time, increasing functionality and systems have been installed in the aircraft cabin. Due to the generally long life cycles of aircraft programs, massive adaptations and modifications of the product design were and still are necessary. The resulting measures lead to a severe elevation of cabin complexity. The existence of continuously rising and partly competing requirements entails extensive efforts in the development. Today the installation of the interior components is the final step in the overall aircraft production process. The cabin architecture is determined by the fact that the components have to be installed in the flight ready aircraft. The parts and modules are carried manually through the passenger doors. Inside the fuselage, the components are attached to the aircraft structure. Due to the aircraft type specific manufacturing process of the fuselage structure, a benefiting situation for the cabin installation may follow. The entire fuselage consists of various segments that are assembled prior to the interior installation. In certain cases, particular components are already introduced into the open fuselage before of the cockpit section is mounted. However, in general the passenger door represents the bottleneck in the cabin integration process concerning the component handling. Only door-suitable units can be used. These restrictions have serious negative impact on the assembly efficiency. In case of the tallest interior components, the lavatories and the galleys, partially even ready prepared and pretested units have to be disassembled to enable their transportation through the passenger door.

Based on the present cabin architecture it is not economically possible to handle the growing complexity nor to achieve further optimization in the assembly process. The fulfillment of the increasing requirements in the future is the motivating factor of different joint research projects between Airbus and PKT. It is the aim to develop novel integration concepts for aircraft cabins. The scheduled measures address different aspects of the aircraft interior. In addition, the included approaches have different scopes concerning a possible consideration and implementation of achieved results in the aircraft cabin architectures. On the one hand, there are concepts that address small adaptations to a few parts. On the other hand, there are concepts that entail radical changes to the component design as well as the associated assembly processes. Hence, these types of concepts require long-term implementation in the aircraft production.

2. STATE OF THE ART – APPLICATION OF DESIGN GUIDELINES (DFX)

A first measure for the optimization of the assemblablity is the application of design guidelines to the product. In relevant literature many guidelines are released to support the developer in the design of parts from an assembly point of view [1, 2]. First developed concepts for the optimization of time efficiency are based on these so-called design for assembly guidelines (DfA). The assembly relevant aspects of the cabin interior components must be designed to comply with these guidelines to reach a high level of assembly accuracy. Consequently a key factor in the assembly is the design of the cabin component interfaces. In case of the aircraft interior, there are several relevant interfaces for the structural attachment and the connection of specific media like water, air, power or information. Next to the handling of the components, the mounting of the interfaces is one of the two primary assembly tasks. An approach for the reduction of assembly time is the use of quick connecting elements for the interfaces, whose functionality is based on a combination of various DfA guidelines.

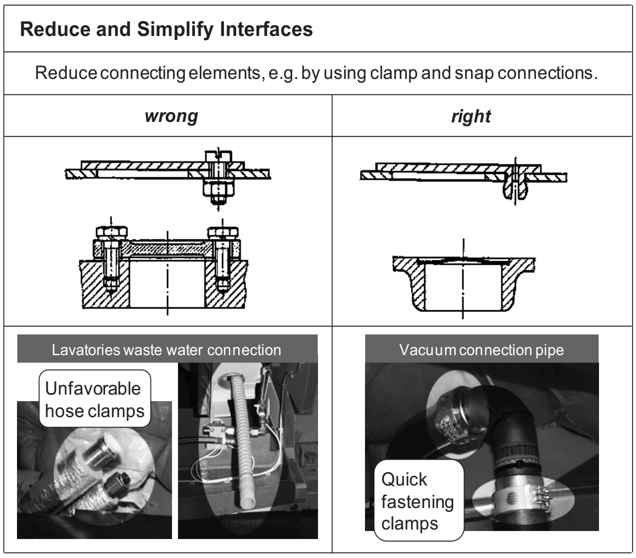

Figure 2. Interface connection solutions optimized with DfA (Design for Assembly)

In Figure 2 two examples for the connection of water pipes in connection with the equivalent guideline are shown. On the left hand side, a solution is presented, in which both hose ends have to be connected manually. The final closure of the interface requires the utilization of special tools and additional parts. From an assembly point of view, a favorable solution is displayed on the right hand side of Figure 2. In this case, an easy to handle quick fastening device is applied, that solely requires levering the latch around the duct.

3. MODULARIZATION OF THE A/C CABIN

In order to optimize the assembly, certain characteristics of the product structures of cabin components are required. The design of the product structure does not only follow the demands of the assembly. In the first instance, it has to comply with the requirements and intended functionality of the actual operation. A procedure for the development of product structures in consideration of various influencing boundary conditions is the key element of modularization methods.

An approach for the modularization was developed at PKT [3, 4]. The aim of the method is the generation of product structures that are designed for variety. The actual procedure is based on the improvement of conventional methods [5]. The procedures therein are adapted to the specific development of aircraft cabins. Several modularized concepts were developed regarding the cabin interior components such as galleys, lavatories, storage compartments, seats and linings. Figure 3 shows a comparison between the actual and a modularized product structure of an aircraft galley.

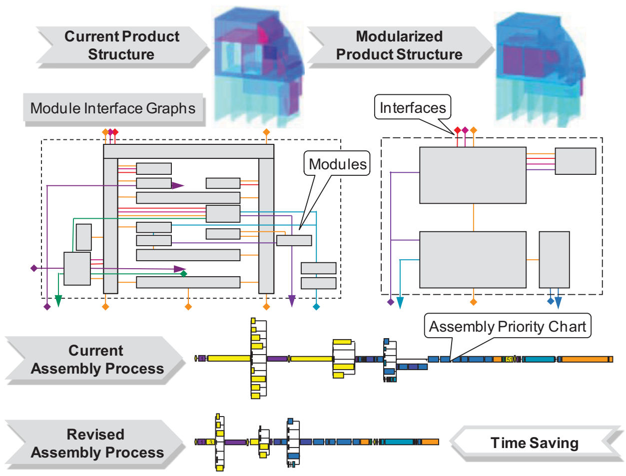

Figure 3. Current vs. modularized product structure – MIG and assembly chart

An essential element of the modularization procedure is the Module Interface Graph (MIG) developed at PKT and displayed in the centre of Figure 3 [3, 4]. The MIG represents the product structure in an abstract form. The illustration contains the components and the interfaces of the module. Boxes display the components, which are mapped approximately to their actual geometrical position. Lines between the boxes represent the interfaces. Different colors and shapes differentiate the specific interface depending on their type such as structural, energy or material. In the presented case of an aircraft galley, the modularization of the initial product structure leads to the aggregation of elements and so to the formation of two taller sub modules replacing the former differential design.

Subsequent to the development, an evaluation of the modularized concepts is performed to point out the achieved benefits. From an assembly point of view, the resulting assembly sequence represents the substantial aspect since it is decisive for the required expenditures regarding lead-time, costs or resources. For the graphical description of the assembly sequence, the assembly priority chart is used as shown in the lower part of Figure 3. This chart consists of a network plan in which rectangles represent the necessary assembly tasks while connection lines outline the interdependencies. The rectangles are plotted at the earliest point of time where the execution of the represented assembly task is possible. The connection lines end at the latest possible point of execution. The length of the rectangle illustrates the specific duration of the assembly task. Due to the reduction of internal interfaces, a saving of lead-time in the assembly can be achieved for the presented modularized galley concept [6].

The previously presented approaches towards novel assembly concepts show an evolutionary character. Essentially an optimization of existing product structures and the design of single parts are performed. For the development of truly innovative concepts new grounds have to be broken.

4. VISIONARY INTEGRATION CONCEPTS

The focus in the development of new concepts should consider the aircraft industry specific life cycle constellations. With regard to the long-term time horizons of the aircraft developments and the long operation times of the aircraft programs, it requires sustainable and progressive concepts to achieve the desired extensive lead-time benefits. In order to generate new ideas for cabin concepts, different approaches were deployed. As shown in Figure 4, brainstorming sessions were performed. In the course of a functional benchmarking analysis, comparable branches, such as the railway, coach or caravan industry, were investigated. In this chapter, various concepts are presented that were generated in the described manner. The concepts are still in the state of initial ideas. The expected benefits as well as the technical feasibility are analyzed afterwards.

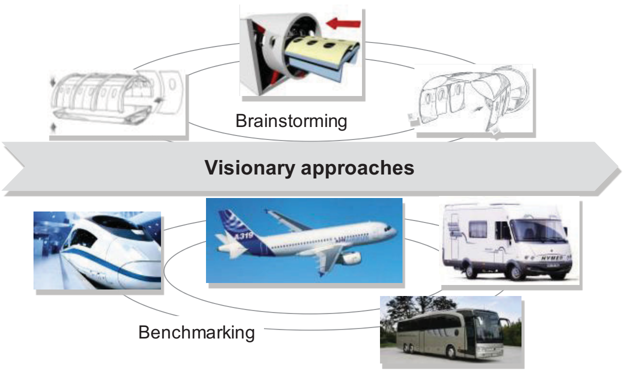

Figure 4. Visionary approach for innovative concepts

A differentiating cabin integration concept was introduced by Airbus. The focus of the concept is the application of large modules. The modules consist of the cabin lining and the overhead storage compartments. As shown in Figure 5, the elements are pre-assembled into an arch-like structure. Thereby a self-supporting structure is achieved. The modules are installed in one-step into the aircraft fuselage.

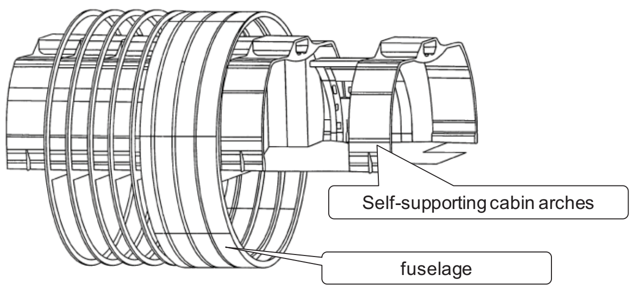

Figure 5. One-step cabin installation

The degree of pre-assembly of the described concept has proved to be too extensive. The resulting measures for transmitting the mechanical loads especially in the upper part of the module lead to additional structural weight. A concept developed by PKT also focuses on the cabin lining. Based on the lessons learned regarding the influences on the structural weight, the degree of pre-assembly was adjusted. The concept provides the pre-assembly of the hatracks and the wall panels of one side of the cabin into a module. In combination with the utilization of a handling device, the parallelization of assembly tasks is facilitated. Based on this basic principle the resulting effects as well as necessary design changes and adaptations are analyzed [7].

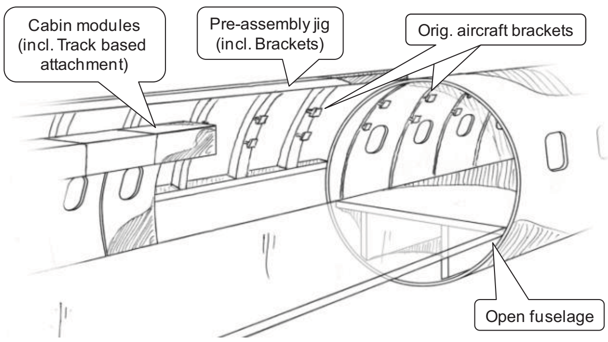

Figure 6. Overview of the track based cabin modules installation concept

The geometrical dimensions of the modules require a major reorganization of the aircraft production process. Since the modules do not fit through the passenger door, a wider entry to the fuselage has to be provided. Currently the fuselage is closed prior to the cabin installation A possible solution is the mounting of the cockpit section at a later point of the aircraft production process.. Thereby the whole fuselage cross section is available for the handling of the cabin components. In order to enable and support the module handling, the use of a special device is intended to which the modules are attached.

Figure 6 shows the resulting assembly situation. The bracket system of the modules is not only intended to provide the attachment but also the handling of the modules. The combination of the two assembly tasks handling and joining is achieved by the use of a rail based fastening system. The modules are attached to the handling device outside of the aircraft to enable and support the transportation and the mounting to the fuselage. Since assembly tasks are performed at earlier phases of the overall aircraft production process, a reduction of lead-time is expected. The utilization of a handling device in combination with cabin modules provides further opportunities. Through the formation of large coherent entities, extensive assembly tasks could be outsourced to a supplier. In addition, the device can be used not only for the assembly, but also to optimize the previous logistic processes.

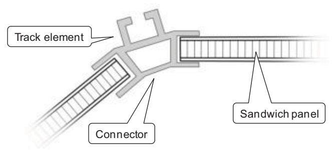

Figure 7. Hybrid design – structural integration of the track element into the hatrack

Next to the analysis of the benefits, solutions for the specific part design have to be developed to achieve the desired functionality. The measures for achieving the intended reduction of the lead-time must not violate with the superior requirements regarding the weight of the components and customer value. A possible specific weight optimizing design concept for the attachment system of the modules is presented in Figure 7. It contains the integration of the track as a structural part of the hatrack. The feasibility of a comparable type of lightweight design was approved in connection with a research project for aircraft galleys conducted by PKT [8].

5. THE FINAL ASSEMBLY LINE OPTIMIZED CABIN

The analysis and evaluation of previously presented concepts results in two key factors for the development of assembly optimized cabin architectures. An appropriate increase of degree of pre-assembly provides an ergonomic organization of labor work and enhanced logistic processes, as already applied in other industries. The parallelization of cabin pre-assembly and final installation processes is decisive for a substantial reduction of the overall aircraft production lead-time. The implementation of these key factors in the design of a cabin architecture resulted in the development of the final assembly line optimized cabin (FAL OK).

The analysis of the product structure and the assembly sequence, as shown in Figure 8, identifies the cabin lining and the passenger service units as the main drivers for the lead-time. Hence, the design of the FAL OK focused on these cabin components. Previously separated parts, such as the overhead storage compartment (hatracks), the service units (PSUs), different lining panels at the cabin ceiling and walls as well as cabin system components within the installation space, e.g. cabin lights and air outlets, were rearranged into one single module.

The hatrack represents the central element of the module. All other components are attached to the hatrack. Either the components are directly connected to the hatrack or supported through a frame element. The attachment of the panels to the frame consists of a film hinge which allows a slight rotation of the panels. As a result the handling of the module is facilitated. Furthermore, the panels serve as maintenance flaps. Opening the panels grants access to covered areas.

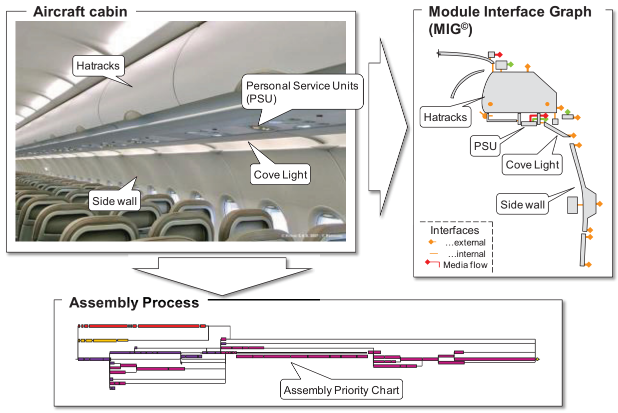

Figure 8. Aircraft Interior – product structure (MIG) and assembly sequence

The modular approach determines the design of the interfaces in between the modules and to the structure for brackets and installed systems. The main structural brackets of the module are located on the hatrack housing. System routings, such as cables and ducts, are aggregated into standardized connectors.

The mounting of the module is primarily determined by the attachment system. Due to the high complexity an appropriate bracket is designed. The bracket enables an easy joining. The manual handling of the modules is carried out as described below. The module is lifted and hooked into the fuselage sided bracket. Now the module is only held by the upper brackets allowing an upward rotation to the final position. With a translative motion the module is snapped in. The handling is supported by positioning elements and end stops. Compared to the present assembly principle, the installation of a module is performed faster. The possibility to handle single modules is in particular obligatory for maintenance, reconfiguration and refurbishing of the cabin during the life cycle of the aircraft.

As a further step several modules can be arranged to super modules. Thereby the actual assembly state of the modules is already achieved outside the aircraft. This degree of pre-assembly provides further applications regarding the installation and testing of the PSUs. By this means nearly the entire interior can be assembled and tested separately from the main aircraft production process, which represents the stated goal of pre-assembly and parallelization. The device based handling of a super module is performed as described below. Pre-assembled super modules set higher requirements to the installation process. A prerequisite is, however, that appropriate measures are taken to enable the handling of assemblies of this size. In order to perform the assembly, a special handling device is set up to convey the super modules into the aircraft fuselage and perform the joining motion. The device is designed to provide a dimensionally stable support of the modules. Thereby an unintended change in the alignment of the ready prepared modules is avoided. The application of directing and end stop elements enables a fast ergonomic handling as well as the achievement of the required positioning accuracy. This is achieved through a track system, temporarily placed on the seat rails. The handling device runs on these tracks, which determines the exact movement of the large embodiment.

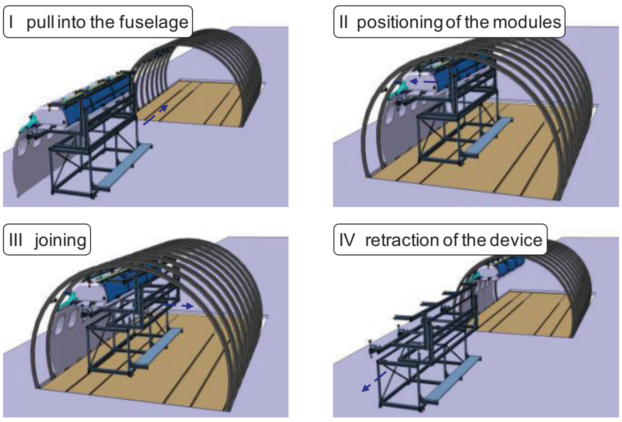

Figure 9. Device supported assembly process

The device based handling and mounting of the super modules requires extensive changes in the aircraft production process. In order to transport the modules into the fuselage, a large scaled access is obligatory. In today's assembly process the interior is installed subsequent to the joining of all fuselage segments. The cabin components are carried manually through the passenger doors. Thus, their maximum size is limited. In the new concept, the fuselage is kept open in the first instance, providing a large opening to perform the cabin installation. Afterwards the fuselage is closed by mounting the cockpit segment. A sequence of the device based handling of the super modules and the mounting process is shown in Figure 9.

For the verification of the feasibility of the developed concept, a technology demonstrator is set up to display the intended assembly principle. In Figure 10 a photo of the demonstrator unit is shown. In place of the module a hatrack dummy is used. To achieve the desired significance of the test arrangement, the actual bracket design is implemented. The existence of the interfaces between bracket and device as well as the attachment principle provides the possibility to display the assembly concept as far as possible in such a state of the development.

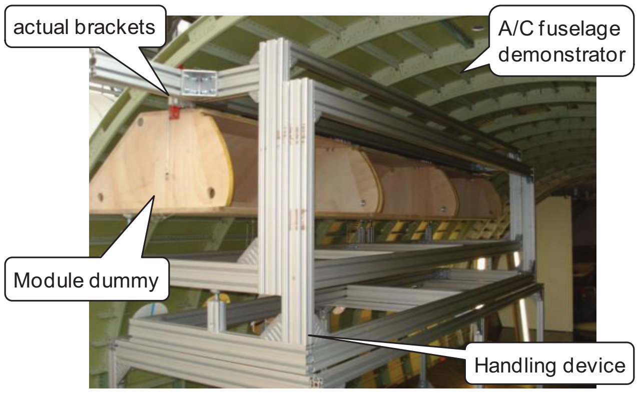

Figure 10. Assembly Concepts technology demonstrator

Based on the development results as well as the findings obtained in the context of the practical application an evaluation is performed. It is the resulting assembly time in particular, that is decisive for the evaluation. Therefore, established methods, such as the DFA analysis according to Boothroyd [9] or the ProKon analysis according to MTM [10], are applied. The results of the evaluation approve the expected benefits regarding the assembly time. The necessary installation time of the modules is significantly shorter, compared to today's cabin architecture. The assembly time accumulated in the final assembly line is directly relevant for the lead-time of the entire aircraft production process. As opposed to this, the assembly efforts that occur in the pre-assembly are rather determining for the production system efficiency.

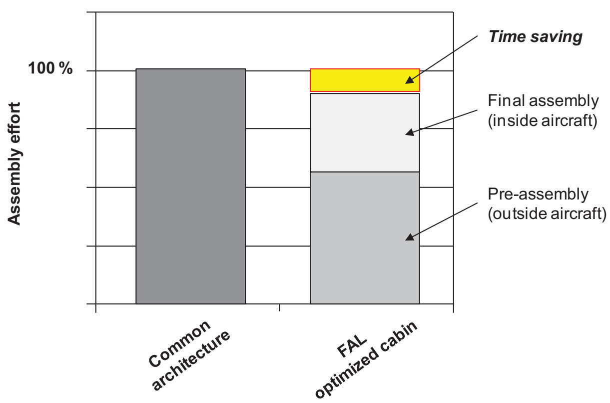

Figure 11. Evaluation of the assembly efforts

In order to perform a evaluation of the new concept, the assembly times, accumulated in both the final and the pre-assembly, have to be considered. The comparison of today's assembly times with the calculated values of the final and pre-assembly of the new concept shows that even the absolute assembly efforts can be reduced. By shifting assembly activities out of the fuselage, the ergonomics is significantly enhanced. The resulting reduction of assembly time prevails the additionally necessary efforts caused by the installation tools.

6. HOLISTIC VIEW ON CABIN PRODUCTION AND ASSEMBLY

The development of novel cabin installation concepts does not only affect the internal production processes but also the diverse elements along the value chain of the aircraft interior. After the design of the cabin module and the final installation concept the proceeding task actually is a step backwards. Approaches for the pre-assembly of the modules and its production environment are to be developed. But next to technologically analyses, i.e. product and process design, the several concomitant aspects are examined. In order to perform a holistic evaluation and validation of the concepts, the economical impacts have to be assessed.

To fit into the existing supplier environment is one of the important aspects of the concepts. It is the manufacturers intention to optimize the supply chain of the cabin interior. As shown in Figure 12 it is the target to implement a hierarchical structure in the supply chain. Regarding the aircraft cabin only one supplier shall be responsible for the cabin integration.

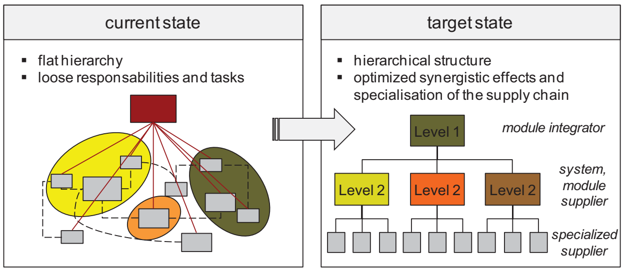

Figure 12. supply chain – current vs. target state

The general benefits of outsourcing, such as the reduction of assembly efforts, lower capital lockup or time saving in the installation process. However, the imminent risks have to be limited. It is essential to provide process reliability and maintain the high product quality. Therefore a severe supervision of the suppliers becomes necessary.

In this context further concepts for e.g. the supplier logistic and the airbus-own production facilities in particular, such as plant layouts, production lines or auxiliary equipment, have to be developed. Regarding the logistic, tools and information have to be made available. On the one hand side, the technological conditions, like module handling during transportation and mounting, must be created. On the other hand, resources to support the supplier in product design and process planning have to be provided.

A possible scenario for entire production process including the pre and the final assembly is shown in Figure 13. In this case an on-site cabin production is chosen. On the right hand side, a flow line based pre-assembly area is displayed. The production starts with the delivery of the parts, which afterwards are preassembled and tested to the install-ready modules. Afterwards the final installation in the aircraft fuselage takes place as described before. Thereby any further organizational structures like near-site, off-site or off-shore production is possible.

In order to be able to perfom a holistic evaluation of the novel concepts, a certain degree of detail has to be achieved. Implementing such concepts in future aircraft models is a strategic decision of the manufacturer. Because of the long product life cycles for civil aircrafts, the product design and the way of production is determined for a long time. But due to this fact, it is as well highly advisable to achieve a large step of innovation during a new development.

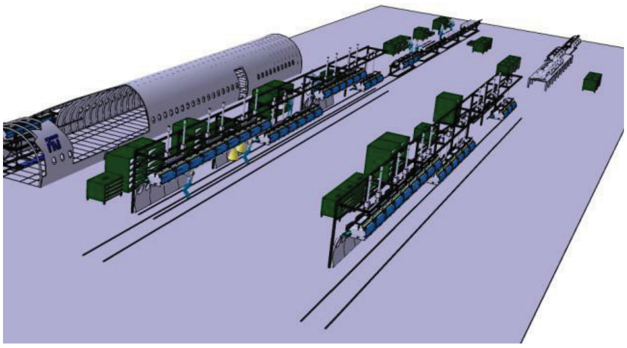

Figure 13. on-site cabin pre-assembly

7. CONCLUSION

The extensive analyses of the product structures and assembly processes of the aircraft cabin provide a solid basis for the development and evaluation of new integration concepts. The presentation of the results in form of the assembly priority chart and the Module Interface Graph enables an easy and effective usage of the gained knowledge. In this way, critical aspects of the assembly, for example the components influencing the lead-time, or optimization potentials can be identified. By means of the adapted method, a procedure was proposed which supports the systematic development of modularized concepts.

Different concepts were developed and analyzed. Thereby key factors were identified. The degree of pre-assembly and the parallelization of processes are decisive for the final assembly line optimized cabin. The concept advanced to a design and architecture that aggregates lining components and cabin systems into large modules. These modules are intended to be pre-assembled outside of the fuselage and carried into by a handling device. The benefits or both sided in the reduction of lead-time of the aircraft and total working hours. Hence, the new architecture and the application of tool sets shall be further enhanced. Furthermore, the concept provides the opportunity to perform research in the field of automation. As already established in other industries, it is a major goal to implement automated processes in the cabin assembly environment.

Regarding the general procedure in the development of novel concepts for cabin integration, further necessary measures are identified. To perform a holistic evaluation and deliver the prove of the concepts, further analyses have to be conducted. It is not only the technology aspects, like product design, that have to solved, but also the planning of processes and calculation of the diverse impacts that result from the concept implementation.

8. ACKNOWLEDGMENTS

The content presented in this paper is based upon the results of different joint research projects of Airbus and the Institute for Product Development and Engineering Design of the Hamburg University of Technology. The projects are public funded by the Federal Ministry of Economics and Technology of Germany as well as the Ministry of Economy and Labour Affairs of the Free and Hanseatic City of Hamburg.

- CAAM – Cabin Assembly and Manufacturing
- CoCaM – Concepts for Cabin Modularization
- ModIS – Modular Interior and System Integration
- Kabtec – Cabin Technology for Comfortable Passenger Platforms .

9. REFERENCES

[1] Andreasen, M.M., 1988, Design for Assembly, Springer-Verlag, London.

[2] Pahl, G., Beitz, 2007, W., Engineering Design, Springer-Verlag, Berlin.

[3] Blees, C., Krause, D., 2008, “On the development of Modular Product Structures: A Differentiated Approach”, International Design Conference – Design 2008, Dubrovnik, pp. 159-168.

[4] Blees, C., Jonas, H., Krause, D., 2009, „Perspective-Based Development of Modular Product Architectures“, Proceedings of the 17th International Conference on Engineering Design (ICED), Stanford, pp. 4-95-4-106.

[5] Erixon, G., 1998, *Modular function deployment: a method for product modularisation*, The Royal Institute of Technology, Department of Manufacturing Systems, Assembly Systems Division, Stockholm.

[6] Whitney, D.E., 2002, Mechanical Assemblies, Oxford University Press, New York.

[7] Krause, D. Gehm, M, Halfmann, N., 2009, „Visionary Integration Concepts for Aircraft Cabin Interior”, Proceedings of the 2nd International Workshop on Aircraft System Technologies, Hamburg, pp. 357-366.

[8] Krause, D., Gumpinger, T., 2008, “Lightweight optimization of an aircraft galley”, 3rd International Conference “Supply on the Wings”, Frankfurt/Main.

[9] Boothroyd, G., 2002, Product Design for Manufacture and Assembly, Marcel Dekker, New York.

[10] Deutsche MTM-Vereinigung e.V., 2006, Produktivitätsmanagement von Arbeitssystemen, Schäffer Poeschel, Stuttgart.