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The Process Chain for Aircraft Cabin Conversion

Identification and Optimization Algorithms

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Abstract

This report gathers part of the results obtained during the research period for the doctoral studies with the topic "Contributions to the Optimization Methodology for Aircraft Cabin Conversion". These results were obtained in cooperation with an industrial partner, called ELAN GmbH, and the University of Applied Sciences in Hamburg. The aim of this report is to investigate matrix based process optimization algorithms. The algorithms are applied to the process chain for aircraft cabin conversions, identified from the perspective of an engineering organization, different from the aircraft manufacturer. The algorithms should increase the efficiency of the engineering system and highlight key processes. The approach of this case study is unique, and the results deliver the optimal sequence of processes throughout the entire cabin conversion project. Results on this topic were published in the proceedings of three conferences.

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List of Abbreviations

AAP	Aft Attendant Panel
AIP	Attendant Indication Panel
C/B	Circuit Breaker
CFK	Carbon (Kohlenstoff) Faserverstärkte Kunststoffe
CIDS	Cabin Intercommunication Data System
CR	Customer Request
CVE	Compliance Verification Engineers
DEU	Decoder/Encoder Unit
DMM	Domain Mapping Matrix
DO	Design Organization
DOA	Design Organization Approval
DOM	Design Organization Manual
DSM	Design Structure Matrix
DSM	Dependency and Structure Modeling Methodology
DTS	Detailed Technical Sheet
EASA	European Aviation Safety Agency
EFPMS	Emergency Floor Path Marking System
EPSU	Emergency Power Supply Unit
ER	Emergency
FAA	Federal Aviation Administration
FAP	Flight Attendant Pannel
ICAO	International Civil Aviation Organization
IFE	In-Flight Entertainment
JAA	Joint Aviation Authorities
KBE	Knowledge Based Engineering
LLT	Long Lead Time
MDM	Multiple Domain Matrix
NTF	Non Textile Floor
OEM	Original Equipment Manufacturer
PD	Principle Diagram
PRAM	Pre Recorded Announcements and Music
PSU	Passenger Service Unit
SA	Single Aisle
SB	Service Bulletin
SSM	System Schematic Manual
STC	Supplemental Type Certificate
TC	Type Certificate
UML	Unified Modeling Language
VCC	Video Control Center

WD	Wiring Diagram
WTM	Work Transformation Matrix

1 Introduction

An engineering organization, especially in the aeronautical industry, needs a very efficient process management. The engineering results ‘travel’ inside the company, as well as between the company and the supplier / customer. Well managing multiple partners and high amount of data are examples of issues on which the efficiency of the entire system very much depends.

On the application of aircraft cabin conversions a methodology is studied for optimizing the process chain. In this report, the accuracy of the processes is not considered primarily, but the way to manage and optimize them. The way to handle the processes is a very important topic for the industry and represents a requirement from the certification authorities.

1.1 Aircraft Cabin Conversions Today

Today, an engineering company, different from the aircraft manufacturer, that delivers the engineering work for aircraft cabin conversions, has two possibilities to remain in the combat for a market share[1]. The engineering company is either on the list of main subcontractors of a large aircraft manufacturer, or has developed the capability to develop itself the complete design, including certification, without the support of the aircraft manufacturer. In the first case, the engineering company is dependent on the aircraft manufacturer and sometimes has to accept conditions, often not advantageous. In the second case, once the capability to deliver a safe design is build up according to the EASA requirements (see Section 3), missing information becomes an important issue, as the aircraft manufacturer – now the competitor – is the only one possessing the original drawings. Typical process flows for both cases are illustrated in Figures 1.1 and 1.2.

Usually the work is delivered in the form of a *Service Bulletin (SB)*. The SB’s represent the form in which the engineering work is further transmitted to the aircraft operator, which has the responsibility to implement the instructions comprised within. Such a document – the deliverable – usually contains:

- the title of the document and the aircraft involved,
- the design change specifications comprising of installation instructions and drawings,
- the requirements and the limitations,
- the operational characteristics,
- the necessary materials,
- the parts lists and kit lists,

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1 Our study (see the paper ‘Business Opportunities in Aircraft Cabin Conversion and Refurbishing’, **Niţă 2010a**) showed a very high potential of the cabin conversion market for the next 20 years.

- warnings and cautions for the workers.

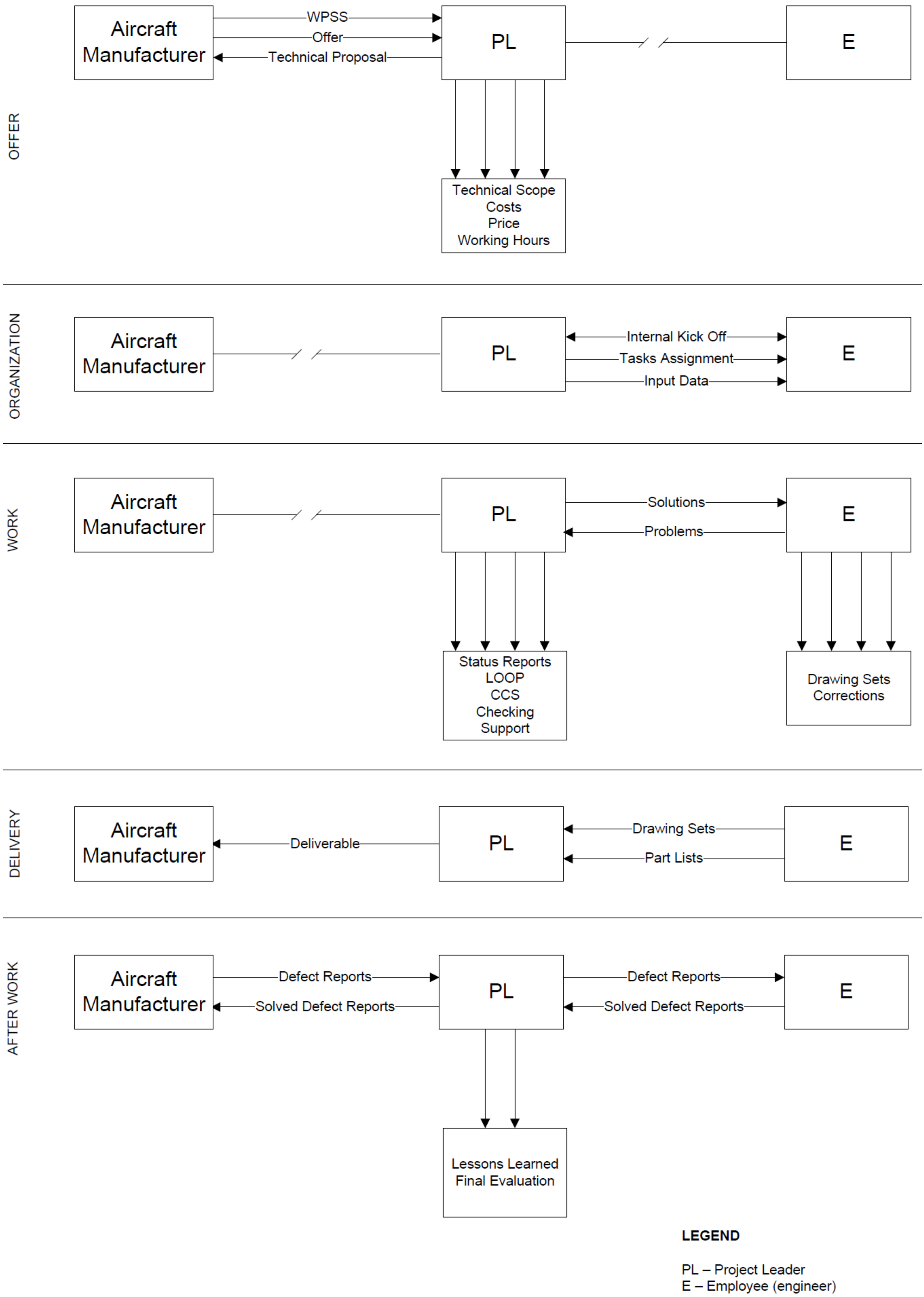

Fig. 1.1 Typical process flow when the company is subcontracted by the aircraft manufacturer

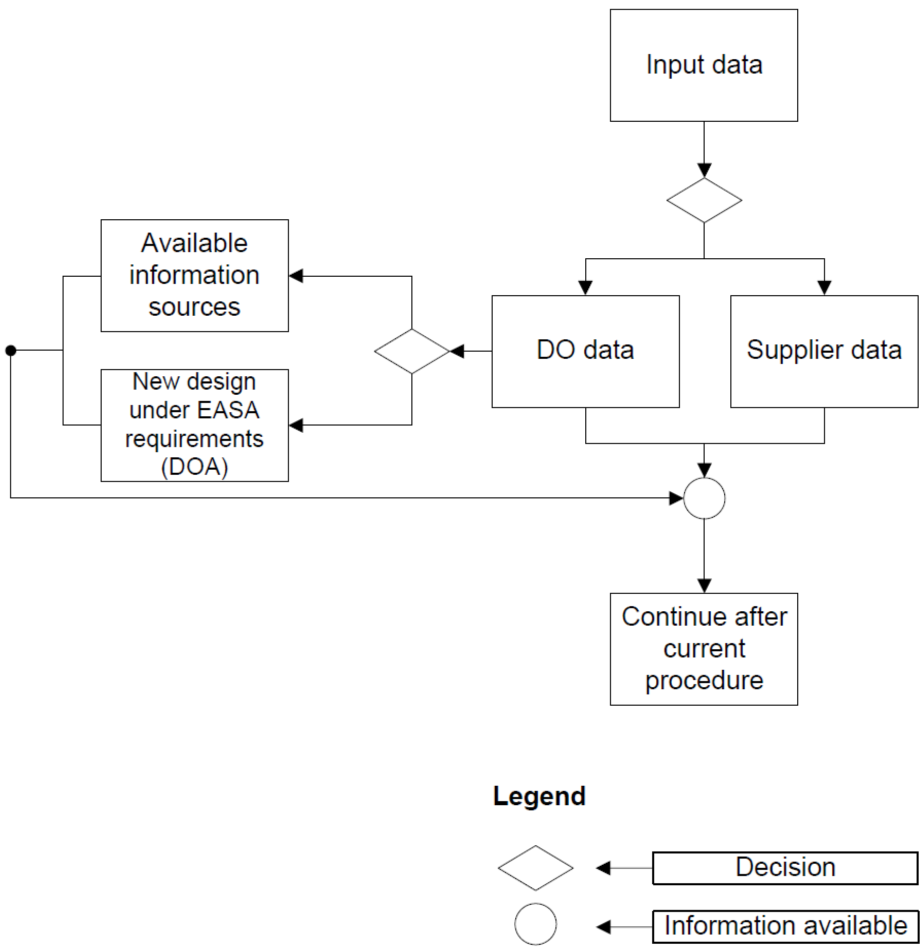

Fig. 1.2 Typical process flow when the company works independently from the aircraft manufacturer. Below, the current procedure refers to the same process flow as in Fig. 1.1, but the aircraft manufacturer box is replaced with a box called 'Customer'

The more interesting scenario is the second one, when the engineering company conducts independent cabin conversions. In this case the customer is the aircraft operator (airline or private person) directly. As showed in Figure 1.2, in order to achieve this, input data is required. The input data required consists mainly of aircraft cabin drawings. Appendix A describes a conversion scenario and the required input information. The aircraft manufacturer will be reluctant in sharing this information to the competitive engineering company. In some cases an agreement can be set[2].

Part of this data can be obtained through other suppliers of the customer. For instance, if the conversion implies changing the IFE system, the audio / video equipment manufacturer may be in the possession of data regarding electrical connection possibilities.

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2 In the USA the tradition is rather different than in Europe. Here agreements are easier to obtain and more advantageous due to the long tradition of OEM independent completion center. In Europe it s more difficult to obtain input information due to a different tradition: here the aircraft manufacturer works with many subcontracting companies, dependent on the OEM. The subcontractors have access to the information, only if the customer is the OEM itself, otherwise they become competitors for the aircraft manufacturer.

The task of delivering the conversion becomes very challenging. The process of changing the cabin from an initial destination / layout to a new one can only be performed under the supervision of the certification authorities. Section 3 describes the company set up criteria which need to be fulfilled.

1.2 Purpose and Structure of Work

This report has multiple objectives. *First*, it aims to present the current picture of aircraft cabin conversion providers:

- in their relation with the aircraft manufacturer,
- in their options for improving the business,
- in their challenges from customers and regulators,
- in their choices for capability growing.

The aircraft cabin conversions market is a very sustainable and profitable market, for a very first, simple reason: cabin upgrades occur in cycles, no matter how the world financial context looks like. For competition motives – greener, cheaper, lighter, more comfortable – aircraft operators need to constantly improve their product – which is represented by the cabin. Aircraft manufacturers also conduct cabin upgrades for their customers, they often cannot face a growing demand. More interesting is to analyze the view of engineering companies aiming to develop their capabilities to undertake independent cabin conversion designs.

The *second* objective is to illustrate the regulatory frame in which the engineering design work needs to be performed. An aircraft is build with several standard cabin configurations. Any change to the original design (called 'type design') needs to be approved by the certification authorities (for Europe, EASA). In order to be able to perform these changes safely, a very good 'Design Assurance System' needs to be established. The process flow optimization becomes a key factor.

The *third* objective is to investigate available process representation models. The most common representation is in the form of flow charts. Flow charts are suggestive and easy to visualize, but only if the process chain is simple. Complex process chains need easier-to follow representation models, capable in the same time of capturing the relations between processes in an unbiased way.

The *forth* objective is to identify the process chain for aircraft cabin conversion from the perspective of an engineering company (design organization), different than the aircraft manufacturer. Input for achieving this objective was given directly from the industry, through the company ELAN GmbH.

The *fifth* objective is to investigate and apply an optimization methodology. Chosen was a matrix based methodology, allowing several optimization algorithms. These algorithms have never before been used in this context.

To every objective a separate section was allocated. An Appendix gives an example of cabin conversion scenario and illustrates the challenges and way to solve them.

Section 1 **Introduction**: sets the scene and presents the current industry situation in the area of aircraft cabin conversions.

Section 2 **Airworthiness of Aircraft Cabin Conversions**: illustrates EASA requirements for conducting safe designs, these requirements are important as they reflect on the process optimization.

Section 3 **Process Representation Models**: compares several process representation methods and selects the one that allows a promising mathematical approach to process optimization.

Section 4 **Process Chain Description**: presents a possible process chain for cabin conversions to be followed by an engineering company different than the aircraft manufacturer.

Section 5 **Process Chain Optimization with Dependency and Structure Modelling Methodology**: applies and extrapolates a matrix based process investigation and optimization method.

Section 6 **Conclusions and Outlook**: applies and extrapolates a matrix based process investigation and optimization method.

2 Airworthiness of Aircraft Cabin Conversions

In aviation, the safety of the crew and passengers is quantified through the term *airworthiness*. If it is shown that the aircraft complies with the applicable standards, a *certificate of airworthiness* is issued for each aircraft individually, demonstrating that the required level of safety is fulfilled. Responsible for providing standards for the aviation safety and environmental protection are certification authorities. Certification authorities are also responsible for approving any design, manufacture or maintenance of airplanes or components, as well as for monitoring the implementation of the safety rules. Certification authorities are:

- International Civil Aviation Organization (ICAO)
- Civil Aviation Authorities
- Joint Aviation Authorities (JAA)
- European Aviation Safety Agency (EASA)[3]
- Federal Aviation Administration (FAA)

Any organization that undertakes design work needs to apply for a Design Organization Approval (DOA). Every product designed by a design organization holds a *type certificate (TC)*, where all the specifications of the product are mentioned. The respective design organization is approved by EASA and the type certificate is also issued by the Agency. This type certificate shows that the design organization has proven compliance of the *type design* with all applicable requirements (21A.14, **EASA 2009a**).

In the case of **cabin conversions**, one is not talking about designing products, but designing changes to products. There are either *minor* or *major changes* to the type design. Minor changes are to be classified and approved either by the Agency or the design organization (further referred to as DO), under a procedure agreed with EASA (EC 1702/2003, subpart D, 21A.95, **EASA 2009a**). Major changes can be classified by the TC holder but can be performed only under the surveillance of the authority. Design Organizations, other than the TC holder, need a *supplemental type certificate (STC)* and the approval from the TC holder to perform the changes (see Subpart E from EC 1702/2003, **EASA 2009a**).

To summarize, cabin conversion certifications are possible under the following categories:

- Change of Type Certificate
- Supplemental Type Certificate - STC
- Repair approval

Optimization of cabin conversion design processes is required by EASA (**EASA 2009a**). This is reflected in the criteria for the DO approval, which will be further shortly presented.

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3 Further on, the requirements coming from EASA will be discussed.

The document in which these requirements are stated is Annex Part 21, Subpart J, to (EC) No. 1702/2003 (**EASA 2009a**). This document sets the requirements that need to be fulfilled by any organization wanting to develop design work for aeronautical products. Requirements from Subpart J interfere with requirements from other sub-parts.

The Acceptable Means of Compliance and Guidance Material illustrate the means by which the requirements stated in the rule can be achieved. Once the compliance is demonstrated, the applicant receives a Type Certificate or, as it is the case, a Restricted or a Supplemental Type Certificate (**EASA 2009b**).

Cabin conversion designs are, as mentioned before, changes to the type design. An applicant for a change to the type design of a product needs to submit an application which has to include the description of the change, as well as the identification of (article 21A.93 **EASA 2009a**):

- parts of the type design and manuals affected by the change,
- certification requirements and environmental protection requirements,
- necessary re-investigation in order to show compliance.

The EASA certification specifications – CS 25 and CS 23 – provide the requirements for certifying cabin related designs. Additional certification requirements in the field of cabin conversions come from operation – JAR Ops.

To set up a design organization in the form required by EASA to issue the approval, several requirements are to be fulfilled:

- A *scope of approval* needs to be clearly defined: For cabin-related activities the technical fields implied in the definition of the scope are:
    - Installation of Avionics and Equipment
    - Environmental Systems
    - Electrical Systems
    - Cabin Interior
    - Galleys or other interior equipment
- A *specialized personnel* covering key functions, depending on the scope of work; the absolute minimum for a very limited scope could be defined for 5 persons, as such:
    - Head of the DO
    - Head of the Office of Airworthiness
    - Compliance Verification Engineer
    - Design Engineer
    - Quality Management Engineer
- A *monitoring system* for preventing undetectable errors and failures, which may not be observed by the Agency.
- A *design assurance system*, that includes the independent monitoring of compliance.

- A *design organization manual* that describes the organization, the relevant procedures and the products or changes to products to be designed.

Through the DOA itself the Agency is looking to develop among the design companies a safer and more complex self-control function. The purpose is to discharge the responsibility of certifying the product on the engineering and certification team of the DO, while EASA is supervising carefully the actions. The technical processes inside the organization, together with the tools, become of major importance.

The implementation of the EASA standards for creating a Design Organization can follow this sequence (Figure 2.1) (**CAMR 2009**):

- Preparation
- Implementation
- Evaluation
- Learning

The *preparation phase* includes:

- Understanding the EASA requirements for DOA
- Identifying the purpose of DOA
- Identifying the objectives for getting the DOA
- Identifying and evaluating the consequences of receiving the approval
- Identifying the consequences of not having a DOA
- Identifying the most important points of the integration of the new organization within the company
- Assigning a responsible person/team capable of evaluating the DO implementation process
- Determining the functions and responsibilities of the personnel involved in getting the DOA
- Identifying the activities, already existing in the company, which can be part of DO
- Defining clear goals and proper management strategy for implementing DO concept
- Identifying the key performance indicators
- Indentifying the type of necessary documents inside the DO, by respecting EASA indications
- Identifying simplest and clearest way to create the documents, by considering aspects like: form, annotations, signatories
- Preparing the *implementation plan*, based on a schedule
- Preparing the implementation processes
- Evaluating the costs and the revenues

Part of the *implementation plan* prepared during this phase should, first of all, be all the aspects quoted in the Part 21 and the other relevant parts referred to in this chapter. Secondly, other sources, such as technical documentation standards or quality management standards, can be taken into account. This means that the implementation plan must include prescriptions regarding:

- The setting up of the Design Assurance System
- The functions and responsibilities of the personnel inside the DO
- The creation of the DOM
- The way the Monitoring System will function
- The tools necessary for the flawless functioning of the DO
- The showing of compliance
- The Quality Management Strategy

The preparation phase is of major importance and implies the contact with the EASA.

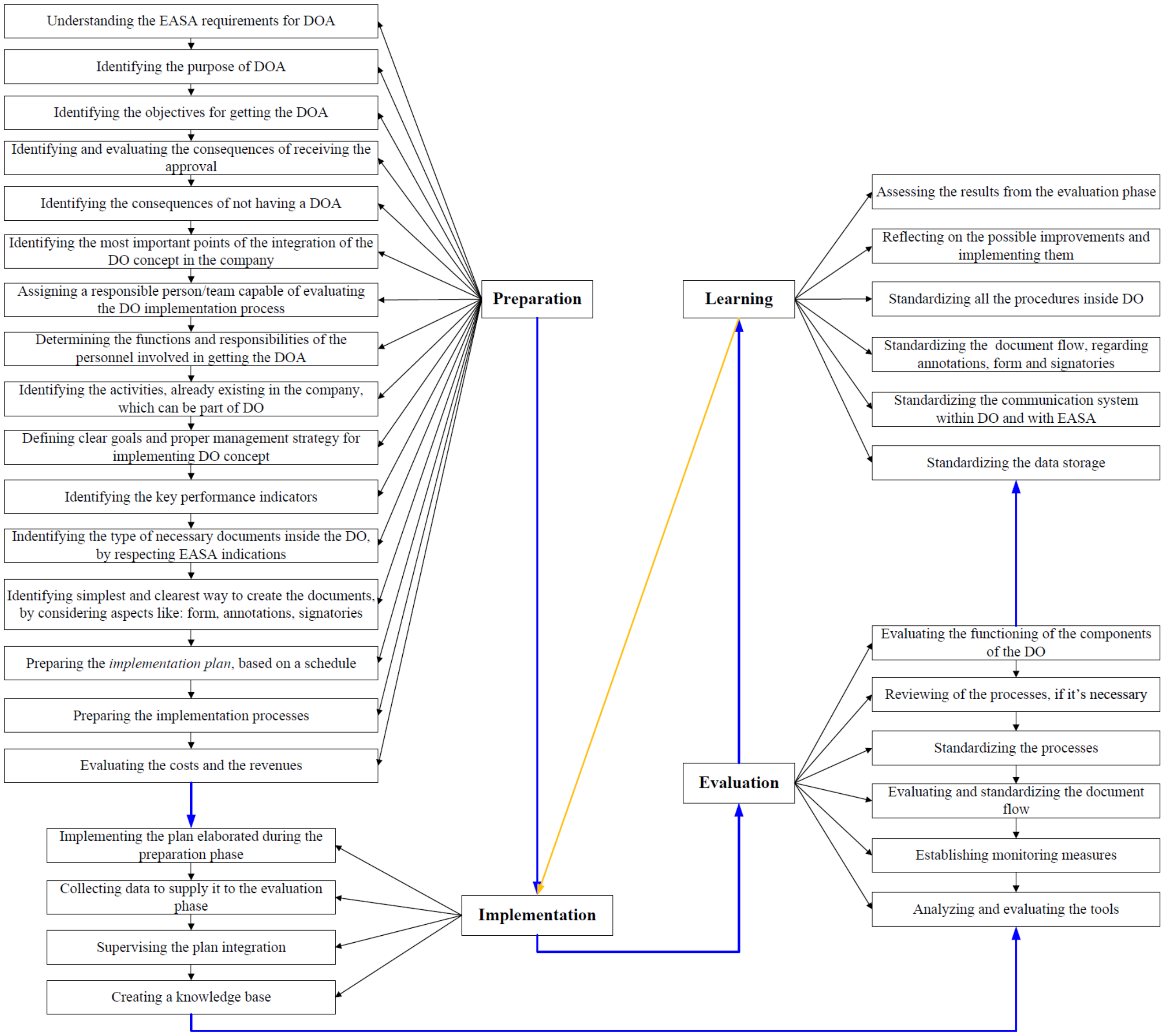


Fig. 2.1 Preparation for DOA implementation – Process Chain representation

The *Implementation phase* includes:

- Implementing the plan elaborated during the preparation phase
- Collecting data to supply it to the evaluation phase
- Supervising the plan integration
- Creating a knowledge base

The *Evaluation phase* includes:

- Evaluating the functioning of the components of the DO
- Reviewing of the processes, if it's necessary
- Standardizing the processes
- Evaluating and standardizing the document flow
- Establishing monitoring measures
- Analyzing and evaluating the tools

The *Learning phase* includes:

- Assessing the results from the evaluation phase
- Reflecting on the possible improvements and implementing them
- Standardizing all the procedures inside DO
- Standardizing the document flow, regarding annotations, form and signatories
- Standardizing the communication system within DO and with EASA
- Standardizing the data storage

These phases were established with the help of the methodology for implementing the concurrent engineering concept developed at the Center for Advanced Manufacturing (CAMR) of the University of South Australia. The concurrent engineering concept will also be presented in the following chapters.

3 Process Representation Models

In order to establish and improve processes, to document them (e.g. for compliance reasons), or to define roles and responsibilities as well as to understand the relation between them, the process planning and modeling activities have a vital importance. Models allow processes to be controlled and analyzed with the purpose of improving them. There are numerous approaches available to support process management, each depicting various aspects.

3.1 Flow Charts

Typically, processes are modeled as flow charts that produce large process maps to describe how a company is progressing from a customer request to the delivery. They are focusing on information flows from one activity to another. Most of them capture the interactions between tasks, documents, events, roles or resources, and time (see Table 3.1). Some of these methods, applicable also in aerospace industry, are (**König 2008**):

- *Structured Analysis and Design Technique (SADT)* - it is part of a series of structured methods, that represent a collection of analysis, design, and programming techniques. Basically it describes systems as hierarchy of functions and can be used as a functional analysis tool; it uses successive levels of details: either through a top-down decomposition approach or by means of activity models and data models diagrams (**Nam Pyo Suh 2001**);

- *Integrated Definition (IDEF)* - is a family of modeling languages covering function modeling, information modeling, knowledge acquisition or object-oriented analysis and design; IDEF0 is a language building on SADT and IDEF1 addresses information models There are up to 14 languages (developed through the US Air Force funding), each having a specific purpose; IDEF 3 refers to Process Description Capture (**Mayer 1995**);

- *UML-Activity diagrams* - includes a set of graphical notations techniques to create abstract models of specific systems; it uses entity relationship diagrams and work flow modeling (**Noran 2009**);

- *Business Process Modeling Notation* (BPMN) - provides a graphical notation for specifying business processes in a Business Process Diagram (BPD); it is similar to UML; it uses elements like flow objects, connecting objects, swim-lanes and artifacts (**Simpson 2004**);

- *XML Process Definition Language (XPDL)* - is a format standardized by the Workflow Management Coalition (WfMC) to interchange Business Process definitions between different workflow products; it has been designed specifically to store all aspects of a BPMN diagrams (**Van der Aalst 2009);**

- *Process Module Methodology (PMM)* - methodology for the flexible planning, monitoring and controlling of highly complex dynamic development processes; The fundamental approach adopted here is to specify the process steps but not the order in which they should occur, allowing the process to be amended easily when they run (**Bichlmaier 1999**);

- *Event-driven Process Chains (EPC),* either event-driven or object-oriented (oEPK) - are used to analyze processes for the purpose of an ERP (Enterprise Resource Planning) implementation, which is a computer software system used to manage and coordinate resources, information and functions of a company (**Van der Aalst 2009**);

- *PERT (Program Evaluation and Review Technique*) - is a method to analyze the involved tasks in completing a given project; it identifies the minimum time needed to complete the total project; it uses key terms like: critical path, lead time, optimistic time or expected time (**Chanas 2001**);

- *Critical Path Method (CPM)* - it determines critical activities using the same approach as PERT: by representing the duration along with the processes and relations between them and by calculating meaningful durations like for instance the latest when an activity can start without affecting the project (**Chanas 2001**);

- *Work Breakdown Structure (WBS)* - illustrates all the activities being part of a project, by breaking them down up to achieving the deliverables; it is a highly used method also in the aerospace sector: Airbus has set the WBS usage as requirement for their subcontractors. The WBS is detailed enough and can be used as management control tool (**AP 1500**). Along with the WBS, the OBS (Organization Breakdown Structure, for personnel and responsibilities) and the RBS (Resources Breakdown Structure, for identifying resources associated to the work package) can be used;

- *GANTT* – is a bar chart illustrating a project schedule, by representing start and finish dates; it is highly used in every domain of activity.

Table 3.1 compares some of the methodologies briefly presented above. These methodologies were studied having in mind the type of processes involved in cabin conversion. However, flow charts are not the only available method (see next paragraph).

Table 3.1 Comparison of common process modelling methodologies (**König 2008**)

	Task				Document				Event					Role / Ressource					Time		
Process Modeling Methodologies \ Constructs	Function	Operation	Activity	Transition	Data Object	Attribute	Input	Output	Event	Message	Object	State	Places	Organizational Unit	Ressource	Attribute	Methods & Tools	Resources	Milestone	Lead Time	Start / End Time
UML	x		x		x	x	x	x	x		x			x	x	x	x		x		
EPC	x				x				x					x	x				x		
oEPK		x				x				x	x			x		x					
IDEF			x				x	x				x									
Petri-Net			x	x									x								
PMM			x				x	x									x	x	x		
PERT			x																	x	x

3.2 Matrix Representation

Another possible way of representation for system analysis and management is the use of matrices. Recently developed, was the Design Structure Matrices (DSM) and its derivatives: Domain Mapping Matrix (DMM) – allowing mapping between two different views on a system and Multiple Domain Matrix (MDM) – combining a DSM and a DMM into a complete system representation.

The DSM is a square matrix that shows relationships between elements in a system (**DSM 2009**). The Design Organization, as EASA requires, needs to function as a system which in the end needs to prove to the authorities that it can deliver a certified design or modification to a design. The optimal functioning of the DO as a system is determined by interactions between its constituent elements. The DSM provides a simple representation, allowing the analysis of these interactions and permitting their visualization.

The first step in using this approach is to identify all the sub-systems of the systems. In our case the system is represented by the set of tasks to be performed inside the Completion Center, for achieving a certified cabin conversion. The tasks names are placed down the side of the matrix as row headings and across the top as column headings in the same order. If there exists an edge from node *i* to node *j*, then the value of element *ij* (row *i*, column *j*) is unity (or marked with an X). Otherwise, the value of the element is zero (or left empty). In the binary matrix representation of a system, the diagonal elements of the matrix do not have any interpretation in describing the system, so they are usually either left empty or blacked out (see Figure 3.1) (**DSM 2009**).

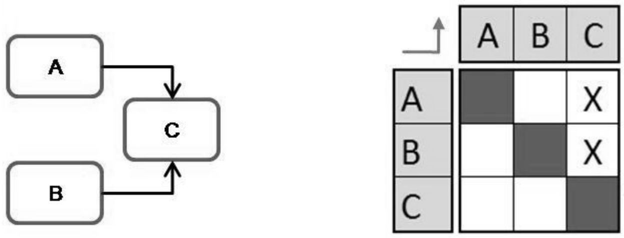


Fig. 3.1 Design Structure Matrix in contrast to a direct graph (digraph) (**DSM 2009**)

The difference between the two representation forms is shown in Figure 3.1. Matrices are useful in systems modeling as they can represent the presence or absence of a relationship between pairs of elements in a system. It provides a mapping of the tasks and allows the detailed analysis of a limited set of elements in the context of the overall structure. Reading along a specific row reveals which tasks receive information from the task corresponding to that row (**DSM 2009**).

The way to 'read' the matrix is:

- Task A transfers information to Task C
- Task B transfers information to Task C

If the arrow would have been positioned the other way around, then the following relations would have been valid:

- Task C transfers information to Task A
- Task C transfers information to Task B

There are three types of configuration possibilities of the interrelations between tasks (see Figure 3.2, **Eppinger 2002**):

- Parallel
- Sequential
- Coupled

The parallel configuration shows that the tasks are independent on each other (example: between tasks A and K there is no information flow). The sequential configuration shows the information flow is unidirectional between two tasks (example: task C receives information from task B). In the case of coupled tasks the information flow is dual, coming from both start and end task (example: task H receives information from task E, task D receives information from task E and task D gives back information to task H). In contrast to Figure 3.1, here the arrow is set downwards, which means the feed-forward information flow is visible in the lower half of the matrix. The user can set the direction as he likes.

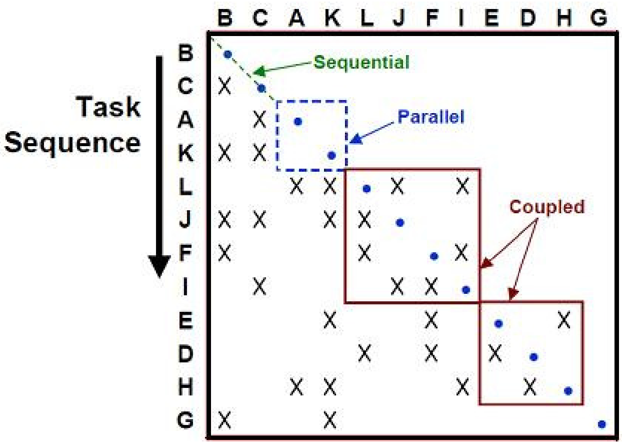


Fig. 3.2 Configuration possibilities of the interrelations between tasks (**Eppinger 2002**)

3.3 Concurrent Engineering Concept

The Concurrent Engineering concept was found to be suitable for optimizing design cycles, especially in the preliminary phases. This paper aims to describe the processes behind an airworthy design, whether it is a complete cabin design or the design of a cabin modification. Optimizing a process chain of a complex system, like a Completion Center, means looking to minimize the errors. Using a concurrent engineering approach, for example by developing parallel design tasks, was found to be helpful with this respect.

In this paragraph, the concept is briefly presented, as a helpful methodology to be considered when implementing design processes inside Completion Centers.

Concurrent Engineering takes into account all the elements of the life cycle of the product at an early stage and in the same time (or concurrently). Therefore, processes like establishing requirements, creating and running computational models or testing the product are optimized through the iterative design approach (**Zhong 2009**).

Some of the driving characteristics of this concept are:

- Parallelization of the design tasks
- Early design reviews
- Software tools, allowing adaptation of the design in an early phase
- Good communication among the engineering team

To achieve the results which come along with the implementation of Concurrent Engineering, it is necessary to create a specific design environment in the form of a facility allowing efficient data interchange and communication between the engineers responsible for different tasks. Such a facility should be modeled through at least the use of (**DLR 2009**, **ESA 2009**):

- An array of design stations equipped with Hardware and Software tools suitable for each discipline
- Video conferencing equipment
- Access to Knowledge databases

The use of this concept within a Completion Centre can be done by integrating the perspectives of all design phases in the early phases of the concept. In cabin refurbishing it is important to consider the certification requirements already in the preliminary discussions. The consequence is reducing later modifications and delays in the end phases of the cabin design.

Why Concurrent Engineering and DSM?
Concurrent Engineering can also be described through the DSM model of representation, as it is shown in (**Schlick 2008**). This is the reason why the decision is taken to research more in depth the matrix way of process representation.

Another argument is that the method has been already applied by one of the most important aircraft manufacturers, Airbus, in an attempt to implement the Multidisciplinary Design Optimization in analyzing complex new projects, like the A3XX (the present A380). A way of dealing with such challenges is by breaking the large task of system optimization into smaller concurrently executed, and yet, coupled tasks, identified with engineering disciplines or subsystems (**Sobieski 1989**). Cabin design and conversion, is similar with aircraft design, in which the Multidisciplinary Design Optimization has been applied. The only difference is the scale: even if cabin design is only a part of aircraft design, there are a lot of interfering systems which need to be integrated. Therefore a representation allowing both a global and a detailed view, an hierarchical and a non-hierarchical view between tasks is to be considered also in the process representation of this paper.

4 Process Chain Description

4.1 The Process Chain for Cabin Design

4.1.1 Process Chain Description

At a smaller scale, the cabin design reflects the process steps of aircraft design. Once the fuselage conception is completed, the cabin requirements for safety and operation must then be reflected in the cabin architecture development. This section approaches cabin architecture development issues and aims to determine the process steps involved by the modeling.

The cabin architecture needs to integrate a large amount of different systems and components:

- Cabin communication
- Entertainment system
- Air conditioning system
- Oxygen system
- Emergency floor path marking
- Lights
- Service (galleys)
- Utilities (lavatories, stowages)
- Seats (flight attendants and passengers)

The overall optimization and integration of parametric models becomes an important issue. When observing the development of system architecture (**Reis 2010**), the following process steps can be identified for the cabin architecture:

1. Creation of a component library
2. Definition of placement constraints
3. Generation of an initial architecture
4. Identification of relevant parameters
5. Investigation of competing architectures
6. Post-processing and analysis of the results

The input data required when defining the cabin architecture (i.e. an initial Step 0) is a fuselage shape optimized with respect to cabin requirements. An optimized fuselage shape accounts for both performance-based parameters, such as fuselage slenderness, and comfort-based parameters, such as number of seats abreast. **Niţă 2010b** presents a handbook method for fuselage preliminary design and cabin optimization.

Steps 1 to 6 use a Knowledge Based Engineering (KBE) approach. This approach uses knowledge databases and data association (**Russell 2003**) in order to automate the design process. Section 2.2 details this concept.

Step 1.) refers to the implementation of a reusable component library into the architectural development. Items like seats, galleys, lavatories or stowage bins can be stored together with their parametric description and linked to the fuselage, inside dedicated zones.

Step 2.) defines first of all the regulatory placement constraints (e.g. no item needs to be positioned within a specified area near the emergency exits). However, operator constraints (e.g. the first overhead stowage bin on the right contains the In Flight Entertainment – IFE system) must be considered as well.

Step 3.) generates possible architectural layouts according to the previously defined constraints.

Step 4.) chooses the relevant parameters which bare the optimization. For the cabin design, a performance based optimization concentrates on reduction of drag, fuel consumption or mass. These parameters are influenced, for instance, by the fuselage slenderness parameter.

Step 5.) investigates the resulting architectures after running the optimization.

Step 6.) concludes upon obtaining the values of each parameter and evaluates the resulting configurations. In the end a valid configuration, fulfilling the constraints, will be generated.
Currently a KBE software called Pacelab Cabin, created by PACE GmbH, is available for generating preliminary cabin layouts. This tool is able to cover the 6 defined steps. However, the capabilities depend on the available database and the optimization possibilities are limited. An optimized cabin architecture can be achieved on the basis of Pacelab Cabin if all the systems in the cabin are considered at the same time. Currently the tool is not able to include for instance the Passenger Service Unit (PSU) and the overhead stowages layout in connection to the seats layout.

The fulfillment of the process steps enumerated above would ensure (**Reis 2010**):

- Optimized physical placement of cabin items.
- Optimized sizing with respect to regulatory, geometric, volumetric, electric and thermal constraints.
- Optimized centre of gravity variance and its impact on aerodynamics, mission and operational flight performance.
- Optimized cabin architecture changes against fuselage sizing process and the impact on mass, range, fuel burn and cost (this evaluation is especially important for cabin refurbishing and conversion).

4.1.2 The Knowledge Based Engineering Concept

The KBE concept was proposed as a viable approach for cabin architecture development. This sub-section aims to deliver the background for a better understanding of this concept.

Several studies have been performed on KBE and its utility. It is commonly agreed that Knowledge Based Engineering aims to capture and reuse product and process multidisciplinary knowledge in an integrated way. The results should reduce time and cost for engineering applications, automate repetitive design tasks (like multiple seat representation in the cabin layout), and support conceptual design activities. KBE allows manipulating the geometry and annexed knowledge and supports the investigation of multiple what-if on their design.

A tool using KBE, such as Pacelab Cabin, gathers technical rules, generated by customer or certification requirements, into a knowledge database. The rules can then be used, modified and updated or newly created by the user. During the negotiations phase in the case of cabin upgrades and conversions, it is important for an engineering office to be able to create fast cabin layouts and show to the customer the many modification possibilities. An illustration of some results obtained with this program is shown in Figure 4.1 (see also **Szasz 2009**).

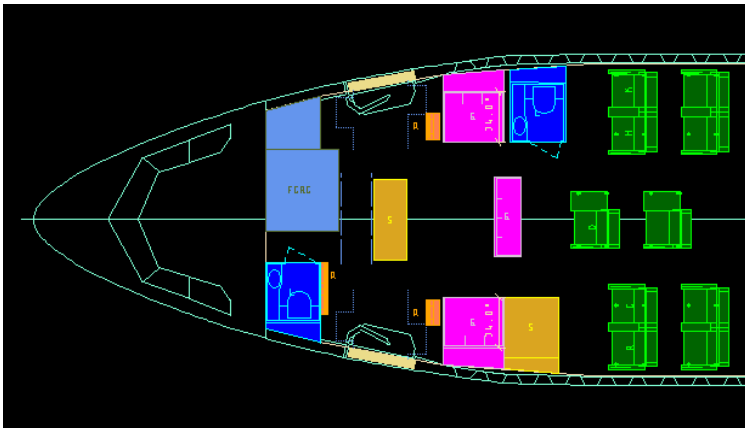


Fig. 4.1 Cabin layout obtained with Pacelab Cabin tool

4.2 The Process Chain for Cabin Conversion

4.2.1 Process Chain Description

There is not just one path towards achieving an optimized process chain for cabin conversion. The processes can be adapted according to the needs and the scope of each project. The only condition for the company is to have a Design Organization Approval (DOA) showing that the EASA prescriptions are fulfilled.

The flow of processes and documents for cabin conversion should be in such a way organized, that it minimizes parameters like: time, costs, effort and, especially, errors. A typical path is described below.

The first attempt to define the customer requirements is made in the Offer Phase. If the offer is accepted by both partners, then the technical document, describing it and the technical implications, serves as input for the Conversion Processing. The output of the processing, summarized in the Hand Over Phase, comes back to the customer, and a loop closes (see Figure 4.2).

In this paper, the proposed Process Chain is divided into three parts:

- Part A, referring to the offer phase description,
- Part B, referring to the description of the processes for completing the conversion,
- Part C, describing the end processes and the outputs received from the customer.

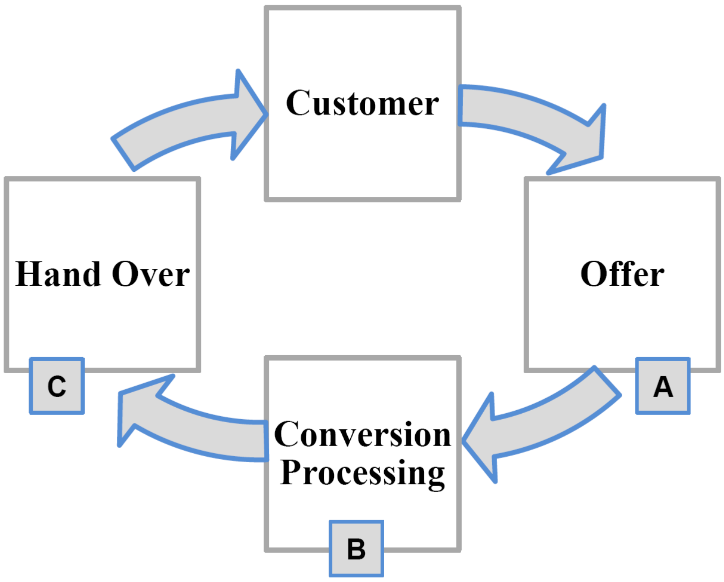


Fig. 4.2 Process chain concept for cabin conversions

A: Offer

The Offer Phase starts with the Customer Request which is formalized through a preliminary document briefly describing the requirements of the customer and the implications within the design organization. In the same time, this document represents the first decision gate for both partners. If the two parts agree, then the Technical Offer will describe in detail the actions which are to be followed in order to finalize the customer request.

Parallel to this activity, the engineering office should make a feasibility study, to see if it is a benefit for the company to accept the proposed task from the customer. For example, it would be quite difficult to comply with the requirements from customers having products not conforming to the type certification basis. If each decision gate ends with a “yes”, the outputs enter then the Process Chain B.

B: Conversion Processing

The conversion cycle gathers all the phases related to the design and certification of the conversion work. These phases are:

1. Concept
2. Definition
3. Design
4. Adjustment
5. Certification

Each phase has its own number of sub-phases, which can also be further divided into smaller processes. Their representation and optimization is performed in Section 5.

1. Concept Phase

The first stage in the development of a product is the conception. The actions required at the beginning of a project are mainly referring to:

- understanding and filtering the customer requirements,
- understanding and filtering the certification requirements,
- making an internal feasibility study,
- studying the design possibilities,
- organizing the work flow,
- developing the preliminary design,
- developing the testing and verification methods.

2. Definition Phase

The definition phase approaches the same issues more in depth, with the purpose of achieving the final version of the design. The main steps are:

- defining the certification basis,
- defining the Means of Compliance,
- defining the process steps,
- assigning and organizing a team,
- analyzing mechanical and electrical loads, tolerances,
- analyzing interference between components,
- testing the design,
- validating the design concept.

3. *Design Phase*

The design engineers perform the design work based on the prescriptions of a Chief of Design, assigned already in the conception phase, and those of the airworthiness engineers and Compliance Verification Engineers (CVE). Mainly, during this phase it is required to:

- perform the design according to the prescriptions elaborated during the earlier phases,
- verify the design (Design Verification Engineers),
- give feedback to the project leader.

4. *Adjustment Phase*

The adjustment phase sums up those activities aimed to improve the overall functioning of the company delivering the conversion. Some of the processes belonging to this phase are:

- getting feedback from every engineering department,
- detecting points of improvement,
- proposing optimized solutions.

5. *Certification*

According to CS 25.21 (**EASA 2009c**) the certification process of an aircraft means proving that the design complies with all the requirements stated in the specifications emitted by the Authority. For efficiency, the certification process should start from the early phase of the conception, in parallel to the design development activities. For reducing time and errors, certain aspects need to be already considered when the concept is developed. The certification process is under the responsibility of the Office of Airworthiness (**EASA 2009a**).

Mainly the steps are:

- establishing contact with the authorities,
- creating the means of compliance (tests and corresponding documentation),
- creating and approving the certification documentation, under DOA privileges,
- creating certification documentation for getting EASA approval (where the privileges do not apply),
- signing the declaration of compliance (responsibility of head of DO).

C: Hand Over

Once the design is performed and verified, the next step is to hand over the results to the customer. The form of the results is written documentation, describing the assembly process in detail. The size and complexity of the technical documentation depends on the size of the conversion project. Besides the technical documentation, assistance should be as well provided. The steps involved in this phase require:

- taking over the final version of the design documentation,

- creating the assembly instructions, based on the design documentation,
- verifying the documentation,
- providing assistance,
- delivering the results to the customer.

The output of the finalized conversion process becomes the input for the hand over phase, and receives the name “deliverable”. Together with the deliverable, the engineering office needs to provide assistance to the customer, once the work package is finished.

Under the hypothesis that the company performs only the design work, and not the manufacture and assembly, the deliverable is in fact a document, gathering all the data necessary for the design to be executed: technical documentation, procedures and instructions for assembly, part lists, instructions and cautions for continued airworthiness and maintenance.

4.2.2 The Elements of the Process Chain

In order to identify each process within the system, they need to be labeled. The chosen coding system will be used by the Data Management System of the design organization, which will allow users to control and administrate the data produced / required by every process. A simple coding system used in this paper is illustrated below.

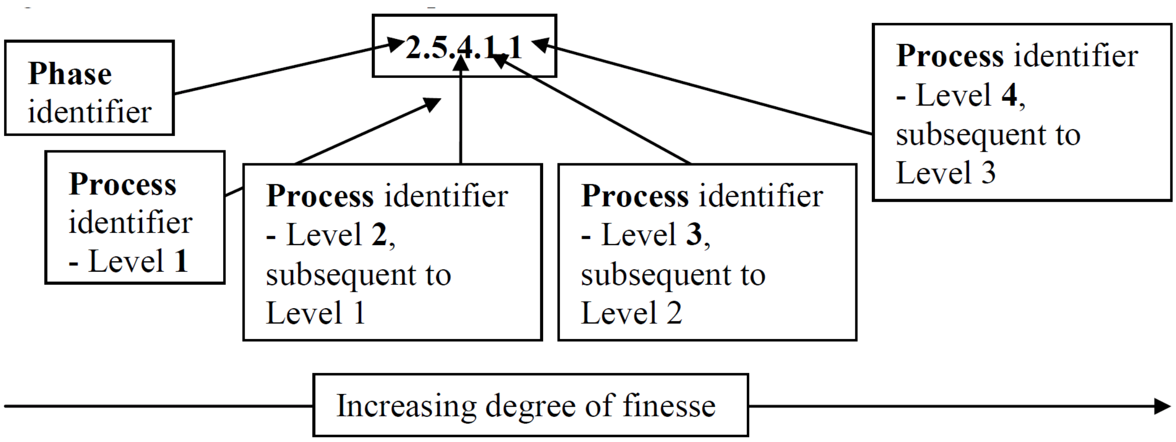


Fig. 4.3 Coding system used for the process illustration

Figures 4.4 to 4.10 list the process chain. Marked in red are those processes that are certification related.

1. OFFER		1.1			Receive request
		1.2			Assign Offer Leader*
		1.3			Analyze request
		1.4			Contact customer and set first meeting
		1.5			On the first meeting: initiate discussions and negotiations
	+	1.6			Write CRTS (Customer Request Technical Sheet) in which:
			1.6.1		Preliminary describe the technical implications
			1.6.2		Make estimations (based on experience) regarding design effort, time, costs
		1.7			Conceive preliminary solutions (for discussing it with the customer)
		1.8			Create preliminary representation of the solutions found (with tools which fit the marketing function, i.e. Pacelab Cabin, Aircraft Scanner)
	+	1.9			Make feasibility study
			1.9.1		Analyse estimated results
			1.9.2		Identify required resources
			1.9.3		Estimate profit
		1.10			Decide if go ahead; if yes, then:
		1.11			Get signed agreement within a second meeting
	+	1.12			Write DTS (Detailed Technical Sheet)
			1.12.1		Estimate the size of the work package
			1.12.2		Identify involved technical fields
		+	1.12.3		Identify certification basis
				1.12.3.1	Identify certification implications
				1.12.3.2	Set preliminary certification requirements
			1.12.4		Identify resources for performing the work
			1.12.5		Make estimations regarding design effort, time, costs
		1.13			Identify suitable project leader and personnel
		1.14			Confront DTS with CR
		1.15			Make adjustments
		1.16			Send results further down (concept) in order for the work to be initiated

Fig. 4.4 Process illustration: Offer Phase

2. CONCEPT		2.1	Analyze customer requirements
		2.2	Perform aircraft inspection
		2.3	Write document describing diagnosis
		2.4	Identify the technical fields involved in the design process*
	+	2.5	Initiate team organization for- and division of responsibilities between
		2.5.1	Engineering
		2.5.2	Design
		2.5.3	Certification (OoA)
	+	2.5.4	Quality Assurance
	+	2.5.4.1	for each technical field
		2.5.4.1.1	Avionics & Equipment
		2.5.4.1.2	Environmental Systems
		2.5.4.1.3	Electrical Systems
		2.5.4.1.4	Cabin Interior
		2.5.4.1.5	Monuments and other Equipment
		2.5.4.1.6	Emergency & Safety Equipment
	+	2.6	Plan the design & engineering process (by the Engineering and Design Office)
		2.6.1	Assign teams for each technical field
		2.6.2	Assign tools to work with
		2.6.3	Choose QM strategy (! Before defining processes)
		2.6.4	Concieve the process (what) chain of the work flow
		2.6.5	Conceive the procedures (how) to be followed
		2.6.6	Make optimization studies
	+	2.7	Plan the certification process (by Office of Airworthiness)
		2.7.1	Contact EASA and TC Holder
		2.7.2	Identify certification basis
		2.7.3	Analyze certification requirements
		2.7.4	Transform Certification Requirements into technical rules
		2.7.5	Identify means of testing and showing of compliance (MOC's)
		2.7.6	Set classification procedures for minor and major chnages according to EASA (AMC&GM Part 21)
		2.7.7	Send application for STC to EASA
		2.7.8	Send application for major changes to EASA
		2.7.9	Identify responsible persons for approving minor changes
		2.7.10	Identify responsible persons for creating the documentation to be sent to EASA for approval (for major changes)
		2.7.11	Verify the consistency of the certification basis
		2.8	Identify required resources and tools
		2.9	Decide if it's necessary to involve subcontractors
		2.10	Conceive preliminary models
		2.11	Consult/report to customer
		2.12	Verify the fulfilling of customer requirements
		2.12	Validate concept (regarding all aspects: work flow, work procedures, design...)

Fig. 4.5 Process illustration: Concept Phase

3. DEFINITION		3.1	Define the QM strategy and follow it when detailing the processes
	+	3.2	Organize work flow (who & what does)/Create Work Breakdown Structure
		3.2.1	Identify and asssign personnel
		3.2.2	Identify tasks
		3.2.3	Define work procedures, corresponding to the type of work
	+	3.2.4	Identify types of documents and document flow
	+	3.2.4.1	to be produced by Design Engineers:
		3.2.4.1.1	Enginnering Orders
		3.2.4.1.2	Instructions for installation und assembly
		3.2.4.1.3	Appendices to CMM (Component Maintenance Manual) and AMM (Aircraft Maintenance Manual)
	+	3.2.4.2	to be produced by Airworthiness Engineers:
		3.2.4.2.1	Documents for showing compliance
		3.2.4.2.2	Approval documents
		3.3	Identify parallel processes and prescribe the parallel process performing
		3.4	Schedule work
	+	3.5	Define work procedures (how to do it) for
		3.5.1	Certification
		3.5.2	Monitoring
		3.5.3	Design
		3.5.4	Quality Assurance
		3.5.5	Relation with subcontractors
	+	3.6	Define the design concept
	+	3.6.1	Perform design studies for each technical field
		3.6.1.1	Identify interferences between technical fields
		3.6.1.2	Identify possible conflicts between technical fields
		3.6.2	Identify the feasible choice
		3.6.3	Validate design concept
	+	3.7	Prepare Certification
		3.7.1	Define Test and Verification Methods, according to the MOC's and specific for the type of design
		3.7.2	Create compliance check lists

Fig. 4.6 Process illustration: Definition Phase

4. DESIGN		4.1	Recieve and understand design assignments from responsible person (Chief of Design)
	+	4.2	Analyze and understand constraints specific to the design:
		4.2.1	Certification constraints
		4.2.2	Customer constraints
		4.2.3	Design limits
		4.3	Optimize tool selection (already indicated in concept phase, but also in concept phase)
	+	4.4	Perform design, including:
		4.4.1	Perfom simulations
		4.4.2	Perform 2D and 3D respresentations
	+	4.5	Perform design analysis and verification (Design Verification Engineer-DVE)
		4.5.1	Analyze the electrical and mechanical loads
		4.5.2	Analyze interference with structure
		4.5.3	Define tolerances
		4.5.4	Perfom assembly analysis
		4.5.5	Identify clashes
		4.5.6	In case of clashes, propose feaseble solutions
		4.5.7	Choose and apply final solution
	+	4.6	Perform design analysis and verification (Compliance Verification Engineer-CVE)
		4.6.1	Confrunt results of the DVE with the prescriptions from MOC's
		4.6.2	Report uncompliance back to the DVE
		4.7	Choose and apply final solution (after receiving feedback from CVE)
		4.8	Produce part lists
		4.8	Produce coresponding documentation (as described in the definition phase)
		4.10	Send documentation to get approval (to the OoA)

Fig. 4.7 Process illustration: Design Phase

5. CERTIFICATION		5.1	Receive documentation to be approved
	+	5.2	Perform test and compliance verification procedures according to MOC
		5.2.1	for each component
		5.2.2	for the assembled components
		5.3	Create coresponding approval reports
		5.4	Send coresponding documentation (e.g. test results) to EASA (for major chnages)
		5.5	Approve minor changes under the DO priveleges
		5.6	Receive STC
		5.7	Recive approval for major chnages
		5.8	Prepare instructuons for Continued Airworthiness

Fig. 4.8 Process illustration: Certification Phase

6. HAND OVER		6.1	Collect technical documentation and approval documents
		6.2	Collect assembly instructions
		6.3	Prepare the documentation in the form required by the customer
		6.4	Deliver results
		6.5	Asign assistance team available upon customer request
		6.6	Register Lessons Learned
		6.7	Archive all data
		6.8	Perform final cost evaluation

Fig. 4.9 Process illustration: Hand-Over Phase

7. ADJUSTMENT		7.1	Get functioning feedback from every engineering department
		7.2	Analyze overall functioning of the DO
		7.3	Detect points of improvement
		7.4	Propose optimized solutions
		7.5	Create functioning reoprts
		7.6	Send reports to management
		7.7	Receive feedback from management
		7.8	Prepare updated procedures, as it is required, after reciveing instructions
			from management

Fig. 4.10 Process illustration: Adjustment Phase

4.2.3 The Completion Center Concept

A Completion Center can deliver a range of modifications from simple cabin upgrades to complete, highly specialized conversions, usually attributed to VIP aircraft. The range of cabin conversions throughout the commercial aircraft life can be as follows:

- *At age 0*: several initial standard cabin layouts are created by the aircraft manufacturer.
- *At age 5 to 20 years*: several cyclic cabin upgrades caused by worn out furnishing or due to change of aircraft ownership are undertaken inside a Completion Center; if the owner is a VIP, the design and engineering work normally demands a complex certification process, especially if the customer is asking for unusual furnishings.
- *After age of 20 years*: the only scenario possible is pax-to-freighter conversion, undertaken either by the aircraft manufacturer of within a Completion Center.

In common understanding, the notion Completion Center, refers to those organizations able to deliver aircraft cabin conversions independent of other companies.

Lately, several other possible ways to define the term Completion Center have come into use. Accordingly, a design organization (DO) can call itself a Completion Center even without seeing the aircraft, by delivering only the design work. Another possibility for a company to call itself Completion Center is to conduct the work for the customers through intermediaries, as a developer. Figure 4.11 illustrates all these possibilities:

- *Possibility 1*: the Completion Center covers only the design and engineering work (D&E) itself. The work embodiment, certification and organization of the whole tasks is done by other companies. Currently engineering offices working as subcontractors for aircraft manufacturers in the area of cabin conversions can grow into becoming an independent Completion Center according to this definition.
- *Possibility 2*: the Completion Center covers the work embodiment while other companies are responsible for organization of all the tasks and the documentation related to design, engineering and certification.
- *Possibility 3*: the Completion Center acts as a developer. A developer works like a building project organizer or a travel agency – it has neither the capability to perform the design and engineering work nor the work embodiment, but it is able to organize these tasks for the customer through third party involvement.
- *Possibility 1+2*: the Completion Center is able to ensure both design and engineering (D&E) as well as work embodiment. Since this type of Completion Center comprises all the work necessary for the conversion itself, an independent developer is not necessary. This definition of Completion Center is the one from the industry's common understanding. It is also the most common type of Completion Center; a well known example of this type of Completion Center is Lufthansa Technik.
- *Possibility 2+3*: the Completion Center acts as a developer and has the capability to do the work embodiment itself. D&E are outsourced.
- *Possibility 3+1*: the Completion Center acts as a developer. It also has the capability to ensure the D&E work itself. The work embodiment is subcontracted to another company.

When looking at the companies dealing today with cabin conversions, some observations can be extracted:

- A frequent scenario is VIP Completion. VIP customers are usually high paying and high demanding. VIP completion on large aircraft can result in big contracts.
- Certification work is performed under the Aviation Authorities, which usually require a certificate showing the capability of performing the design (DOA – Design Organization Approval). However, a company can function as a Completion Center without DOA, if certification work is subcontracted.

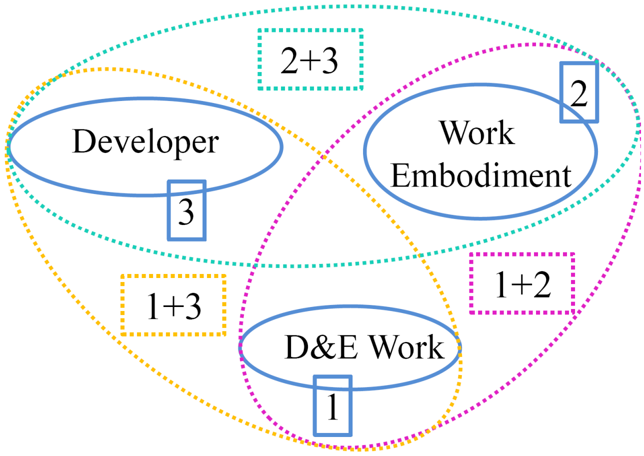


Fig. 4.11 Completion Center concepts

5 Process Chain Optimization with Dependency and Structure Modeling Methodology

5.1 The DSM Methodology

The Dependency and Structure Modeling Methodology started in the 1980's from the idea of using graph theory in order to represent the sequence of design tasks of a complex engineering project as a network of interactions (**Steward 1991**). This network is represented by a quadratic matrix with identical row and column headings, called Design Structure Matrix (DSM), containing relations and interactions in their nodes (see Figure 5.1).

5.1.1 Types of DSMs and their Application

There are several types of domains as well as relations which can be expressed through a DSM. This diversity leads to a DSM classification as shown in Figure 5.2.

Static DSMs do not depend on time, therefore the elements exist simultaneously. Such elements are components of a system, in which case the DSM is component-based, or members of a team, in which case the DSM is people-based. A static DSM analysis would provide results with respect to product decomposition or information flow among members of an organization (**Browning 2001, Bartolomei 2009**).

Time-based DSMs consists of time dependent nodes. The elements of the matrix can be represented by activities. In this case the DSM analysis provides their optimal sequencing. The nodes (or elements) can also be represented by parameters related to system activities. An analysis of such a DSM would help identifying activities that influence the design parameters (**Bartolomei 2009**).

		1	2	3	4	5	6	7
Offer	1	1						
Concept	2	1	2	1				
Definition	3	1	1	3	1			
Design	4	1	1	1	4		1	
Adjustment	5	1	1	1	1	5	1	1
Certification	6	1	1	1	1		6	
Handover	7	1	1	1	1		1	7

Fig. 5.1 Example of DSM showing the relations between the main phases of the process chain for cabin conversion

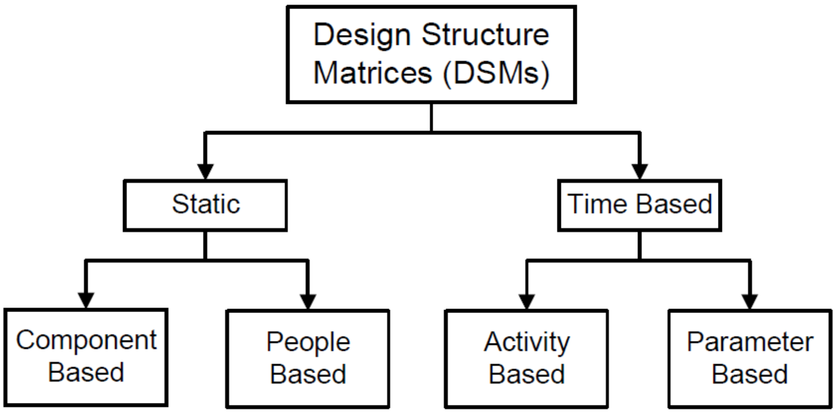


Fig. 5.2 Classification of DSM (based on **Browning 2001**)

The way to read a DSM can be shown based on Figure 5.1:

- The input information can be read along the rows – i.e. process 4 (design phase) receives information from processes 1, 2 and 3 (offer, concept and definition).
- The output information can be read along the columns – i.e. process 4 (design phase) gives information to process 3 (definition).
- The information exchange is marked through the logical operator true / 1.

The order can be inversed if the user decides to change this convention. In this case one can read the input information on the column and vice-versa. Usually this convention is indicated by an arrow mark above the matrix (as shown on Figure 5.1).

The logical operators only show the coupling between the nodes. It is possible to replace them by numbers in order to show the degree of dependency between the elements (**DSM 2009**):

- 1 – high dependency
- 2 – medium dependency
- 3 – low dependency

Browning 2001 and **Pimmler 1994** use positive and negative numbers, called coupling coefficients, to express the ranking of the interactions (see Table 5.1). Negative numbers need to be carefully implemented into the tools which optimize DSMs, as they may not function properly.

The key factor in using the DSM methodology is the correct input of the logical operators, respectively coupling coefficients into the matrix. Researchers of this topic (**Browning 2001**, **Pimmler 1994**, **Danilovic 2007**, **Bartolomei 2008**) agree on the following preparing steps:

1. Clear definition of system boundary and functionality
2. Identification of system components

Proper fulfillment of Steps 1 and 2 make step 3 possible, which needs additional information from the members of the organizational staff and engineers:

3. Identification of interfaces between components.

Table 5.1 Interaction quantification scheme (based on **Pimmler 1994**)

Information	Weight	Information exchange is…
Required:	+ 2	…necessary for functionality
Desired:	+ 1	…beneficial but not absolutely necessary for functionality
Indifferent:	0	…does not affect functionality
Undesired:	- 1	…causes negative effects but does not prevent functionality
Detrimental:	- 2	…must be prevented to achieve functionality

The engineers need to be questioned with respect to the type and frequency of interactions between the components, in order to estimate the right position and intensity of the coupling coefficient. The additional sub-steps are required:

3.1 Preparation of questionnaires
3.2 Gathering and analyzing the results.
3.3 Implementing the results into the matrix

A Design Structure Matrix can only be used to analyze interactions between elements of the same type. In order to see for instance which team is suitable for which activity, one would need to combine a people-based DSM with an activity-based DSM and analyze the interactions as a whole. This analysis is possible in the frame of a Domain Mapping Matrix (DMM). A DMM is a rectangular matrix which examines interactions between two domains. The literature about DMMs indicates that there are at least 5 major domains which interact in product development (**Danilovic 2007**):

1. Goals
2. Product
3. Process
4. Organization
5. Tools

The interactions inside the five domains listed above are represented in DSMs. The interactions between the domains are illustrated with DMMs (see Figure 5.3).

DMM analysis methods are relatively new, thus the literature is limited. The advantage of expanding the analysis beyond single domain information gives however enough reason to consider the DMM approach. To summarize, the main characteristics of both DSM and DMM are listed in Table 5.2.

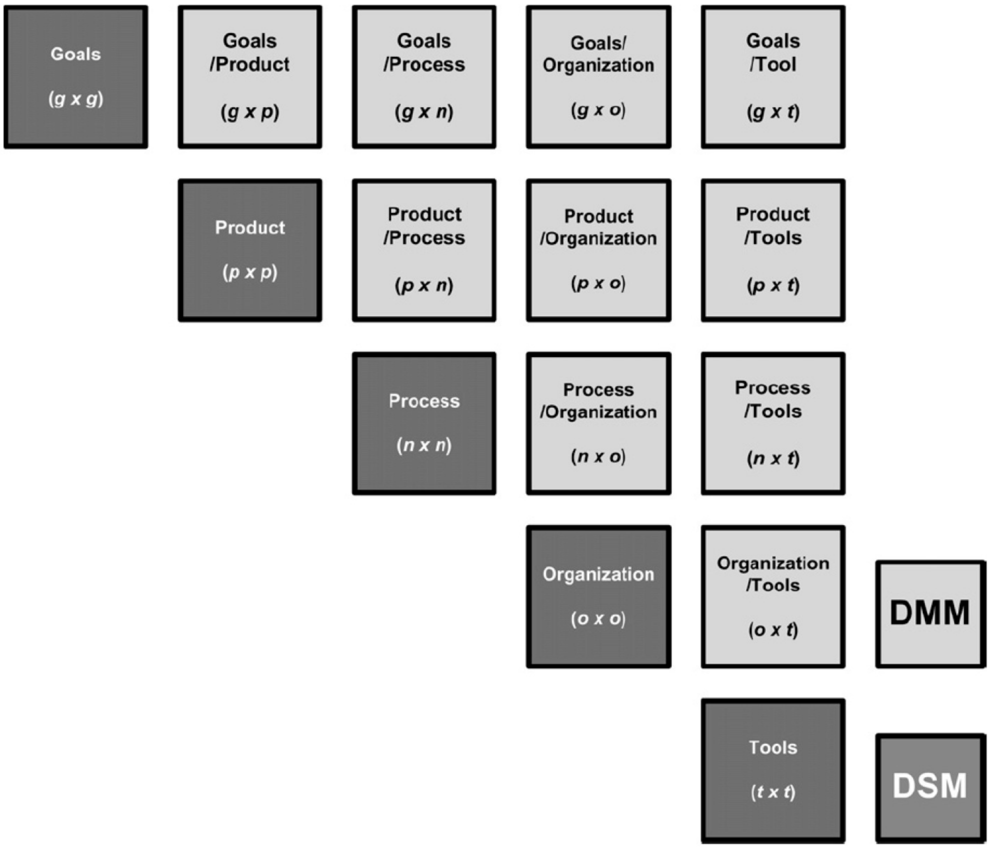


Fig. 5.3 DSMs and DMMs for the five project domains (**Danilovic 2007**)

Table 5.2 Main characteristics of DSMs and DMMs (based on information gathered from **Browning 2001**, **Danilovic 2007**, **Bartolomei 2008**)

Criteria	DSM	DMM
Representation	*nxn* matrix	*nxm* matrix
Dimension	Single domain	Dual domain
Focus of Analysis	Tasks Activities Parameters Components People Information flow Deliverable flow	Components / Organization Project / Organizational Structure Functionality / Product Architecture Information flow

5.1.2 Optimization Algorithms

Several analysis algorithms are applicable depending on the type of elements represented into the matrices. The aim of the investigation towards the DSM methodology is to apply it for the optimization processes required to perform an aircraft cabin conversion. The interest of this technical note is therefore to highlight and apply those algorithms suitable for activity based components analysis.

In Section 4 a number of 143 processes for completing a cabin conversion (while considering a low degree of detail) were identified. The analysis of a great number of processes with the

DSM method requires the automation of the optimization. Highly detailed DSMs use programmed algorithms and computer aid.

If the purpose is to optimize the sequence of the activities, the suitable algorithm is called partitioning or sequencing. If the purpose is to assign proper personnel to specific tasks, the suitable algorithm is called clustering, as it allows grouping of the highly related elements into clusters (**Danilovic 2007, Bartolomei 2008, Eppinger 2002**).

Partitioning aims to reorder the sequence of the elements in order to obtain a lower triangular matrix (according to the convention from Figure 5.1, otherwise the algorithm would deliver an upper triangular matrix). This is achieved by manipulating the rows and columns of the matrix such that the coefficients move closer to the main diagonal and reduce the negative feedback between the elements. The result is a minimized waiting time between activities. The conclusion to be drawn (**Bartolomei 2008**) is that minimizing feedback eliminates the process iteration and spares time.

When looking at the matrix in Figure 5.1, it can be observed that coefficients above the diagonal indicate the necessity of a task to wait for the completion of another task which is to be fulfilled in the future.

The problem formalization can be expressed through the following exemplary question for element number 5: Can process number 5 be fulfilled after processes 6 and 7? If yes, then insert 1. Do processes 1, 2, 3, 4 give information to process 5? If yes, then insert 1.

The following observations after analyzing Figure 5.1 can be extracted:

1. The concept phase can suffer modifications after the definition phase.
2. The definition phase can suffer modifications after the design phase.
3. The design is influenced by the certification requirements, and can later suffer modifications accordingly.
4. All phases provide information for the adjustment phase.
5. All phases, besides adjustment and handover give information to certification phase.
6. Handover phase receives information from all other phases, besides adjustment, to which it gives feedback.

Applying the partitioning algorithm to the matrix in Figure 5.1 means reordering the phases in the most economical manner. Due to the fact that the dimensions of the matrix are small, a manual manipulation is possible. The following steps are required (based on **DSM 2009**):

1. Identification of the elements which do not receive information from the others (by looking for empty columns) and moving them to the right.
2. Identification of the elements which do not give information to the others (by looking for empty rows) and moving them to the left.

3. If after steps 1 and 2 there are no remaining elements in the DSM, then the matrix is completely partitioned; otherwise, the remaining elements contain information circuits, which can be further optimized.

DSM 2009 provides a tool, developed at the Technical University München, which can automate the process of partitioning. Figure 5.4 shows the partitioned matrix obtained with this tool from the original matrix shown in Figure 5.1.

		Offer	Concept	Definition	Design	Certification	Handover	Adjustment
		1	2	3	4	6	7	5
Offer	1	1						
Concept	2	1	2	1				
Definition	3	1	1	3	1			
Design	4	1	1	1	4	1		
Certification	6	1	1	1	1	6		
Handover	7	1	1	1	1	1	7	
Adjustment	5	1	1	1	1	1	1	5

Fig. 5.4 The partitioned matrix obtained from the original matrix shown in Figure 5.1

From the results obtained, the following conclusions can be extracted:

- The adjustment phase was moved at the end of the sequence; it is the last to be fulfilled, once it receives the feedback from all other phases.
- There are still coefficients above the diagonal (market in light blue) but they are required for the proper functioning of the system.
- The light blue indicates that the information exchange is bidirectional, which means the three phases are coupled.

Besides partitioning, another algorithm may be of interest when it comes to setting up a completion center. The clustering algorithm will be further illustrated, but its application is beyond the purpose of this paper.

While partitioning is suitable for time-dependent elements, clustering is suitable for time-independent systems, such as product architecture or project organization (**Danilovic 2007**). Clustering focuses on identifying groups of items. It is, for example, useful when the elements of the matrix are people, which need to be grouped in teams. When it comes to designing a product, another application of the clustering algorithm is in the system decomposition and can help identifying the sub-components suitable for the system modularization. The procedure is similar to partitioning: columns and rows are reordered with the purpose to underline the elements which are highly interconnected. Interactions between clusters are, in the same time, minimized (**Bartolomei 2008**).

Table 5.3 Comparison between DSM and DMM (based on **Danilovic 2007**)

Dimensions	DSM		DMM
	Partitioning analysis	Clustering analysis	
Partitioning algorithm	Block diagonalization / Triangularization	Clustering in blocks along the diagonal	Move items into clusters
Result of the analysis	Sequence of items, activities	Cluster of items	Cluster of items
Visualizatio n of dependenci es	Feedback and circuits Loop of items Parallel items Sequence of items	Cluster of items Dependencies of clusters	Cluster of items Dependencies of clusters
Key words	Tasks Activities Information flow Deliverables	Parameters Components People Organization Information flow	Components / Organization Project / Organizational Structure Functionality / Product architecture

Partitioning and clustering are algorithms suitable for DSM analysis. When it is required to analyze the interaction between two domains within a DMM, the algorithms need to be adapted. **Danilovic 2007** provides an analysis with respect to applicable algorithms for DMMs. His conclusions are summarized in Table 5.3.

5.2 Analysis of the DSM for the Process Chain for Cabin Conversion

In the previous section a DSM analysis was already performed on the coarse matrix (illustrated in Figure 5.1) with the purpose to exemplify the functioning of the partitioning algorithms. The following paragraphs will apply the algorithm for the fine matrix, which includes all the processes identified in Section 4. Other two types of analyses are as well illustrated: the eigenstructure analysis and the cross impact analysis.

5.2.1 Partitioning Algorithm

The processes were introduced in the EXCEL tool (**DSM 2009**) and the algorithm was run. By manipulating the rows and columns, a minimal feedback process configuration was obtained. Figure 5.5 illustrates, as far as possible, the partitioned DSM.

This analysis required a long preparation time and the main difficulties consisted of:

- understanding the dependencies between each process,
- inserting them into the matrix,
- having a clear view over the whole complex structure.

After overcoming these difficulties and running the algorithm, the following conclusions were extracted:

- Definition, Design and Certification phases are coupled (light blue); they create an information cycle which needs iteration, and therefore further optimization.
- Other small couplings exist between the teams for engineering, certification and quality assurance.
- A detailed analysis of the matrix and of each of the illustrated dependency allows a better understanding of the results.

5.2.2 Eigenstructure Analysis

When aiming to optimize a large number of processes, it helps conducting an analysis which allows the extraction of the most important ones. The eigenstructure analysis for DSMs was developed by Smith and Eppinger in (**Smith 1997**). In our case it helps underlining those processes which have a major influence on the system.

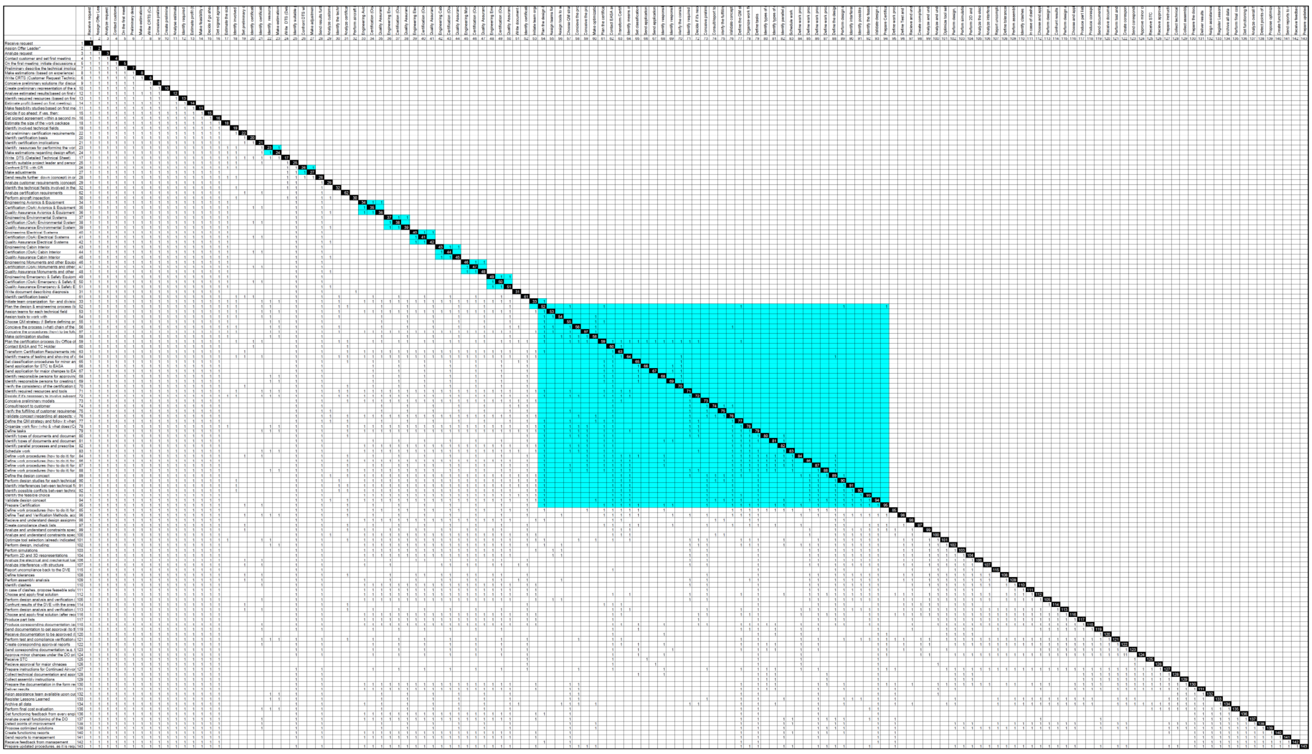


Fig. 5.5 The partitioned DSM resulted after running the partitioning algorithm on the original DSM matrix

The eigenvalues and eigenvectors determine the nature of the convergence of the design process in a similar way with the aircraft dynamics:

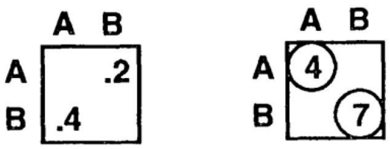
- the eigenvalues give information about the rate of convergence,
- the eigenvectors give information about the shape of the natural motion.

An interesting similarity between the dynamical behavior of a physical system and the behavior of the tasks/processes of an engineering system can be noticed. In both cases large magnitude positive eigenvalues give information about the convergence of the system.

Another interesting analysis is to optimize the duration of the development time (**Smith 1997**):

- Serial tasks can be evaluated by summing their individual times.
- Parallel tasks can be evaluated by finding the maximum of those task times.

In this case a Work Transformation Matrix (WTM) (**Smith 1997**) needs to be used. Each iteration causes rework; the amount of rework is quantified through this matrix. The off diagonal elements of WTM represent the strength of dependence between tasks – for our analysis, the rework necessary for each task. The diagonal elements represent the time that it takes to complete each task during the first iteration (see Figure 5.6).



(a) Strength of Dependence Measures **(b) Task Times**

Fig. 5.6 Work Transformation Matrix (WTM) (**Smith 1997**)

The eigenstructure analysis of the process chain was performed on the WTM under the consideration that the amount of rework is 100%. In this way the problem became simpler to handle (by inserting 1 instead of proportions of 1) and the results were covered by the largest safety margin possible. The steps for conducting the analysis were:

1. Building the WTM.
2. Calculating the eigenstructure i.e. eigenvalues and eigenvectors of the matrix.
3. Interpreting the magnitude of the eigenvalues.

The results are summarized by Table 5.4.

Within a Completion Center, it seems that certification, along with quality assurance play a key role along with the planning the design and engineering process and the team selection. A second major importance is represented by the tasks grouped under the design analysis and verification. The results are plausible, especially when considering the way EASA developed the DOA requirements. For EASA the self control capability of each design organization presents a major importance.

Table 5.4 The processes with the largest eigenvalues

Process ID	Process Title	Eigenvalue
50	Organizing team for certification	6.43
51	Organizing team for quality assurance	2.21
52	Planning the Design & Engineering process	2.21
53	Assigning Teams for each technical field	2.31
106	Analyzing electrical and mechanical loads	1.62
113	Performing design analysis and verification	1.62
121	Perform test and compliance verification	1.00

5.2.3 Cross Impact Analysis

Another type of analysis which can be performed based on the DSM is the Cross-Impact Analysis. The data is analyzed by means of a Cross Impact Matrix, as illustrated in Figure 5.7. The red numbers represent the strength of the influence exercised by each factor / task over the rest of the factors / tasks. It is assumed for our analysis that the influence is always either 1 or 0. Depending on the convention, the tasks are either passive or active. The aim of the Cross-Impact Analysis is to identify several meaningful influence zones and the processes belonging to them. The values representing the strength of the relations are summarized per row and per column. The results are graphically represented as shown in Figure 5.8. There are five meaningful zones which can be identified:

1. ***Zone I: Reactive Processes*** – Changes of elements in this area have a strong influence on the system; they give a lot of information to the rest of the components.
2. ***Zone II: Dynamic Processes*** – Changes of elements in this area have an important influence on the system; the information exchange is strong on both sides.
3. ***Zone III: Impulsive Processes*** – Elements in this area have a small influence on the system but are strongly influenced by other system changes.
4. ***Zone IV: Low Impact Processes*** – Elements in this area have a small influence on the system and are poorly influenced by other system changes.
5. ***Zone V: Neutral Processes*** – Elements in this area find themselves at the intersection with other domains; neutral means safe from unexpected effects.

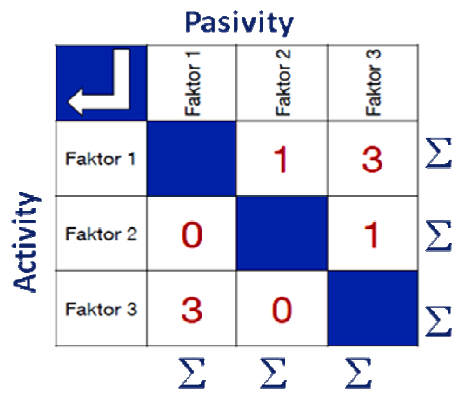


Fig. 5.7 Cross Impact Matrix example (based on **Phleps 2009**)

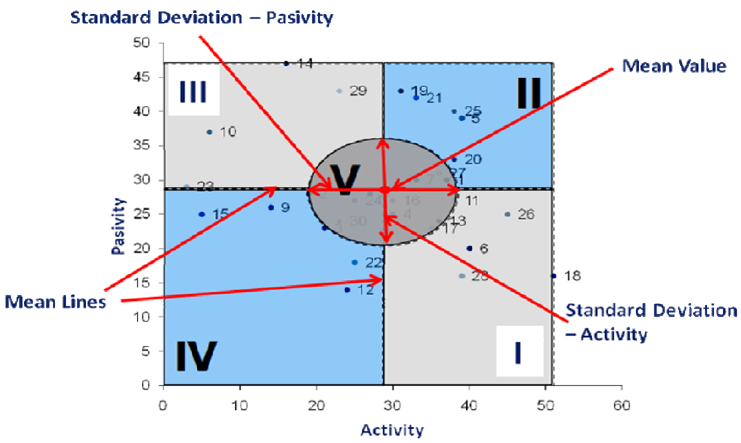


Fig. 5.8 Cross Impact Diagram (based on **Phleps 2009**)

Based on the DSM, the following results for the parameters describing the diagram were obtained through EXCEL calculation (see Table 5.5):

Table 5.5 Results for the parameters describing the Cross-Impact diagram

Partitioned DSM	Activity	Pasivity
Sum	5271	5271
Mean Value	36.86	36.86
Standard Deviation	40.067	19.147
Minimum	0	0
Maximum	142	85

Due to the large number of processes the diagram is not easy to interpret. However ‘clouds’ of processes can be identified. The diagram is shown in Figure 5.9 and an overview of the results in Table 5.6.

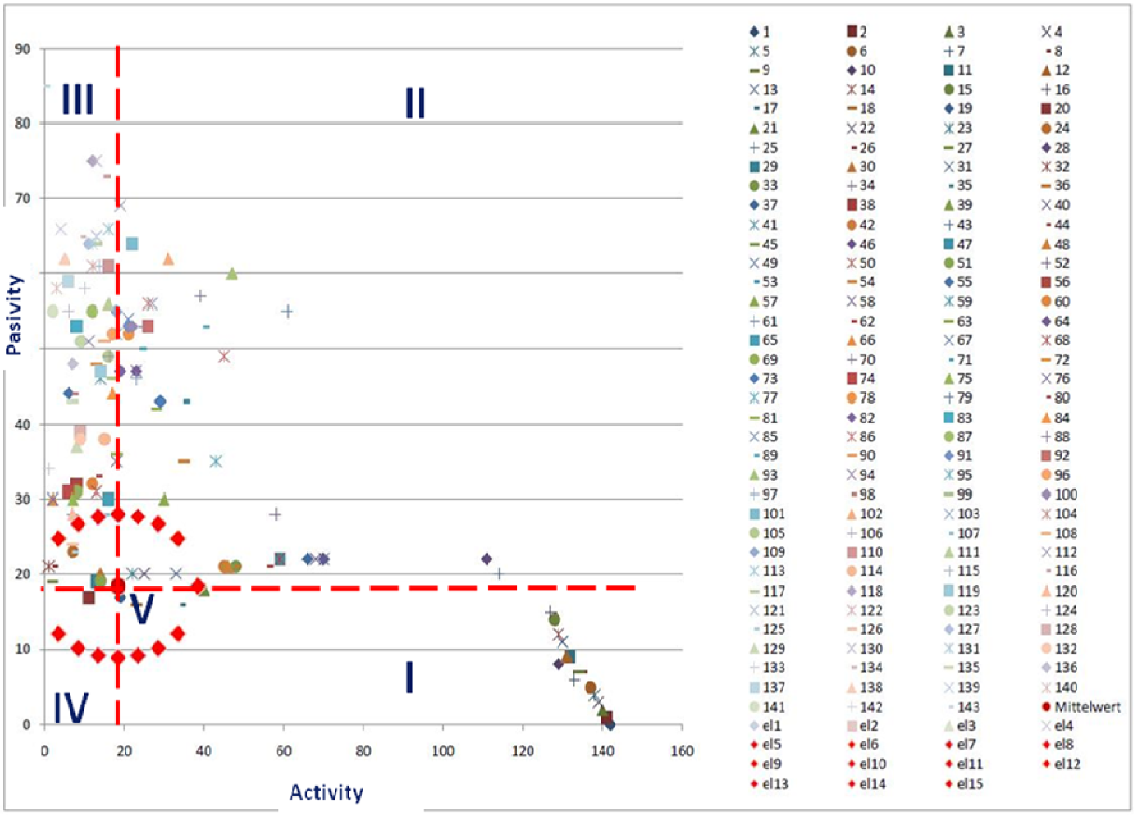


Fig. 5.9 The Cross-Impact Diagram based on the DSM

Table 5.6 Selected processes for each zone of influence

Zone I	(2) Assign Offer Leader (126) Receive approval for major changes (9) Conceive preliminary solutions for discussing it with the customer (based on the first meeting) (10) Create preliminary representation of the solutions found (12) Identify required resources (based on the first meeting) (14) Make feasibility studies (16) Get signed agreement
Zone II	(94) Validate design concept (87) Define work procedures for quality assurance (79) Define tasks (definition phase) (93) Identify feasible choice (when it comes to interferences) (design phase) (73) Conceive preliminary models(concept phase) (61) Identify certification basis (concept phase) (54) Plan the design and engineering process
Zone III	(137) Analyze overall functioning of the DO (133) Register Lessons Learned (75) Verify the fulfillment of the customer request (139) Propose optimized solutions (for the functioning of DO) (143) Prepare updated procedures for the functioning of the DO (138) Detect points of improvement (of the DO) (119) Send documentation to EASA (to get approval)
Zone IV	(27) Make adjustments of the DTS after confronting it with CR
Zone V	(17) Write DTS (18) Estimate the size of the work package (24) Make estimations regarding design effort (30) Perform aircraft inspection (31) Write document describing diagnosis (32) Identify the technical fields involved in the design process (concept phase) (62) Analyze certification requirements (concept phase)

Processes in zone I, like feasibility studies or getting the signed agreement, strongly influence the rest of the processes: unless the contract is signed and the technical proposal accepted, the rest of the processes are not run anymore.

Processes in zone II, like validating the design concept or identifying the certification basis, are very important for the functioning of the system and require a lot of information from the rest of the processes.

Processes in zone III, like proposing solutions for an optimized functioning are processes which require a lot of feedback information from the rest of the processes, while their influence may be important in the future, and not for the respective project / iteration.

Processes in zone IV, like adjusting a document, once new information is available, have a low impact on the system.

Processes in zone V, like estimating the size of the work package and design effort, are in the neutral zone. They are important for the system, but the results are rather expected.

6 Conclusions and Outlook

The necessity of optimizing the engineering processes is a key factor in the aeronautical industry. In Europe many subcontracting companies depend on a large aircraft manufacturer. In their attempt to gain more freedom, a growth in their capability is demanded.

This report showed how a simple matrix approach can aid this process. The optimization was performed on a high number of processes, which made the implementation of the algorithms rather difficult. The larger the design structure matrix, the more complex its preparation for optimization (i..e. setting the relations between the processes).

The analyses performed on the detailed DSM were:

- *The partitioning algorithm*, delivered the optimal sequence of the basic processes inside the completion center. This algorithm had as an objective minimizing the feedback information. However, due to the high number of processes, the partitioning algorithm had to be run several times, and the results may still be locally invalid. Another point which influences the accuracy of the results is the fact that these processes are rather general processes; most of them can be further divided into sub-processes / subtasks. In this case an overall analysis with DSM would be impossible due to the large number of relations which need to be established. In this case the matrix would be too large, and the automation of the relations input is not possible. It makes more sense to conduct such an analysis on smaller DSMs characterizing a smaller subsystem, comprising of one or several phases.

- *The eigenstructure analysis*, based on the WTM extracted from DSM, started with the idea of finding similarities between the functioning of an engineering system and the dynamic behavior of an aircraft. The way such a system oscillates is similar with the ‘oscillations’ inside a design organization, when rework is required. The results underlined those processes with the largest eigenvalues, i.e. with the greatest influence on the engineering system. This analysis can be further extended if for each process the rework load is fractionally expressed. This type of analysis on WTM is especially suitable for reconversion tasks, as it allows the estimation of how much work is required for the rest of the cabin items if one item is being replaced / reconverted. It also allows the calculation of the total time or the partial times for performing the cabin conversions.

- *The cross impact diagram* delivered groups of processes belonging to five spheres: reactive, dynamic, impulsive, low impact and neutral. Indeed the process chain assumes tasks which are vital for the entire chain as well as tasks which do not have an important influence on the system. The results are plausible. They could be however used on smaller DSMs in order to identify especially those tasks which poorly influence the system. Such tasks may be further coupled or ignored.

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Appendix A

Example of a Conversion Scenario and Required Input Information

A.1 Description

The cabin modification example consists of the installation of the Enhanced Cabin, aimed to provide a better appearance and improved comfort for passengers. The following subtasks are included:

- the installation of the enhanced CIDS;
- the installation of changes with respect to cabin interior:
  - ceiling panel,
  - overhead stowage compartment including boxes, doors and grip rails,
  - seat row numbering,
  - cove light panel,
  - side wall lining;
- the installation of changes with respect to the IFE system

A.2 Delivery Milestones Plan

Table A.1 Delivery Milestone Plan for the selected conversion example

Milestone	Due Date	Deliverable
Z00	06.03.2009	**Kick Off Meeting**
Z01	12.03.2009	**LLT ATA 25**
Z02	31.03.2009	**Drawing Set 1**: Partition installation Seat installation Hatrack box and Hatrack door EFPMS Sidewall lining Griprails InstallationEquipment 80VU CIDS equipment inst. and CIDS cable routing, each 25%
Z03	21.04.2009	**Drawing Set 2**: NTF Endpanels Emergency Exit Jointstrip Seat Track cover Doorframe lining Cove light panels Ancillery parts

			Door frame 4 – insulation VCC-inst. Monitor-inst. CIDS equipment inst. and CIDS cable routing, each 25%
Z04	06.05.2009	**Drawing Set 3**:	
			PSU PSU new air outlets Ceiling Curtain rail Ceiling F14-F21 FAP-cover Hatrack connection parts Ceiling F65-F68 2000VU mod. to 115VC Adaption of available VCC inst. Inst. of Wiring for 2000VU, 80VU - LHS Hatrack CIDS equipment inst. and CIDS cable routing, each 25%
Z05	06.05.2009	**LLT ATA 23**	
Z06	27.05.2009	**Drawing Set 4**:	
			Emerg. Equipment Emerg. Equipment brackets Cabin placards P-Loc status3 Sys. prov. For PRAM in IFE, video, audio incl. routing Wiring prov. between 1st LH-Hatrack,2000VU and 80VU CIDS equipment inst. and CIDS cable routing. each 25%
Z07	10.06.2009	**Drawing Set**:	
			Top drawing
Recap		**Recap Meeting after Drawing Completion**	
Z08		**Working Party Support for S/C drawing set**	
Recap		**Recap Meeting after Working Party**	

A.3 Mechanical Refurbishing Tasks

Table A.2 Description of mechanical tasks, required input data, difficulties encountered when the data would be missing, alternatives to unavailable data and feasibility of the task

EC	Input data	Difficulties	Alternatives	Feasibility
Seat Installation	**F**uselage contour. **M**onuments: location, dimensions. **S**eats: documents from seat manufacturer (dimensions). **S**eat rails: location, type.	**G**etting data from seat and monuments manufacturer. **D**etermining the dimensions and position of the monuments, without the original layout: e.g. location of the reference point.	**D**irect measurements. **A**dditional data from seat manufacturer. **P**hotographs (with dimensions). **D**ata from monuments manufacturers.	**+ +**

Seat track cover	**M**onuments: location, dimensions. **S**eats layout. **I**nformation about the seat track covers.	**T**here are three types of seat track covers used by Airbus; if there is no other manufacturer, these parts must be ordered from Airbus; a new design involves having DOA.	**D**irect measurements. **P**hotographs (with dimensions). **D**ata from monuments manufacturers. **D**ata from seat track cover manufacturer (if there is one different than Airbus).	**– +**
EFPMS	**M**onuments: location, dimensions. **S**eats layout. **S**eat rail position. **P**ath Marking manufacturer info (e.g. Lufthansa produces non-electrical EFPMS).	**F**or electrical EFPMS the complexity of this task is greater, as electrical connection possibilities must be investigated. **G**etting the correct dimensions and positions.	**D**irect measurements. **P**hotographs (with dimensions).	**+ –**
Sidewall panel Sidewall emergency exit Cove light panel	**F**uselage contour. **L**ining contour. **L**ocation and dimensions of seats and monuments. **I**nformation about brackets.	**I**t is impossible to reproduce the same type of lining without the original drawings. **A** new design, in accordance with the airline requirements can only be achieved under DOA.	**B**uying the parts from Diehl (small chance of happening). **S**elf measuring. **S**elf (new) designing – only under DOA.	**– –**
Ceiling	**F**uselage contour (does not depend on the position of the monuments). Information about brackets. **I**nformation about electrical connection possibilities (e.g. EXIT sign).	**I**t is impossible to reproduce the same type of ceiling without the original drawings. **A** new design, in accordance with the airline requirements can only be achieved under DOA.	**B**uying the parts from Diehl (small chance of happening). **S**elf measuring. **S**elf (new) designing – only under DOA.	**– –**
Door frame lining	**F**uselage contour. **L**ining contour. **L**ocation and dimensions of seats and monuments. **I**nformation about brackets.	**I**t is impossible to reproduce the same type of ceiling without the original drawings. **A** new design, in accordance with the airline requirements can only be achieved under DOA.	**B**uying the parts from Diehl (small chance of happening). **S**elf measuring. **S**elf (new) designing – only under DOA.	**– –**

Hatrack bin	**M**onuments: dimensions, location. **S**eats: dimensions, position. **F**uselage contour. **F**uselage frames.	**T**here are only special connection points where the hatracks can be mounted on the fuselage frames – this would require aircraft manufacturer drawings, but company could handle this based on experience.	**I**nformation can be made available by the hatrack bin manufacturer – for SA: Fischer. **U**sually a retrofit project implies the replacement or adaptation of one of the hatracks.	**+ –**
Hatrack door, grip rails, covers	**M**onuments: dimensions and location. **D**ata from hatrack doors manufacturer. **D**ata about the hatrack bins.	**T**he current hatracks, rails and doors come from Diehl (doughter of Airbus – small chance of getting information). The new hatracks and hatrack related parts are produced by Fischer.	**D**irect measuring. **P**hotographs (with dimensions).	**+ –**
Hatrack connection parts	**M**onuments: position and dimensions. **S**eats layout. **F**uselage structure layout – the position of the frames.	**T**he hatracks are connected to the structure, therefore information must be made available for the area belonging to the fuselage frames; the location of these frames must be known.	**H**atrack manufacturer may provide information about the fuselage frames. **A**ircraft inspection. **D**irect measuring.	**+ –**
Curtain and curtain rail	**M**onuments: position and dimensions. **S**eats layout.	**I**f there are already connection holes in the monuments, their position must be known.	**A**ircraft inspection. **D**irect measuring. **P**hotographs (with dimensions).	**+ +**
Emergency equipment, Emergency brackets	**E**R layout from the Airline. **T**he quantity and location according to the legislation. **D**ata about the dimensions of the ER equipment from the manufacturer. **T**he hatrack layout and dimensions. **T**he flight attendant seat layout and type.	**T**he ER equipment must be secured through brackets within the hatrack, under the seat of the flight attendants, or within other monuments (e.g. dog house); the layout of these monuments along with the dimensions of the equipment must be known. **A**irbus produces part of the ER equipment.	**A**ircraft inspection. **D**irect measuring. **I**nformation from the ER equipment manufacturer.	**+ –**

Ancillary parts	**T**hey refer to: baby basinets, literature pockets, or magazine racks. **M**onuments layout: position and dimensions. **S**eats layout **D**ata from the ancillary parts manufacturer: dimensions.	**G**etting the monuments and seats layout.	**A**ircraft inspection. **D**irect measuring. **P**hotographs (with dimensions).	**+ +**
Placards cabin, seat row numbering, ER, doors	**E**R layout. **M**onuments: position and dimensions. **I**nner layout of the monuments. **N**umber of seats.	**T**he placards are produced usually produced by the aircraft manufacturer (e.g. Airbus); either the airline or the DO must choose from the catalogue, and buy them accordingly.	**A**ircraft inspection. **D**irect measuring. **F**or new monuments, the inner layout can be obtained from the monuments manufacturer.	**+ +**
NTF (Non Textile Floor)	**F**uselage contour. **M**onuments layout. **L**ocation of floor connectors for monuments. **F**light attendants seat layout and seat type (connected on the floor or not).	**T**he NTF is required in the area near the doors and monuments and under the galley (the lavatory has its own NTF) **G**etting the exact cabin layout in this area, as well as the exact galley specification.	**A**ircraft inspection. **D**irect measuring. **I**nformation from galley manufacturer.	**+ –**
Joint strip	**P**osition of the curtains. **F**loor layout and floor type.	**T**he joint strips connect the NTF and the textile covering. The floor is part of the primary structure, therefore information about the floor can only be obtained from the aircraft manufacturer. **I**f the floor is from CFK, one cannot make holes in it, and it must be ordered from aircraft manufacturer	**I**f the floor is not from CFK, aircraft inspection my be enough to find out if there are available holes; if not, such a design modification must be certified under DOA.	**+ –**

PSU	**S**eats layout and seats type. **M**onuments layout. **H**atracks layout. **D**ata for each device contained in the PSU and related legislation.	**T**he PSU requires work from both mechanical and electrical engineers; data must be available with respect to the electrical connection which goes through the hatrack and beyond. **A**irbus is the one producing the covering parts between 2 PSU's	**A**ircraft inspection. **D**irect measuring. **P**hotographs (with dimensions).	**+ –**

Legend **+ +** the task can be conducted

+ – the task could be conducted but difficulties and lack of information are expected

– – the task could be conducted under certain circumstances, but it would be difficult to implement, and certain unknown aspects make the duration of the engineering work unpredictable

A.4 Electrical Refurbishing Tasks

Table A.3 Description of electrical tasks, i.e. IFE and new enhanced CIDS with respect to required input data, difficulties encountered when the data would be missing, alternatives to unavailable data and feasibility (do-ability) of the task

IFE	Input data	Alternatives	Feasibility
Monitor Installation	**S**SM **W**D **C**onnection diagrams **P**art numbers **M**anufacturer data (drawings) **W**iring bundle **S**eats layout **M**onuments layout	**A**ircraft inspection **D**irect Measuring **D**ata from Manufacturer **O**wn research (e.g. aircraft documentation)	**+ +**
VCC Equipment	**L**ocation of the VCC (from Airline) **D**imensions of the VCC (from manufacturer) **C**onnection diagrams (from manufacturer) **P**art numbers **M**anufacturer data (drawings) **R**elated regulations	**A**ircraft inspection **D**irect Measuring **O**wn research (e.g. aircraft documentation)	**+ +**
E-Rack 80VU	**S**SM **W**D **C**onnection diagrams **D**imensions and location	**A**ircraft inspection **D**irect Measuring **O**wn research	**+ –**

Circuit breaker panels 2000VU	**P**D **W**D **C**onnection diagrams **D**imensions and location	**A**ircraft inspection **D**irect Measuring **O**wn research	**+ –**
<u>**New enhanced CIDS**</u>	<u>Input data</u>	<u>Alternatives</u>	<u>Feasibility</u>
Cable routing	**O**riginal cable routing **S**SM **W**D L**i**st of harnesses **H**ook-up List	**A**ircraft inspection **D**irect Measuring **O**wn research and experience	**+ –** **– –** Depends on the size of the change
Equipment installation & Bracket installations	**S**SM **W**D **E**quipment related data (from manufacturer) **B**racket related data (from manufacturer)	**A**ircraft inspection **D**irect Measuring **O**wn research and experience **D**ata from equipment manufacturer	**+ –**
DEU			**+ +**
FAP, AAP, AIP installation			**+ +**
Smoke detection			**+ +**
Ballast Units			**+ +**
EPSU			**+ +**
Exit light lens			**+ +**
Pin programming			**– –**
C/B			**– –**

Legend
- **+ +** the task can be conducted
- **+ –** the task could be conducted but difficulties and lack of information are expected
- **– –** the task could be conducted under certain circumstances, but it would be difficult to implement, and certain unknown aspects make the duration of the engineering work unpredictable

A.5 Conclusions

<u>Mechanical Tasks:</u>

- A feasible alternative for missing information is always inspecting the aircraft, measuring and making photographs. Observations / difficulties with this concern:
    - The first condition in this case is to have the aircraft available enough time for the inspection.
    - It may be the case that the aircraft is not available for inspection – in this case a solution must be found together with the airline, depending on the

complexity of the refurbishing – they may have an aircraft with a similar layout standing on ground.

  - This is rather the Lufthansa Technik way – they have aircraft available.
  - If the airlines are not willing to set an aircraft inspection date, another possibility is to seek the agreement either with completion centers like Lufthansa Technik, or with aircraft disposal companies.
  - When measurements in front and in the rear of the fuselage are required, a systematic method (like in FEM) must be applied and enough measuring points must be selected, in order to get to the required measuring tolerance.
  - A problem in measuring is defining the 'point zero', which must be constant along the entire project; the flexibility exist to choose a different point for each case/aircraft.

- The cabin layout – position and dimensions of seats, monuments and hatracks along with the fuselage contour is almost for all refurbishing scenarios required. When measuring all the dimensions and rebuilding this layout, the question arises: how exact are the measurements, how big the tolerances should be. The answer may come only from practice, and experience will play a major role.
- Depending on the type of the refurbishing/upgrade/modification, specific information is required. Usually several small tasks within the same project are related and require the same type of information: e.g. when a hatrack bin requires a modification, this must be done according to the seats and monuments layout; once these layouts are known, they may be used for instance also for the carpet installation. Therefore, the same information (seats, monuments layout) may be used several times – the effort for gathering it must be efficiently managed, in accordance with (as far as possible) its plural utility.
- The long term advantage of this approach – rebuilding the designs based on aircraft inspection – is that an own database will be formed and used as a knowledge base.
- Several items are either very difficult or impossible to measure – e.g. lateral covering (lining). The alternative is to measure only basic dimensions and to redesign the hole lining again, in accordance with the airline wishes. A small lining modification would not be possible, but to redesign it and to produce a new concept is possible. However, this is achievable only under DOA.
- DOA gives enough flexibility to cover, theoretically, the missing parts of measuring and inspecting, by creating new designs. This involves certification activities (granted in any case by a DO approval). Another issue is the production of these new designs. The engineering company may consider getting a POA (Production Organization Approval) as well.

Electrical Tasks:

The tasks involving electrical engineering are challenged by the complexity of the wiring network of an aircraft, particularly due to the fact that these networks may vary from one aircraft to another of its kind. Basically the input information, always required when it comes to refurbishing electrical devices, is (**Michalke 2009a**):

- A general understanding of the electrical wiring of the entire aircraft/the system involved in the refurbishing, by means of Principle Diagrams (PD).
- Additionally basic information provided by Wiring Diagrams (WD), which contain the description of the circuits as well as their identification placards.
- Connection diagrams, in order to understand the functioning of the system.

When it comes to installing new electrical devices, a very good source of information is the manufacturer of the respective device, who provides information with respect to the electrical connections, necessary source of power, and may also have additional information about the wiring network of the respective system in the aircraft.

Very useful in understanding the overall functioning of the electrical systems are the Wiring Diagram Manual (WDM) and the System Schematic Manual (SSM).
Table A.3 summarizes, for this example, the items which needed electrical engineering processing, the input information required for each item, as well as the conclusion towards the feasibility of the respective item modification. The data was gathered with the aid of **Michalke 2009a** and **Michalke 2009b**.

Difficulties:
- A long inspection time would be required for understanding the system, the connection possibilities, as well as the implications of each change.
- Most of the equipments are produced by aircraft manufacturers (e.g. Airbus) or aircraft manufacturer partners and their information is required
- If a new equipment is installed (especially for CIDS, e.g. a new smoke detector), it must be verified that the respective equipment can function inside the system, as part of a whole.
- The complexity of an ‘aircraft manufacturer independent’ task (with electrical implications) is rather unpredictable, as unexpected problems may occur during the conversion processing, which otherwise might have been easily solved with OEM input. A prediction of the duration for the conversion scenario under these circumstances is difficult to make. This would be unacceptable in practice, however the company would grow in experience and the duration would decrease in time.