THE PROCESS CHAIN TO A CERTIFIED CABIN DESIGN AND CONVERSION

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Abstract

The present economical context shows a growing market for cabin related activities. This initiated the idea of an investigation into certification requirements with respect to cabin design and conversion. Background information for obtaining a Design Organization Approval from the responsible authority is presented. The Completion Center concept is introduced and the process chain for cabin conversion is illustrated from the perspective of a medium sized engineering office. An investigation is conducted towards the available representation models used for the visualization and optimization of processes. After conducting this analysis, the Design Structure Matrix representation is chosen. The process chain for a complete conversion can be divided into three parts. A: Offer, B: Conversion Processing, C: Hand Over. The complete process is (to make it simpler) illustrated with an example of a partial cabin conversion (modification). The investigation shows a high complexity of the task of cabin conversion. This complexity can only be mastered in an organization that controls itself rather independently from the surveillance of the Certification Agency. The present regulations pay more attention to the aircraft manufacturers than to subcontractors. This, however, will change soon: according to the European Aviation Safety Authority, the future will see the formation of specialized Centers of Excellence, formed by both manufacturers and engineering offices working on the certification of their products together.

1. INTRODUCTION

1.1. Background

An aircraft satisfies the passenger's need for mobility. The cabin should provide the necessary comfort for the travel. An aircraft cabin needs to be designed so as to account for different types of requirements. Parameters like safety, costs and branding must be considered. If the requirements change, the need to convert the cabin becomes an issue. Therefore, a cabin is designed and often converted several times. Not only must the initial design be certified, but also the conversion. The path to conduct a certified conversion is shown by the Certification Agencies: it can only be accomplished by approved Design Organizations (DO) awarded a Design Organization Approval (DOA). Within the DO the processes for conducting the design must be set up according to the rules of the Certification Authority.

Previously, the aircraft manufacturers used the strategy of outsourcing the work to subcontractors represented by engineering offices. Presently, the subcontractors seek to build up the ability to undertake bigger work packages and to enlarge their capabilities, independently from the aircraft manufacturers. However, in the process of setting up this capability, they need to follow the same path, as described above. Accordingly, more and more engineering offices need to apply for a Design Organization Approval (DOA).

In like manner, the market is expected to grow; this also leads to an increasing number of DOA applications.

In this context, there is need to investigate the processes towards a certified cabin design and conversion, and to seek the optimal approach for carrying out these tasks, from the perspective of an engineering office.

1.2. Key Terms

A previous understanding of some of the key terms involved in the research of this topic is required:

– *Process*: following the definition of EN 9100/2003, a process can be defined as the activity using resources, and managed in order to enable the transformation of inputs into outputs; in this paper a process approach is used for investigating and describing the development of the cabin [1].

– *Process Chain*: illustrates the processes, as part of a system, and the relations between them.

– *Certification:* is the sum of the activities for showing compliance with the applicable airworthiness standards; the compliance is proven by holding a type certificate, while the authorization for operation is shown by the certificate of airworthiness [2].

– *Cabin:* the cabin is the compartment and interior surrounding passengers and crew but also all systems, functions and services that ensure a safe and comfortable operation both in flight and on the ground.

1.3. Purpose of the Paper

The aim of this paper is to investigate the processes behind the conversion of a cabin. The environment and requirements of a proper organization which are necessary to conduct cabin conversions are studied. This requires an investigation towards obtaining the Design Organization Approval. The DOA shows the capability of performing an airworthy design; therefore the description of the processes is strictly correlated with the requirements for getting such an approval. A proper method for the representation of the processes is sought. It is found out that by using a Design Structure Matrix, the optimization of the processes is also possible. However, this paper only aims to describe the tasks in cabin refurbishing, while the optimization of the processes represents a new topic.

2. CABIN DESIGN AND CONVERSION

2.1. Definitions

- *Cabin Layout*: represents the sum of the items and their arrangement comprised in an aircraft cabin; elements of the cabin layout are: seats, monuments (galleys and lavatories and their system adaptation kit), overhead stowage compartments, sealing panels, side walls or door panels, carpets and curtains, emergency equipment and attendant seat together with the associated systems. Configuring a cabin layout means finding an optimal position for all these items, in the restricted space given by the cabin cross section, while respecting the certification rules and the interference with the structure of the aircraft [3].
- *Cabin Design*: implies design and certification activities for the cabin related systems and cabin interior components of an aircraft; it usually refers to the creation of a new cabin, while used cabins are *redesigned* (or converted);
- *Cabin Conversion*: starting from Cabin Zero [4], which is the standard cabin of an aircraft, customers may require specific features for their product. A cabin conversion is defined as the sum of the activities and processes necessary to transform the layout of a cabin from the original destination to a new one, having a new mission. Depending on the transformation scenario: Pax-to-Pax, Pax-to-Freighter, or Pax-to-VIP, the complexity of the activity changes, as well as the certification requirements [5].
- *Customization*: is the process of tailoring aircrafts to individual needs and wishes of an airline by integration of predefined options and individual customer requests into a basic aircraft model or specification [6].

2.2. Manufacturer Activities

As a direct interface with the passengers, the cabin plays a major role in fulfilling customer satisfaction. Therefore the cabin becomes an essential tool for the airlines to differentiate from competitors. The designer should comply with the need of individual design, service and branding [6].

Manufacturers often need to design ‘from inside out’ so to fulfill the customer requirements. As a highly customized part of the aircraft, the cabin design represents a complex work field to be managed, including phases like conception, definition, validation, testing, delivery and after sales support.

Type Certificate holders having quite a big market share in aircraft manufacturing are Boeing and Airbus. For Airbus, the Cabin Zero concept is used in cabin design. This concept generates activities like [4]:

- Studying the systems interface
- Detecting systems misbehavior in the development phase
- Creating the platform for performing tests:
  - EMI tests
  - Acoustic tests
  - Vibration Tests
  - Air Flow Distribution tests
  - Virtual flight test scenarios, involving cabin systems
- Facilitating solving the problems towards a mature cabin.

2.3. Completion Center Activities

Those organizations, aiming to develop the work for a complete conversion, call themselves Completion Centers (CC). While the aircraft manufacturers build a new cabin, a Completion Center deals with cabin conversions. Inside a Completion Centre all the activities related to the design, certification and monitoring are carried out, starting from customer request, up to delivery. Often the customer request is highly demanding, like a VIP conversion. However, a Completion Center deals also with conversions of smaller complexity, like cabin modifications.

A completion center does not necessarily handle every activity which is part of the conversion process chain itself. The decision "make or buy" has to be made and some activities will be outsourced given smaller players in the field or expert companies the possibility to participate [5]. Existing Completion Centers, like Jet Aviation in Basel, undertake especially the VIP conversions, as this market segment is continually growing. This market expansion represents a reason to involve subcontractors in the business [7].

The legal frame for conducting the conversion process within a CC is the organization having a Design Organization Approval (DOA), issued by the European Aviation Safety Agency (EASA). DOA grants the environment for conducting an airworthy design, as it will be shown later. See Figure 1 for a better illustration.

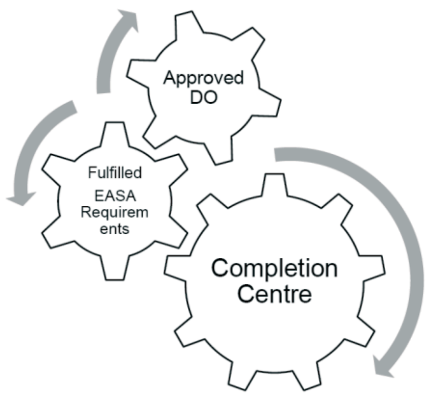

FIG 1. The mechanism behind the conversion within a Completion Center

Once a Completion Centre is able to develop an airworthy design, the customer requirements become the focusing point of the engineers. For instance, the Completion Center of Lufthansa Technik conducts a requirement capturing or fact finding phase, as an initial design process, before a contract is signed. This phase, which can take between a few weeks to eight months and averages around six months, involves answering questions about the mission profile of the aircraft, typical city pairs the operator flies, how the living quarters should look like and if the operator is willing to trade off some range to include unique interior elements [7].

2.4. Artificial Intelligence and Knowledge Based Engineering

The cabin layout configuration or reconfiguration represents a complex task; many disciplines relate to one another and many rules have to be accounted for, in order to optimize all the parameters involved in this task: like arrangement, type and position of the cabin interior components (seats and monuments). Tools developed for cabin conception use Artificial Intelligence (AI) and Knowledge Based Engineering (KBE) concepts [3].

The AI concept is defined as “the study of intelligent behavior achieved through computational means” [8]. Such computational systems exhibit the characteristics we associate with intelligence in human behavior – understanding language, learning, reasoning, solving problems [9].

An application of the AI concept is the expert systems technology. This technology allows the development of configuration systems. The aim of such a system, in our case, would be to solve the difficulty in configuring a cabin layout, which results by considering all restrictions and requirements at the same time [3]. Such restrictions are coming from the airworthiness authorities, or from the technical requirements of the manufacturer or suppliers, but also from the airline, by imposing for instance the seat pitch or the division per classes. Other factors which can be optimized are costs or lead times.

Artificial Intelligence has two major concerns: Knowledge Representation, addressing the problem of capturing the full range of knowledge required for intelligent behavior in a formal language and Search: a problem-solving technique that systematically explores successive and alternative stages in the problem-solving process [10].

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 [3].

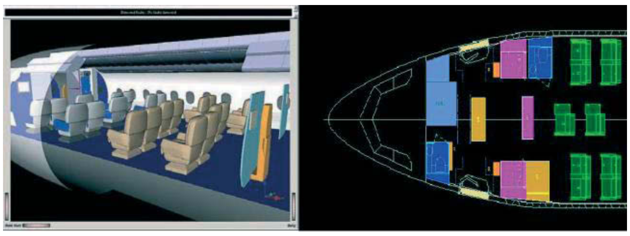

FIG 2. Cabin Layout representation example by using the Pacelab Cabin tool

A tool using the KBE approach when creating a cabin layout is Pacelab Cabin [11]. This tool uses technical rules, generated from customer or certification requirements, as knowledge representation. The rules, gathered into a knowledge database, can be used, modified and updated or newly created by the user. During the negotiations phase in the case of cabin conversion or refurbishing, 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 2.

Other scientific approaches at a university level aimed to combine the benefits of both concepts AI and KBE. By integrating the conceptual hierarchy model and by developing expert systems, such as PLAKON (at University of Hamburg), the configuration of a cabin, considering all the constraints, was successfully conducted on the example of medium and long range aircrafts [3].

3. SAFETY

Three entities interact for achieving the safety requirements: the designer, the operator and the regulator.

- *The regulator* sets the rules and certifies the products.
- *The designer* establishes and maintains an airworthy design.
- *The operator* operates and maintains the design within the procedures and limits specified by both the designer and the regulator [12].

3.1. Certification Authorities

The regulator is represented by the Certification Agencies. There are several organisms authorized to conduct the safety assessment activities. At an international level, the International Civil Aviation Organization (ICAO) was founded in 1947 and now gathers 188 members [13]; the annexes contained in the legislative documentation specify the principles and objectives to be followed by the national authorities, indicating the minimum level of airworthiness required to be maintained by the standards of the member states. However, the certification requirements and specifications are covered by the airworthiness standards, following the recommendations of ICAO documentation. On a European level, these specifications are developed by the European Aviation Safety Agency (EASA), having the support of the Joint Aviation Authorities (JAA) [14]. Through the transition from JAA to EASA, a unification of the European authorities was achieved under a single responsible organism, with the task to provide common standards for the aviation safety and environmental protection in the EU countries, being in the same time responsible for approving any design, manufacture or maintenance of airplanes or components, as well as for monitoring the implementation of the safety rules [15].

3.2. Design Organizations and Design Organization Approvals

The *Design Organization* (DO) is a term used by EASA to designate that organization comprising of the design activities for developing products and the internal and external (subcontractors or suppliers) organization for conducting this design work. Through the term *product* EASA refers to the aircraft, engine or propeller. The design activities can only be approved if the DO proves it’s capability by holding a *Design Organization Approval* (DOA), (article 21A.14, Subpart B) [15]. This approval implies the existence of a Design Assurance System, of an Independent Monitoring System and a Design Organization Manual, which are required to be set up according to the Annex 1, to the Implementing Rule 1702/2003, called Part 21. The Subpart J from Part 21, together with the Acceptable Means of Compliance and Guidance Material, specifies the requirements of EASA in order for a design organization to receive a DOA (Subpart J) [15]. We can conclude that the design work needs a corresponding technical organization; once the compliance is demonstrated, by holding a DOA, the applicant receives a Type Certificate or, as it is the case, a Restricted or a Supplemental Type Certificate (Subpart J) [15].

3.3. Requirements for Obtaining a DOA for Cabin Conversion

3.3.1. Minor and Major Changes

The conversion of a cabin can be defined as the *sum of changes to the type design* of the aircraft. The type design represents the sum of data, consisting of the drawings, specifications, information on materials and processes and on methods of manufacture and assembly, created by the design organization holding the type certificate (article 21A.31) [15].

According to the Agency, there are two types of changes to type design: minor and major. Two aspects need to be considered: the *classification* and the *approval* of the design changes. The holder of a DOA receives the privilege to classify the changes under the specifications of EASA; the procedure is shown in Figure 3, while Table 1 incorporates the examples of major changes related to cabin.

Another privilege obtained with the DOA, is the approval of minor changes and repairs, without the Agency's involvement. De Florio [2] makes a relevant observation regarding this aspect: the purpose of the authorities through the DOA is a transfer of the responsibilities from the control of the product to the control of the organization, by means of audits of products or systems. The aim is to promote the self-control of the organization on its way to designing safe products, independent from the surveillance of the Agency. However, major changes can only be approved by the Agency. The design of major changes (like transforming a cabin interior from pax to cargo) can be performed also by other than the Type Certificate (TC) holder of the product. An engineering office, not being the designer of the product, wanting to deliver a complete conversion, can apply for a Supplemental Type certificate (STC), according to Subpart E from EC No. 1702/2003 (article 21A.111) [15]. The applicant for a STC, needs to demonstrate the capability by holding a DOA. The Implementing Rule mentioned earlier, shows that another possibility is to make an agreement with the Agency towards an Alternative Procedure to DOA (article 21A.112B (a)) [15]. The disadvantage is that the privileges, mentioned in the previous paragraph, are not granted anymore, and the DO is more dependent on EASA. Table 1 shows some examples major changes which can be performed under STC, either by having a DOA (case A) or by applying for an alternative procedure (case B) [16].

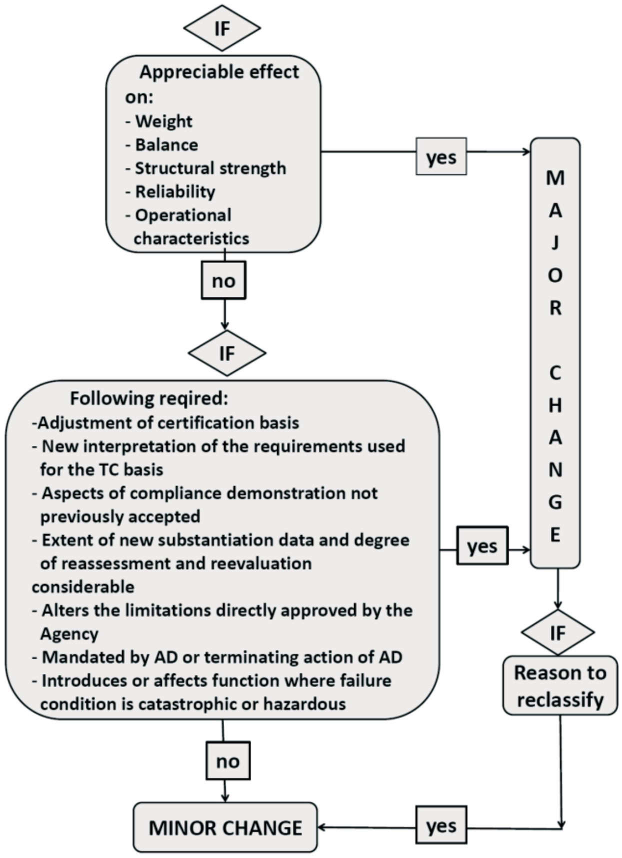

FIG 3. Classification process of minor and major changes [16]

TAB 1. Example of major changes for cabin safety [16]

Example of major changes for cabin safety
➢ New cabin layout affecting pax & crew safety or requiring changes in emergency evacuation
➢ Introduction of dynamically tested seats
➢ Pitch between seat rows
➢ Distance between seat and adjacent obstacle like a divider
➢ Cabin layouts that affect evacuation path or access to exits
➢ Installation of new galleys, toilets, wardrobes, etc
➢ Installation of new type of electrically powered galley insert
➢ Pressurization control system

TAB 2. Examples of major changes in type design, under Supplemental Type Certificate [16]

	Kind of STC	Discipline	Category
CS 23	Change to seating configuration	Structure	B
	Light weight floor panels	Structure	B
	Avionics upgrades (EFIS, GPS..)	Equipment	B/A[1]
	Engine instrument replacement	Equipment	B
	Autopilot system installation	Equipment	A
	WX radar installation	Equipment	B
	Aeromedical system installation	Equipment	B
CS 25	Cabin Layout (installation of seats, galleys, simple class or business economy class, etc)	Cabin Safety[2]	B
	Floor path marking	Cabin Safety	B
	Crew rest compartment	Cabin Safety	A
	Change of cargo compartment classification (from class D to class C)	Cabin Safety	A
	Cargo door	Structure[3]	A
	Changes from passenger to freighter configuration	Structure	A
	CVR; VHF; NAV; Meteo Radar, GPWS	Avionics	B
	DFDR	Avionics	B/A
	Autopilot, HUD, EFIS, FMS; ILS; RVSM ; TCAS, EGPWS	Avionics	A

3.3.2. Design Assurance System

The Design Assurance System (DAS) represents the organizational structure, responsibilities, procedures and resources of the DO, required to perform an airworthy design (GM to 21A.239) [16]. The DAS has to satisfy four major tasks (article 21A.239) [15]:

- To ensure the proper functioning of the design organization
- To define and implement systematic actions which prove compliance
- To monitor the compliance, including the manner in which it accounts for the acceptability of the parts and appliances coming from suppliers and subcontractors
- To ensure that its responsibilities are properly discharged

The planned and systematic activities within the DAS which show the capability of performing an airworthy design need to be continuously evaluated and corrective actions must be implemented when required.

3.3.3. Design Organization Manual

The Design Organization Manual (DOM) must specify all the instructions and procedures within the organization, required to perform the design. It must include the description of (21A.243 (a)) [15]:

- Design tasks performed under the approval
- Structural organization of the departments and interrelations
- Responsibilities, resources and procedures comprised in the design assurance system
- Means of design and testing: human resources, facilities and equipment
- Monitoring system
- Recording data system
- Responsibilities of the Office of Airworthiness
- A List of signatories

3.3.4. Personnel

The functions and responsibilities of the staff members, as stated earlier, must be properly discharged. According to the paragraph 21A.239 (referring to the Design Assurance System) [15], the number of personnel for assuming the main responsibilities is depending on the scope of work. The absolute minimum for a very limited scope could be defined for 5 persons:

- Head of the DO
- Head of the Office of Airworthiness
- Compliance Verification Engineer
- Design Engineer
- Quality Management Engineer

For an engineering office performing cabin design and reconfiguration, the management organization could look like in Figure 4.

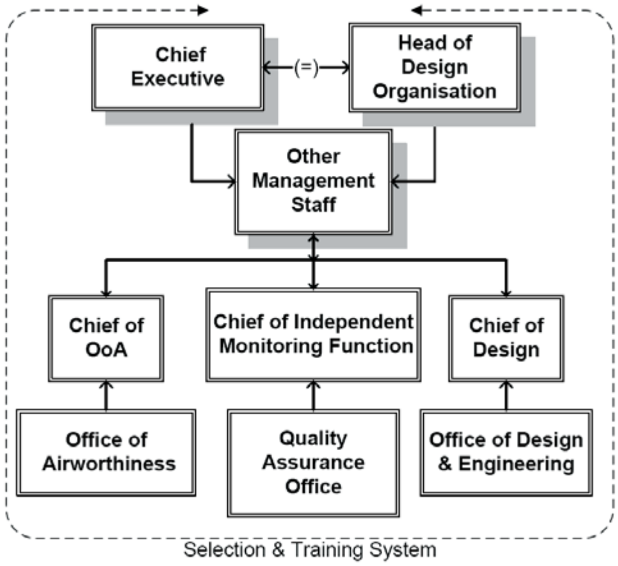

FIG 4. General description of the EASA required Management Staff in a Design Organization

4. PROCESS CHAIN DESCRIPTION

4.1. 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

[1] B/A means that an assessment of consequences in terms of handling qualities, performance or complexity of showing of compliance may lead to classification in group A [16]

[2] Basically all changes related to cabin configuration should be in group B [16]

[3] STC which leads to reassess the loads on large parts of primary structure should be in group A [16]

them. There are numerous approaches available to support process management, each depicting various aspects.

4.1.1. 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 [16]. They are focusing on information flows from one activity to another. Most of them capture the interactions between tasks, documents, events, roles / resources, and time (see Table 3). Some of these methods, applicable also in aerospace industry, are [17]:

– *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 [18];
– *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 [19]
– *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 [20];
– *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, swimlanes and artifacts [21];
– *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 [22];
– *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 [23];
– *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 [22];
– *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 [24]
– *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 [24];
– 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 [25]. 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 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).

TAB.3 Comparison of common process modeling methodologies [17]

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

4.1.2. Matrix Representation

Another possible way of representation for system analysis and management is the use of matrices. Well researched and documented are the Design Structure Matrix (DSM) and its derivatives: Domain Mapping Matrix (or DMM, allowing mapping between two different views on a system) and Multiple Domain Matrix (or 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 [26]. 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 10) [26].

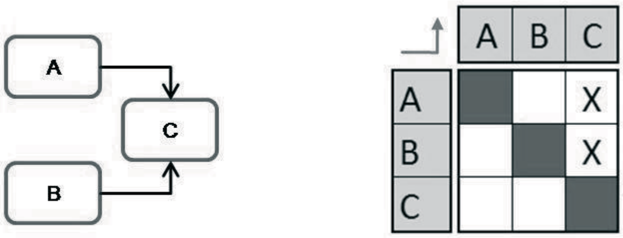

FIG. 5 Design Structure Matrix in contrast to a direct graph (digraph) [26]

The difference between the two representation forms is shown in Figure 5. 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 [26].

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 6, [27]):

- 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 5, 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.

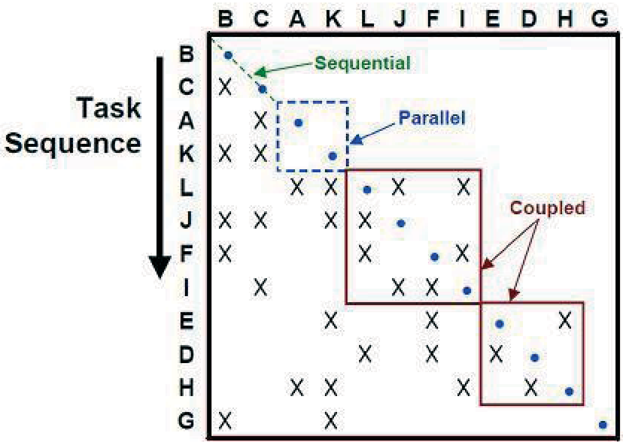

FIG. 6 Configuration possibilities of the interrelations between tasks [27]

4.1.3. 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 [28].

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 [29], [30]:

- 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 (as shown in chapter 3). 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 [31]. 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 [32]. 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.

4.2. Manufacturer's Processes

In general, the design of a cabin can follow the same milestones as for the design of the aircraft, with a less emphasis on the feasibility phase [33], [34]. The design phases would consist of:

- Concept Phase
- Architecture Phase
- Definition Phase
- Design Phase
- MCA (Major Component Assembly) Preparation Phase
- FAL (Final Assembly Line) Preparation Phase
- Manufacturing & Testing Phase
- Adjustment Phase
- Final Project Phase

Each Phase can be divided into specific sub-phases:

- Organization
- Design
- Engineering
- Electrical Systems
- Mechanical Systems
- Structure Design
- Cabin & Cargo Furnishing
- Manufacturing & Assembly

In this paper, having in mind the hypothesis of an engineering office, the perspective of a TC holder will not be addressed in a detailed manner; it is of interest, and part of the purpose of the paper, to identify the process chain for cabin conversions (under STC).

4.3. Completion Center Processes

There is not just one path towards achieving an optimized process chain (as shown in the previous paragraphs). The processes can be adapted according to the needs and the scope of the company. The only condition the company needs to fulfill is to follow the prescriptions of the EASA with respect to DO functioning. 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.

The first attempt to define these requirements is made in the *Offer Phase*. If the offer is accepted by both sides, then the technical document, describing it and the technical implications, heads towards the *Conversion Processing*. The output of the processing, summarized all together in the *Hand Over Phase,* comes back to the customer, and a circle closes. The correct functioning of this system returns feedback from customer and allows the update of a virtual catalogue. For a better understanding see Figure 7.

In this paper, the Process Chain description 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.

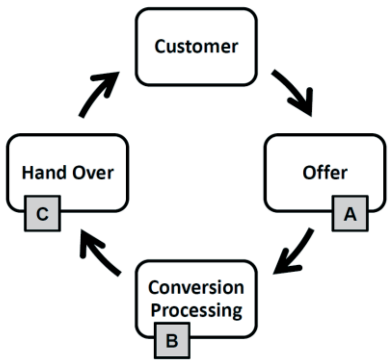

FIG 7. Completion Center Processes Concept

4.3.1. Design Phases

As showed in the previous paragraphs, it can be useful to implement in the conversion processes the tasks of the concurrent engineering, described first of all through the parallelization of tasks.

The description proposed in this paper shows a three dimensional process modeling inspired by the concurrent engineering. For the tasks representation in cabin conversion and refurbishing the following steps were followed:

- Engineers from engineering offices were interviewed
- Different sources of data were analyzed (industry cooperation with university, conference papers, etc)
- A list of tasks was created
- The relation between tasks was analyzed
- A DSM matrix was completed

In the next paragraphs the phases are briefly presented; afterwards the phases will be broken into detailed tasks and the relation between them will be illustrated by detecting parallel tasks (as in concurrent engineering) and by representing the tasks and the information flow between them into a Design Structure Matrix.

The main phases of the conversion process are represented into the horizontal plan. The certification of the design should cover all the phases and should be introduced from the early stage of the concept of the design process. Therefore it will be included into the vertical plan (indicated through a pyramid), which meets the horizontal plan in all the points represented by the phases. The assembly of the two plans forms the solid view on the development process (see Figure 8).

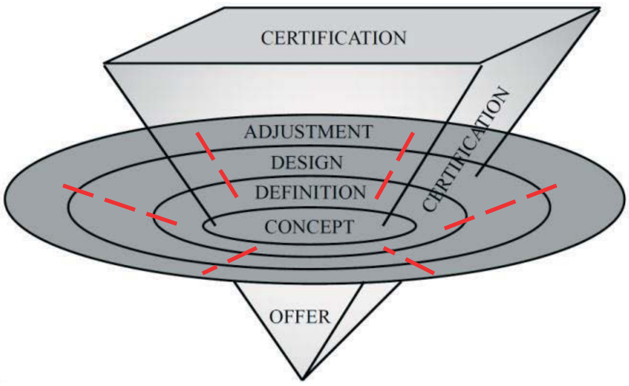

FIG. 8 Representation of the conversion processing cycle

The horizontal plan is represented by circles. The circle is the geometrical form of representation which allows communication between engineering teams in all directions (dotted line). The *Certification* phase, represented in the vertical plan, has a volumetric form, due to its major implications over the work activities. The *Offer* phase is represented as a starting point of the process, sustaining the whole development cycle. This decision, whether to start or not, is the result of the negotiations between the customer and the engineering office.

Aspects from concurrent engineering integrated into the approach represented in Figure 8 are:

- Communication among engineering teams
- Parallelization of tasks: the showing of compliance function is initiated from the early phase of the conception, validating all the phases.

4.3.2. A: Offer

The Offer Phase starts with the Customer Request which is formalized through a preliminary document called Customer Request Technical Sheet (CRTS). The CRTS briefly describes the requirements of the customers and the implications within the Completion Centre. In the same time, this document represents the first decision gate for both sides. If the two parts agree, then the Technical Offer document 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 (see Figures 9 and 10).

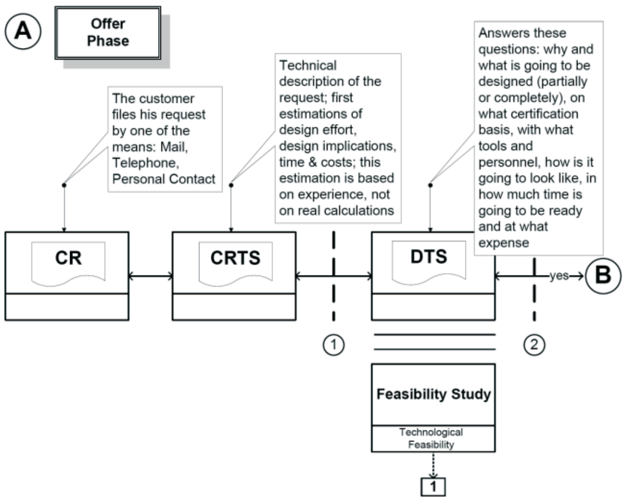

FIG 9. Process Chain Description A, Offer Phase

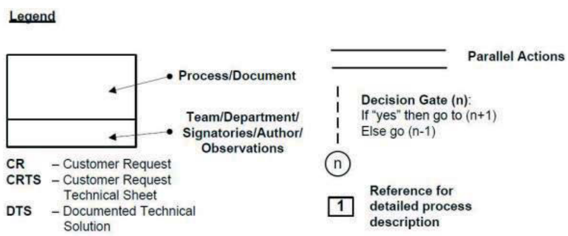

FIG 10. Legend to Process Chain A, Offer Phase

4.3.3. B: Conversion Processing

Process Chain description B, is represented in the horizontal plan and the upper half of the vertical plan shown in Figure 8. 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

Each phase has its own number of sub-phases, which can also be further divided into smaller processes. The generation of this matrix, gathering the phases and sub-phases, was made by using the resources shown in reference [26] and will be shown in the next paragraphs.

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 (OoA together with EASA)
- 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 the Chief of Design, assigned already in the conception phase, and those of the airworthiness engineers and CVE's. 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 responsible

4) Adjustment Phase

This phase allows the improvement of the design. While implementing the design definition into practice, different technical fields can get into conflict. It may be the case, for example, that due to the necessity of repositioning of a monument in the design phase, new electrical contacts have to be designed. These faults should be detected by the design verification engineers in the design phase. During this phase such situations are analyzed and adjusted, based on the reports of the Design Verification Engineers. Therefore, the main steps to be followed are:

- taking over the defect reports from the DVE's
- analyzing the available solutions
- finding the optimal solution
- restoring the design
- validating the design

5) Certification

According to article CS 25.21 from [35] 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. 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 (head of DO)

4.3.4. 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 work package. 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

Figure 11 shows the summary and the instruments used for the phases situated in the horizontal plan of representation. The representation concept was inspired by [36].

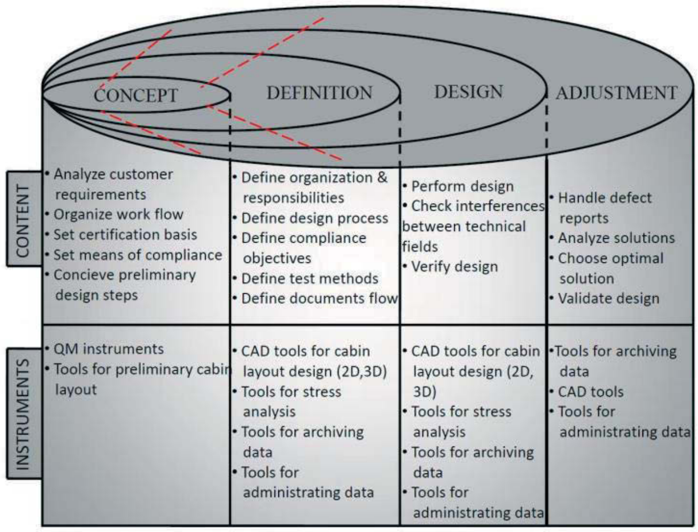

FIG. 11 Basic content and instruments for each phase represented in the horizontal plan

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 (see Figure 12.).

We assumed so far, that our hypothetical engineering office can only perform the design work, and not the manufacture and assembly. Therefore the deliverable is 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.

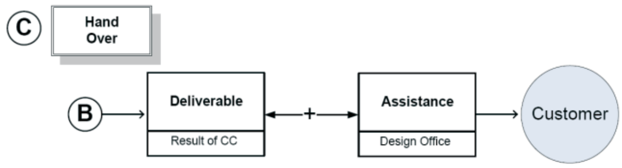

FIG 12. Process Chain Description C, Hand Over

4.3.5. Matrix Representation

The complexity of this approach consists of identifying the elements of the system and the relations between them. The elements together with the corresponding relations form domains. A DSM cannot contain more than one domain; however the representation of more DSM’s can be coupled into one matrix, called Multiple Domain Matrix.

More than one hundred processes have been identified as belonging to the phases briefly presented earlier. In the case of such complex systems three variants can be adopted for use:

1) Coarse Matrix - showing only the main phases and the relations between them;
2) Fine Matrix - showing the relation between all tasks;
3) Hierarchical Matrix - as a combination between the two, but more interface friendly, allowing the visualization of relations between all tasks, but not in detail.

The list of processes can be fed into DSM tools for further optimization. Having the relations between the processes, and the way to visualize the feedback loops, algorithms, like partitioning, clustering or triangularization, can be applied in order to minimize the delays and the waiting times. However this paper aims only to present the relation chain between tasks, while the optimization kept as a subject for later investigation.

		1	2	3	4	5	6	7
Offer	1	1	X	X	X	X	X	
Concept	2		2	X	X			
Definition	3		X	3	X			
Design	4			X	4	X	X	
Adjustment	5			X	X	5	X	
Certification	6				X		6	X
Hand Over	7							7

FIG 13. Coarse DSM Matrix

Figure 13 shows the coarse matrix. The reading direction is upwards. Therefore the interpretation is:

– Each phase delivers information downstream in a feed-forward sense.
– The Offer Phase gives information to all other phases, becoming the initial condition for conducting the design work.
– Between Design and Adjustment phases the information flows upstream as feedback, due to the existing x mark under the main diagonal
– Certification is a process giving feedback especially to Design and therefore also to Adjustment, which means that the three phases are coupled

Instead of using an X mark, the relations can be quantified and numerical DSMs can be generated. Relations of minor importance can be neglected and feedback loops reduced. The algorithms mentioned earlier are explained in reference [26], where research and commercial tools are recommended for use.

More meaningful is at this stage to see the hierarchical matrix, obtained from the fine matrix, since the size of the fine matrix makes the reading difficult. For elaborating the fine matrix behind the hierarchical matrix shown in Figure 14, an Excel Program [26] allowing also the partitioning of the matrix, has been used.

Figure 14 shows the phases, the corresponding tasks, and the relations between them. We can notice the similarities between the course matrix and the hierarchical matrix. Where the big X marks have not been drawn, the connection between the processes is considered to be small enough as to neglect the information flow between the processes and to consider them independent.

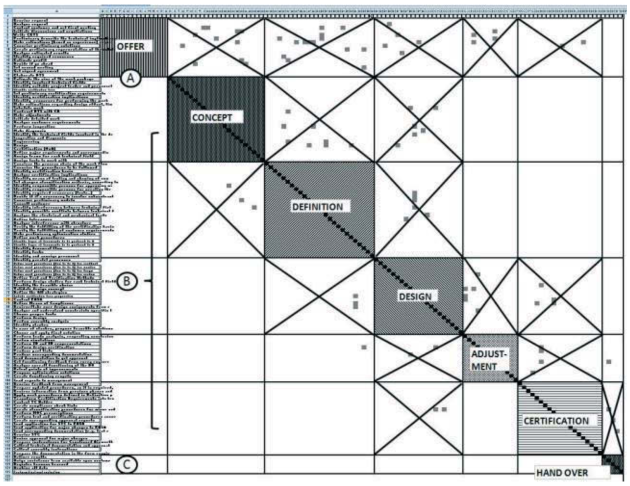

FIG. 14 Hierarchical DSM Matrix

4.3.6. Example: Cabin Modification

In addition to complete conversions, modifications to aircraft cabins can also be conducted within a Completion Center. In Figure 15 an example of partial modification is shown, starting from the customer request, up to delivery. Due to the smaller number of processes, a direct representation is chosen.

After the negotiations taking place in the Offer Phase, the requirements from the customer find an answer in the Documented Technical Solution (DTS). The Delegated Team (DT) can draw the preliminary conclusion towards the classification of change. The DTS will be part of the

Change Proposal (CP). The CVE will receive and analyze the CP, and will approve by signing the CAS (Change Approval Sheet), if the change is minor; if the change is major EASA involvement for approval is required. The approved Change Proposal forms the SB (Service Bulletin), which, together with the part lists and kits, as well with the maintenance and continuing airworthiness instructions, forms the deliverable, which goes to the customer.

5. CONCLUSIONS AND RECOMMENDATIONS

Several aspects must be considered when setting up a Completion Center, inside which cabin design and conversion is made possible for others then the aircraft manufacturers (or TC holders):

1. The organizational aspects, comprising of procedures and approvals, for creating the environment towards developing a compliant design
2. The tools for designing, archiving and administrating data
3. The infrastructure for performing the design and the required tests for showing compliance
4. The qualified personnel able to split all the responsibilities.
5. The way representing processes and procedures inside DO which allows optimization

Related to the aspect 1, the frame is represented by an organization having a DOA. EASA asked the industry about its opinion on the DOA concept. The questionnaire was evaluated by EASA and the following tendency was detected [37]:

Cooperation of different OEMs (Original Equipment Manufacturer) and/or Suppliers will increase leading to the creation of "Centers of Excellence" that will specialize in certain systems/parts and provide design and development expertise for various international programs.

If we keep in mind this tendency, a remark to the DOA system would be: the Agency should provide proper discharge of certification capabilities, to the suitable organization, independent from its formal organization.

A formalized relationship between major partners is now however possible. The "Centers of Excellence" can be composed of (parts of) companies who (temporarily) join in a well defined manner for a single or for multiple projects.

Another observation is: partners and suppliers are more and more located outside the EU and the USA (e.g. India, China); in such areas, reliance on the DOA system alone may not provide the necessary airworthiness safeguards.

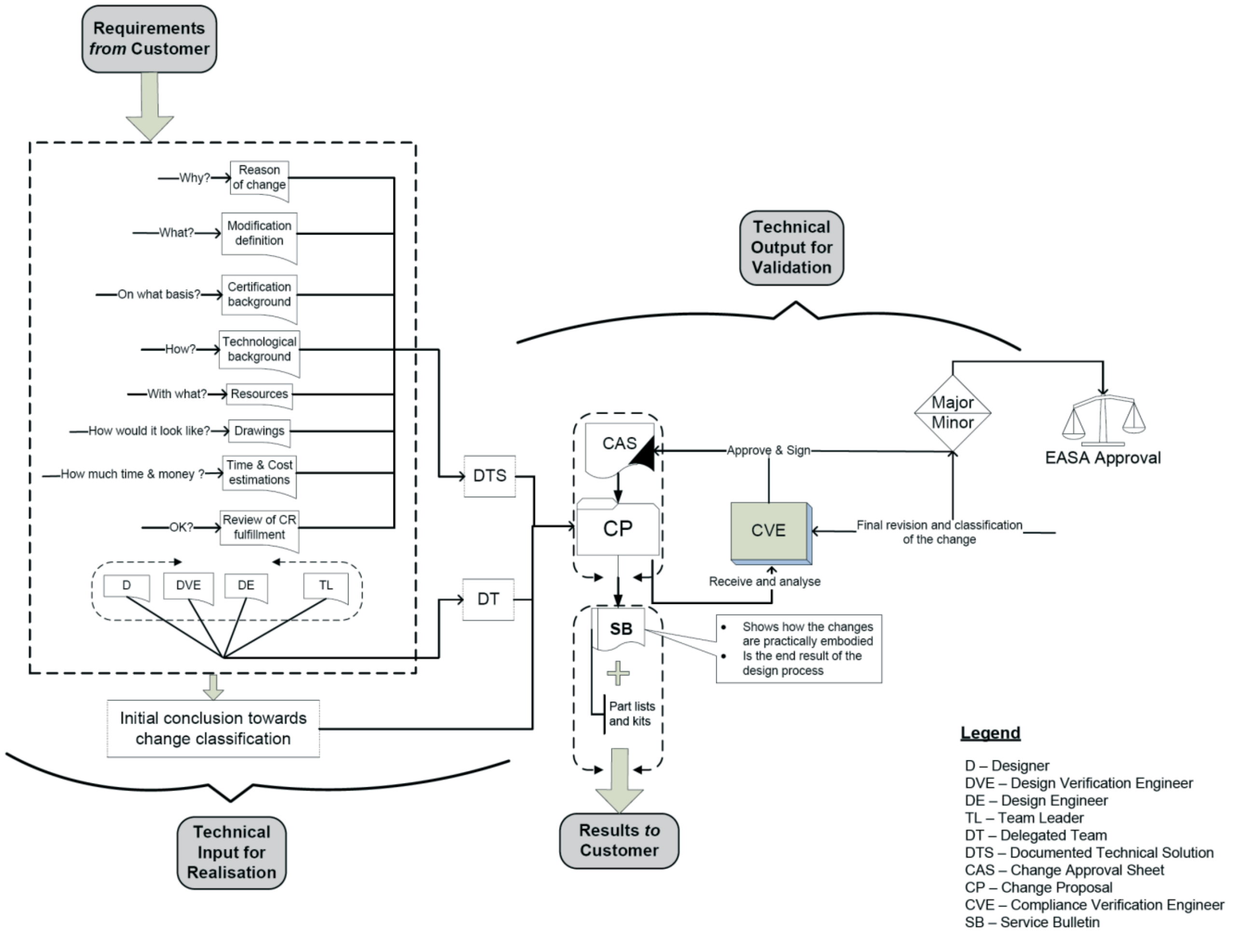

FIG 15. Process Chain description for partial cabin conversion example

The Agency proposes other three possible future certification concepts, replacing DOA, each with pros and cons [37]:

- Modular approach to certification – which would ensure a clear definition of responsibilities
- Industry self certification – the safety would be provided under privileges and responsibility of the product developer
- Third party certification – referring to outside agencies taking over the certification work; this would encourage the greater focus on improvement of resources and would also cause a costs reduction.

Related to the aspect 2, the pertinent observation is that the existing range of tools for drafting, for 2D and 3D representation, for quality management implementation, for administrating data and monitoring the design, must be tailored according to the needs and the scope of the design organization. A formalized relationship between major partners is now however possible. The "Centers of Excellence" can be composed

Aspect 3 and 4 involve investments; therefore feasibility studies must be performed in order to see if the Completion Center represents a business case for the engineering office wanting to perform cabin design and conversion.

The last aspect draws attention to the importance of the Quality and Management methodologies and strategies used for developing the 'product' called cabin design and conversion. Investigations need to be conducted for choosing proper models. The success of an optimized system definition becomes more and more a key factor. Choosing the right model out of the large range of tools and concepts can make the difference in market shares.

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