CONCURRENT ENGINEERING FOR GROUND SEGMENTS AND OPERATIONS CONCEPTUAL DESIGN

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Abstract

TU Darmstadt together with ESA/ESOC is currently building up a concurrent design laboratory as part of „ESA_Lab@TU Darmstadt", supported by a cooperative professorship on space systems at the Technical University of Darmstadt. Special focus is on the specific requirements of ground segments and operations conceptual design, considering the relevant engineering disciplines in an adapted method. The paper explains the approach for methodology and tools, and gives an overview of the facility currently built up and its applications.

1. CONTEXT

Space activities have seen fundamental changes in the last years. Under the label "Space 4.0" or "New Space", new players, be it institutional, industrial or private have come up. New ventures ranging from nano systems up to mega constellations have been conceived and deployed, allowing for an even wider use of space for the direct benefit of citizens. Ground Segments and Operations in this context have also seen increasing importance, since these aspects link the upstream space system with the actual utilisation, containing also the major value-adding parts of a space system, i.e. the products of space missions.

At the same time digital methods in design, development, deployment and utilisation have come into focus, aiming for a more agile and efficient development cycle using digital models and tools in a consistent way. Concurrent and digital engineering have gained increasing importance and a large number of concurrent engineering facilities have been established worldwide. While these methods are commonly applied in space systems conceptual design, the focus so far was mainly kept in the area of the space segments and payloads, while ground segment and utilisation aspects were usually covered as part of the overall space system, using standard approaches and designs. However, new space systems more and more come up with an increased level of complexity and interdependency of ground segment elements, such as size and topology of constellations, formations, increasing and variable levels of automation and autonomy, distributed operations schemes including non-space actors, technology push factors in IT including artificial intelligence methods, web- and cloud-based system topologies, virtual methods.

Picking up the need to review and evolve the approaches for ground segment and operations concepts, design and development, ESA has launched an initiative for "Innovation in Operations". From this token, a variety of system design issues have come up, needing a solid design analysis as the basis for technical and managerial decisions on new space systems. This is why ESA is targeting the introduction and fostering of the concurrent engineering capability with a special focus on ground segments and operations design.

One recent axis in this direction is the installation of a joint professorship "Kooperationsprofessur" for space systems between the European Space Operations Centre ESOC and TU Darmstadt. This also picks up the concept of an "ESA_Lab@TU Darmstadt", with a first core element being a Concurrent Design Laboratory tailored to the particular needs of Ground Segments and Operations design.

Concurrent Engineering (CE) is a state-of-the-art method within the space industry. This well-proven concept for designing complex space systems and missions in the pre-phase 0/A with a team of engineers and scientists of different disciplines generates an effective and time efficient design management system. One of the first Concurrent Engineering Facilities (CDF) in the space sector was the CDF in ESTEC, Netherlands, where CDF studies already have been successfully carried out for the past 20 years. Since the efficiency of this new approach and methodology to space mission design was recognized on the basis of ESTEC, CDFs were also established in various locations such as ESEC (ESA Academy) in Redu, Belgium, and DLR Bremen, Germany. Although numerous CDFs exist within the space sector, the method is not yet established for ground segment engineering and operations design studies. For the application within this area, the key elements of CE which are the process itself, a multidisciplinary team, the integrated design model as well as the software and hardware used in the facility have to be customized to the needs and requirements given by the ground segment.

While concurrent engineering for the space segment in the majority of the use cases can be focused on a standardised set of expert disciplines (e.g. power, thermal, data handling, communications etc.), the engineering design problem for ground segments in the

doi:10.25967/490211

above-mentioned contexts is usually much more diverse. It includes engineering aspects and disciplines, involving often non-space aspects such as for example large scale ground data handling, processing and distribution as well. As a consequence, the design process, the models and tools need to follow diversified requirements in a much more agile way.

2. ESA_LAB@TU DARMSTADT: CONCURRENT ENGINEERING LAB

In 2019, ESA initiated the “ESA_LAB@” network for strengthening the link between ESA and research entities/ academia and industrial partners. It consists of a network of research partners in ESA member states. While academia/ research institutions contribute with space, scientific expertise, students, teaching and research, and their own network, ESA is contributing with competence through experts, interesting and relevant research topics, contacts to space entities and access to other ESA platforms in education, research and development.

The ESA_Labs have different focal areas of research, reflecting the specific expertise in the respective organisations. For ESA_Lab@TU Darmstadt, the main focal points have been defined to be concurrent engineering/ digital engineering for complex technical systems, fully digital design and development cycle “Industry 4.0 for Space 4.0”, Space Safety models, methods and tools.

In this context, a concurrent engineering lab (CEL) is currently established as a joint research lab of ESA and TU Darmstadt addressing the lack of a facility where concurrent engineering is performed on the one hand for the analysis and assessment of new strategic areas with respect to ground segment and operations and on the other hand for research programmes of all faculties of the TU Darmstadt as well as for practical experiences for students.

The following sections will explain which aspects make the establishment of a Concurrent Engineering Lab interesting for ESOC and TU Darmstadt and which requirements have to be met for the design of infrastructure, models, methods, IT and software based on these points.

2.1. Utilisation Perspectives

The basic idea of the CEL is to strengthen innovation, efficiency and agility in ESOC’s ground systems engineering processes and therefore support the ground segment infrastructure evolution.

As mentioned before, new challenges and opportunities have emerged for space activities. In this context the trend is moving over to System of Systems (SoS) so that space systems are seen more as part of an overall system instead of having the focus on one individual segment. At the same time an increasing number of different players are involved in space activities creating an interaction between governments, the private sector, society and politics. Also new achievements in new technologies such as nano systems and mega constellations have been conceived and deployed to allow an even wider use of space for the direct benefit of citizens. Future mission trends such as shared and distributed systems, autonomous systems and hybrid systems are also being pursued in the Ground Segments and Operations area. Consistent with these new trends, the concurrent engineering lab will facilitate the creation of innovative ground segment and operations concepts. Moreover, the method can be applied for a variety of tasks such as analysis and assessment of new requirements, contingency situations, trade-offs or optimisation processes, preparation and support of technical reviews as well as providing a second line support for ESTEC CDF sessions containing complex ground segment engineering problems.

2.2. The utilisation perspectives for TU Darmstadt

For TU Darmstadt, the concurrent engineering lab will provide an environment researchers and students. In particular, further research in the area of systems engineering, digital engineering, Industry 4.0 / Space 4.0 and space traffic managements can be carried out. Additionally, in the field of education there will be the opportunity to introduce the CE process as a “Hands-On” to university students as part of the university curriculum. This can be done by offering tutorials or design and research projects with the objective to solve a space or aviation specific mission on the basis of CE. The Concurrent Engineering Lab goes also beyond the field of mechanical engineering and is accessible to all other departments of the university. The design to be developed according to these needs allows each department to intuitively use the lab for its studies and conduct sessions in it for its specific missions.

2.3. Design requirements

In order to meet the requirements of the visions of ESOC and TU Darmstadt for the CE Lab, a facility must enable a flexible and intuitive working environment for a variety of disciplines. This is essential both for the ground segment engineering area, as compared to the space segment the disciplines and targets involved in the missions vary constantly, and for the University as different departments and research interests intend to work with the lab without much prior knowledge and preparation. This leads to the question of how to design the infrastructure of the lab, in particular the models for the process and the IT platform or software and in terms of design methodology how to approach a useful structuring of a general problem. As compared to traditional concurrent engineering facilities, the Darmstadt utilization scenario is expected to be significantly more demanding in terms of flexibility.

3. PILOT USE-CASE

In preparation of the Concurrent Engineering Laboratory (CEL) and the required design process tailoring, use cases of needs for applications of the concurrent design method in ground segments and operations was established, one of them being a Deep Space Optical Communication System (DOCS) for ESA’s Space Weather Mission in the Lagrange Point L5. It is a typical example, where the design of a system element (in this case the choice of data transmission technology) has a significant impact on the ground segment design, not only for the required ground optical terminals, but also for all subsequent ground system elements dealing with data transmission, handling and control.

Therefore, this topic served as the ideal case study, delivering a given mission architecture (Figure 1) as well as general ground segment requirements derived from the mission requirements.

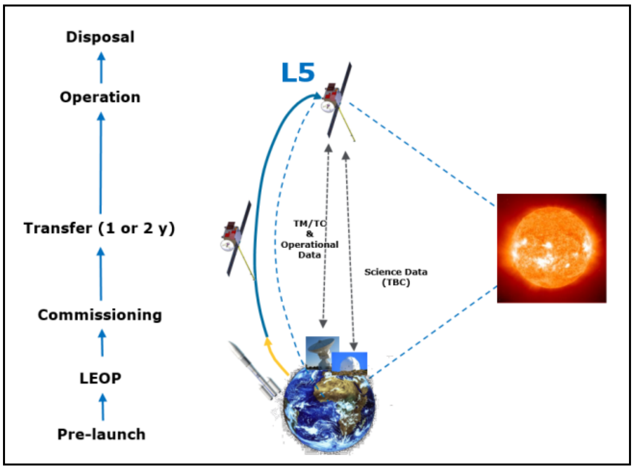

FIGURE 1. Mission Architecture

From a formal point of view, the sessions supposed to serve as an exemplary demonstration for prospective concurrent design activities in the area of ground segment and operations, taking place in the Concurrent Engineering Lab as part of the ESA_Lab@TU Darmstadt. The process supported the specification of the future Concurrent Engineering Lab in terms of software and methodology aspects. The definition of disciplines and its interfaces showed how the basic setup for ground segment and operations activities can look like in the concurrent engineering framework. Moreover, it confirmed the assumption that the domain models are not as standardized as for the space segment since they have a number of and more complex interfaces and interdependencies. Within the group of ESOC experts it was a first chance to promote the new working method and to show the benefits which emerge applying the principles of concurrent engineering: working as one team, working simultaneously by defining common constraints, requirements and objectives within a given timeframe.

The content-related purpose of the investigation was to demonstrate that the concept of optical communication can be applied to the L5 mission by quantifying the technical performance and outlining the operability of the complete communication chain. With the involvement of the relevant ESOC disciplines and the mission as the customer, trade-offs were supposed to be performed.

In the design activity, the investigation and assessment of different options concerning the following elements were identified to be key:

- Communication performance (data rate, data volume, availability and coverage, data handling, latency and link budget)
- Operational concept (e.g. commanding, data transfer, operational modes)
- Implementation aspects (available components, technology and software developments)
- Development and operational costs, risks and schedule

As a result, the architectural design of the ground segment including all essential components (such as the Optical Ground Station on the ground segment and the DOCS terminal on the space segment), its interfaces and the required operational processes were defined. This also included an analysis of available technologies as well as respective development needs.

3.1. System Elements and Domain Models

In cooperation with the project manager of the mission it had been outlined which disciplines had to be involved. First of all, it requires representatives of the mission including the project manager and an expert dealing with the interfaces of the spacecraft to the ground segment as well as a technical expert for the DOCS Space Terminal. These mission representatives act as the customer since the ground segment delivers its functionality of operations to the mission. They need to have an overall perspective about the study approach and deliver the requirements. In all engineering processes there is the need to have a systems engineer taking responsibility for the structure of the process and therefore act as a team leader and moderator. Typical for the concurrent engineering method is the definition of domain models covering the different expert areas.

For the purpose of this use case analysis, the specific disciplines/domains were identified, being “Ground Stations”, “Ground Data Systems” and “Ground Data Infrastructure” as well as “Operations”, “IT Support Mission Operations” and “Flight Dynamics” for the operational aspects (Figure 2). In addition, experts in the area of cost analysis were essential.

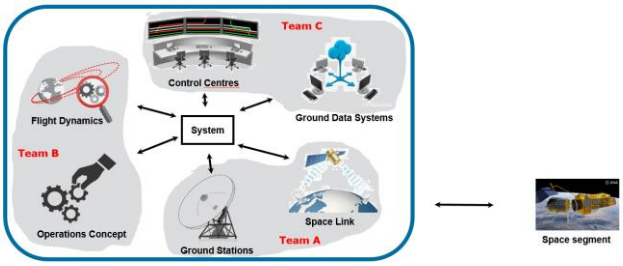

FIGURE 2. System Elements for DOCS Concurrent Engineering Use Case

The teams (A, B, C) were built in order to have a suitable structure for the first brainstorming. For the concurrent engineering sessions, the whole group of experts is working as one team which is the basic framework of simultaneous engineering.

As already discussed before, the compilation of experts in the area of ground segment is not as standardized as for the space segment. However, the given concept can be seen as a basic framework and needs to be tailored to other missions, projects or studies involving the mission manager or customer. The basic methodology followed a traditional design process as shown in Figure 3.

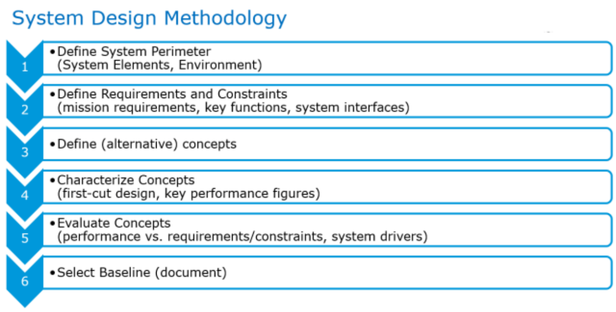

FIGURE 3. System Design Methodology

In the end, the architectural design of the ground segment including all essential components (such as the Optical Ground Station on the ground segment and the DOCS terminal on the space segment), its interfaces and the required operational processes were defined. The architecture is shown in Figure 4. The red lines indicate the elements which have been added in order to utilize the Deep Space Optical Communication System (DOCS) on-board the spacecraft

3.2. Lessons Learned

The pilot use-case allowed to perform a first test of a concurrent engineering process in the interdisciplinary area of ground segment and operations utilizing an actual ESOC mission. It demonstrated that the method is beneficial and valuable in this working environment.

For some of the experts representing the different domain models, it was the first contact with concurrent engineering method. They got to know the principles of this engineering method and also helped to define how the structure of sessions and the report structure should be established for future projects. However, the test case also proved that an engineering tool for simultaneous working is indispensable. It was difficult to achieve that all participants always had the current status of information, the architectural changes and the latest figures of the cost estimation. Moreover, the sessions took place in ESOC meeting rooms, so that the atmosphere of having an engineering session was not able to achieve. A dedicated lab is essential to avoid being dependent on the meeting room availability, to create a dedicated concurrent engineering working atmosphere and to provide the appropriate infrastructure concerning hardware and software.

In view of further use cases and in particular for the utilisation of the CEL, it was concluded that a long-term planning with the experts involved as well as the required management support is indispensable. The session structure will have to be kept flexible, depending on the composition of the expert team (internal, external).

4. STATUS & PLANS

Following the cooperation agreement between TU Darmstadt and ESA in 2015 on joint research activities, ESA_Lab@TU Darmstadt / CEL is the first key element of joint research. A room in the mechanical engineering building at the TU campus "Lichtwiese" was chosen as a suitable location for the lab. On the one hand, the ESA employees have the chance to get out of their familiar working environment and concentrate fully on the CE process and the future mission, on the other hand this also facilitates the access to the CE Lab for the students of the TU Darmstadt. Meanwhile, construction works on the location have been concluded and the installation of the equipment is ongoing.

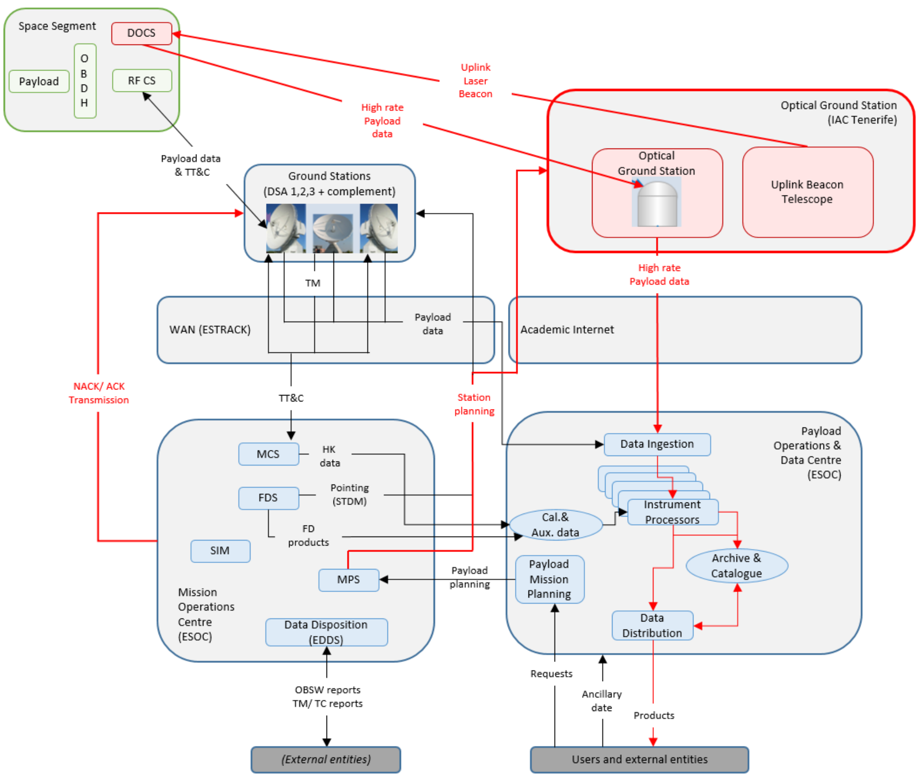

FIGURE 4. Ground Segment Architectural Design

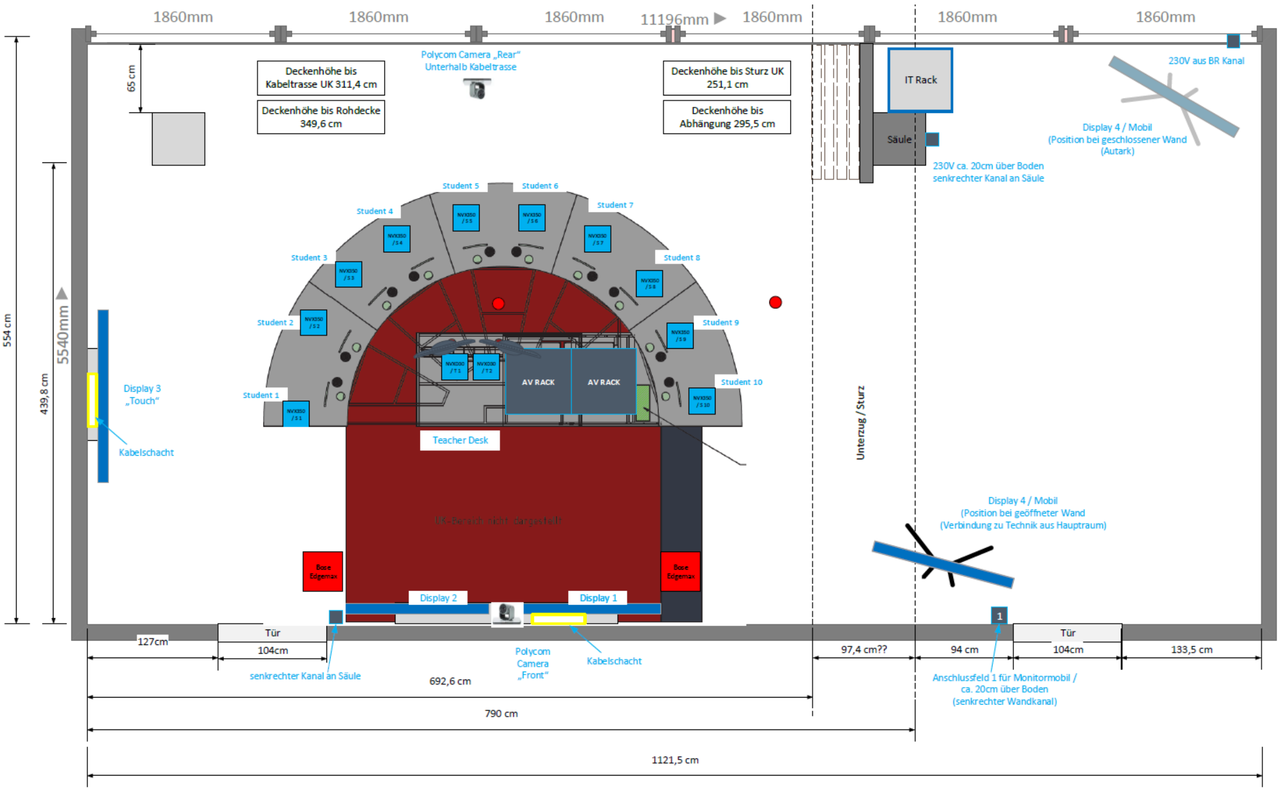

FIGURE 5. The CELab@TU Darmstadt Layout (Source AVN Solution GmbH)

4.1. Layout and Infrastructure

The layout and infrastructure of the Concurrent Engineering Lab@TU Darmstadt is based on the ESTEC Concurrent Design Facility (CDF), however tailored to the specific needs of the Darmstadt use cases. The design of the ESTEC CDF has been developed and aligned with over 200 sessions to create a suitable environment for the design process, interactions, co-operations and the involvement of the specialists. [1]. The Darmstadt CEL design implements a horseshoe arrangement for 10 design domains (Figure 5).

The centre is defined by the front desk of the team leader/ system architect to moderate and manage the design sessions. The front desk is located on a platform that accommodates the cabling to connect the workstations for the technical disciplines with the displays, servers and audio-visual equipment. Large display screens are integrated in the wall panels to the platform. The table combination with the orientation of the screens is shown in Figure 6. This design allows to integrate the whole IT and audio-visual equipment in one physical entity in a very efficient way.

Each of the eleven workstations is equipped with a desktop PC, a 24-inch monitor, a socket module for charging mobile devices and a connection cable for laptops which can be integrated into the working environment. In addition to the two large monitors on the front wall a 75-inch touch monitor is integrated on the left wall side of the lab which can also function as a whiteboard and is equipped with an additional PC.

As an extension to the core concurrent engineering table, adjustable tables on the right half of the room can be used to create up to eight additional workstations. They can be used e.g. for specialists who can participate in the session using their own laptops. Optionally the lab can be divided into two rooms by a flexible partition glass wall system which creates an additional small meeting room for splinter working or discussion groups next to the main room where CE sessions are taking place. Figure 7 shows the closed partition glass wall.

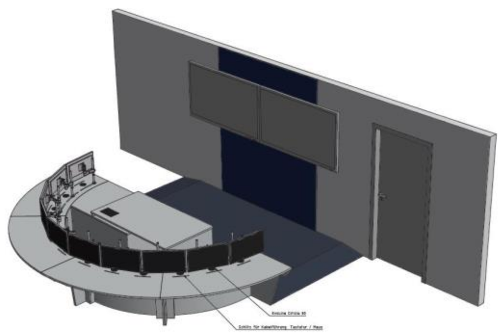

FIGURE 6. Layout of the workstations in the main room (Source AVN Solution GmbH)

For this purpose, there is also the option of using the tables as high desks. The meeting room will be equipped with a mobile 65-inch monitor that can be used as a support monitor for a session with an open glass wall. Videoconferencing for including external experts or linking with other CE facilities will be another standard feature of the facility.

With a Crestron solution it is possible to display the content on the individual monitors from any PC workstation. Each workstation is provided with a virtual user interface on the desktop which allows the respective PC to display content on one or more other monitors. A tool is also provided to share the content in a video conference.

FIGURE 7. Closed flexible partition glass

The basic central functions such as switching the entire system on and off, volume control, switching between video conference and presentation mode, controlling lights and blinds, assigning sources to displays, etc. are controlled via a wired touch panel at the team leader workstation. All controls of the monitor content are able to be moved to all monitors or to the content input.

4.2. Outlook

Currently, the planning of the infrastructure of the room and the conference technology has been completed and is being implemented. The end of the final installation and an inauguration date is intended for December 2019.

In addition to a well-defined environment structure, the provision of relevant software tools for the CE participants is just as important.

On the one hand, the specialists need the tools specifically used in their domain (e.g. Matlab, CAD programs, etc.) and general basic tools (e.g. MS Excel, video conferencing tools, etc.) in order to conduct further input, calculations or requirements during the session. Therefore, the next step will be to define and implement the domain tools which need to be available to the participants for productive work.

On the other hand, a software infrastructure must be provided into the CE Lab which allows each participant to simultaneously access and exchange information in a model-based data pool and is monitored by the team leader. An open source application that fulfils these requirements is the Open Concurrent Design Tool (OCDT) which was specifically developed for the CDF in ESTEC and will be used as a baseline for the initial test phase. [2] In the course of the test phase, alternative approaches will be analysed, taking into account in particular suitability for "on the spot users". Due to the variety of missions conducted in the CE Lab and the resulting continuous change of new participants, a tool with an intuitive and simple interface is required to reduce the learning time at the beginning of a new CE study.

In order to iteratively implement suitable processes, models and tools into the CE Lab, pilot workshops are planned by ESA (see Section 3). Each session will be evaluated to adapt the models and tools to the requirements of the participants and integrate them into the CE Lab until a satisfactory CE process is achieved.

In addition, further research will be conducted in the field of system design to benefit from the latest approaches and integrate them into the CE Lab. In this case, a further connection to the university can be created and contributions can be made through student project works. It is also planned to contact other concurrent engineering facilities for community meetings, expert knowledge and experience sharing.

REFERENCES

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