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Concurrent Engineering in later project phases: current methods and future demands

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Abstract

The department of System Analysis Space Segment of DLR´s Institute of Space Systems in Bremen has successfully demonstrated the benefit of Concurrent Engineering (CE) in more than 60 studies since the implementation of the Concurrent Engineering Facility (CEF) in 2008. The core competence developed and optimized during these years is mainly the execution of early project phase studies (0 / A) to prove the feasibility of the mission and system design. The research objective of the CE team is to further develop the well-proven process for early phase studies towards an application of the CEF and the CE methodology in later phases, with a special focus on preliminary design activities (Phase B).

The team´s underlying hypothesis is that this endeavour can only be successful through an efficient combination of software (i.e. the data model) and a tailored process. A critical aspect for peak productivity that needs to be controlled by the process is that the right people and all currently required information are available for collocated work, e.g. using the CEF. The process must furthermore foresee an effective approach to work concurrently on the data model during CE sessions but also to continue to do so in a collaborative manner outside the CEF. Thus, the final aim is to streamline the development process and to achieve an optimized result in a reduced period of time.

After a short overview on related work, this paper presents DLR´s activities in this field. It summarizes the results and take-away messages from a conducted survey with key personnel from spaceflight projects concerning their demands and requirements. Finally, based on this survey, a first set of recommendations and actions are sketched to finally enable the support of ongoing design projects through an optimized usage of CE in later phases.

Keywords: Concurrent Engineering, CEF, Process, Phase B, MBSE

Acronyms/Abbreviations

AIT	Assembly, Integration and Testing
AIV	Assembly, Integration and Verification
CE	Concurrent Engineering
CEC	Concurrent Engineering Center
CEF	Concurrent Engineering Facility
CIC	Centre d'Ingénierie Concourante
CNES	Centre national d'études spatiales
DLR	Deutsches Zentrum für Luft- und Raumfahrt
ECSS	European Cooperation for Space Standardization
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre
IDM	Integrated Design Model
MBSE	Model-based Systems Engineering
OCDT	Open Concurrent Design Tool
PDR	Preliminary Design Review
PM	Project Management
PRR	Preliminary Requirements Review
SRR	System Requirements Review
SVN	Subversion

1. Introduction

Organisations systematize their work in processes to carry out the work efficiently and achieve the defined goals. These processes are in some cases formally characterized, in others they are the result of the work-mentality and evolve from best-practices and experience from former projects by involved team members.

Changes in the way of working by introducing new processes or re-engineering the existing methodologies may result in pushbacks, especially when the processes are imposed from an external entity without a proper involvement of the end users during the process definition, as it might make wrong assumptions and not consider the actual work environment and user needs.

The present objective of DLR`s Institute of Space Systems is to further develop the well-proven process for the initiation, preparation, conduction and post-processing of Concurrent Engineering (CE) studies during early project phases and to adapt it to bring the acknowledged benefits of collocated, simultaneous work also to later project phases, as a first step to the Preliminary Design Phase (Phase B according to ECSS).

As DLR`s Concurrent Engineering Facility (CEF) is presently offered mostly as horizontal service (i.e. with a wide range of customers from different sectors), the CEF core team members are not continuously supporting the ongoing projects, but join the project for a short period of time (i.e. a few month) to guide them through the CE activity. This outside view onto projects makes it difficult to create new processes which finally would also be applied and supported by the users.

To bridge this gap, as a first step to define the new CE process for later project phases, a survey has been conducted among the most important CEF potential user community (i.e. institute internal) to document the current work methodologies in projects in general, in Phase B in particular, and to query the user demands and ideas for the application of CE in the preliminary design of a space system.

Based on the common definitions and current state of the art, this paper presents the methodology of the ongoing research, the results and derived conclusions of the conducted survey, and a first set of recommendations to implement CE in Phase B.

2. Related work and definitions

The research topic for CE in later phases has to be approached in consideration of various existing design standards and methodologies, as they are used as a starting point or assumed to be fundamental elements of the to-be-defined process. The following short descriptions also serve as definition of terms as used in the frame of this paper.

2.1 ECSS Phase Description

When talking about phases in the course of this paper it always refers to the different phases of a project as defined by the ECSS-M-ST-10C / ECSS-E-ST-10C standards [1, 2]. The most relevant phases w.r.t. CE and this paper are the phases 0, A and B entitled as “Mission analysis/needs identification”, “Feasibility” and “Preliminary definition”. Each of these phases consist of a set of major tasks, which should be elaborated during the phases and at least one review, which is used to judge the readiness of the project to move into the subsequent project stage. As this paper focusses on Phase B, the most important reviews are the System Requirements Review (SRR), which is held in the course of Phase B and the Preliminary Design Review (PDR) at its end as final activity before proceeding to Phase C.

2.2 Concurrent Engineering @ DLR

Currently, the biggest use-case for the CEF is the conduction of Phase 0/A activities to create the mission concept or to assess the mission`s feasibility. This application is referred to as CE in early phases. A specific process has been defined and optimized over the years for the initiation, preparation, conduction and post-processing of these CE studies [3]. It lasts either one or two weeks, depending on the complexity and objectives of the study as well as the availability of the team members and of the facility itself, as identified during the initiation and preparation phases.

There are three main sequences that are identified within a CE study (c.f. Fig. 1):

- **Moderated sessions**: moderated, cooperative CE sessions that involve all participants of the study
- **Non-moderated time**: time slots foreseen for work in small groups or individually
- **Presentations**: there are Kick-off presentations in the beginning of every study and the Final Presentations at the end are also part of the documentation. On a “need to” basis further presentations can be given by team members to provide relevant and important information to all team members.

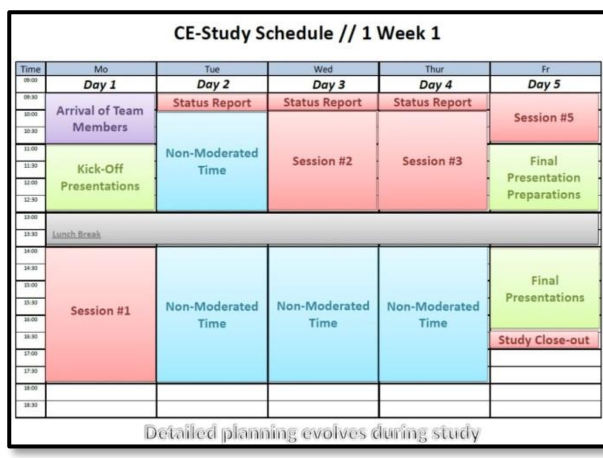

Fig. 1. One-week study approach (example)

Any study starts with Kick-off presentations and a first moderated session. After that, time is distributed between additional moderated sessions and non-moderated sessions depending on the study’s depth and objectives, until the last day of the study.

The last day includes the last session, employed primarily for model updates and final clarifications to

ensure consistency, as well as the Final Presentations, which close the CE study with a small overview of the results from each subsystem. Those presentations are still to be considered as a working session if there is new important information available, or if some issues were unconsidered by any domain expert.
During the moderated sessions, the Team Leader is responsible of maintaining the work rhythm, and guiding the discussion in a productive way, both facilitating the exchange of ideas and defusing any tension that might be produced. However the work of the moderation is based on the principle of as little involvement as possible, as much as necessary.

Typically any study-day after the first one will start with a summary/recapitulation of how things were left the previous evening, including decisions and important remarks, open action items and discussions (also noting the potential participants) and a summary of the most important budgets (mostly mass and power), independently of whether that morning is planned for non-moderated work or a moderated session.

The CEF core team is a central part for the successful preparation, conduction and post-processing of CE studies. The team typically receives requests with several months lead-time, and becomes involved in the project for a limited period of time, supporting multiple tasks that are necessary for the execution of a successful study (i.e. problem formulation, setting of requirements, initial analyses and trades, planning and agenda definition, enforcing deadlines). During the study the team leader takes over the role of an unbiased moderator but also supports the systems engineer and project manager in tracking of action-items, consistency checks and other aspects. Therefore, depending on the study`s mission type, only a general understanding of the topic or system being studied is required (although more in-depth knowledge is always beneficial).

2.3 Data model & MBSE

The use of a common shared data model for the design of the system has always been one of the main pillars of CE, as it supports the direct communication and leads to a consistent design. Even though, it can be observed that a lot of the different Concurrent Engineering Centers (CECs) develop their own tools to accommodate for the specific needs and structures within the hosting institution, the motivation and the underlying principles are similar. Examples for such institutional tools are ESA`s Open Concurrent Design Tool (OCDT) [4], DLR`s Virtual Satellite [5] or the IDM-CIC (Integrated Design Model - Centre d'Ingénierie Concourante) developed by CNES [6]. With the current trend towards digitization and Model-based Systems Engineering (MBSE) under the umbrella of Industry 4.0, this way of working is now also applied more often in the engineer`s work outside the scope of CE. [7]

The tool which is used at DLR`s CEF to create and work on the data model is an in-house development referred to as "Virtual Satellite". Even though initially developed for the exclusive use during CE studies, this tool and the underlying data model is currently further developed towards the usage throughout the system`s complete design life-cycle. First experiences in using this tool in a Phase B environment have been collected in the frame of DLR`s Small Satellite Technology Platform (S2TEP) project by replicating the systems engineering budgets and design specifications into the VirSat data model. Valuable feedback and the definition of requirements and extended capabilities specifically needed in Phase B have been created by following this approach without including the tool prematurely into the critical path of the project. [8]

2.4 Collaborative Engineering as extension of Systems Engineering

The Systems Engineering principles stem from a need to manage the growing complexity of technology developments and since then have been globally implemented and accepted. The systems engineers take over a centralized role to collect, consolidate and distribute information and tasks without direct interaction of the single domains among each other. Today the technical complexity is overlaid by an increasing interconnection and interdependency of systems, which makes it necessary to not only have the dedicated systems engineer looking at the whole system, but to involve the complete design team in the systems thinking paradigm. Collaborative Engineering goes closely together with computer supported or web-based design and thus the usage of the described MBSE concept and central data models to make the overall system`s design accessible for the complete team even when working remotely and/or asynchronously. [9]

2.5 CE in later phases

The development of a CE process in later phases (i.e. Phase B) is an open research task and during the literature research no known precedence which demonstrates this concept in a structured way has been discovered. Therefore, the assumptions and conclusions in this paper are not verifiable and the actual benefit not quantifiable yet. The recommendations given in this paper are based on the experience from work in the CEF during early design studies, results from the survey, as well as subjective opinions of the authors. The assumptions and suggestions need to be tested by applying them to existing projects in order to evaluate their efficiency, draw conclusions, and to create lessons-learned.

3. Research Methodology

The aim of DLR`s research topic, with the working title “CE@Phase B”, is to study the usual tasks and challenges that appear in later project phases, analyse the current project management processes at DLR, and derive from there the ways to apply CE effectively in later phases. This shall be done in several steps:

a) Conducting a survey and interviews with experts, addressing technical key personnel from former / ongoing projects about their experiences, current working methodology, needs and recommendations
b) Analysis of the results and condensation of common challenges and tasks which could benefit from the use of CE
c) Develop process(es) to make the best possible use of CE and the CEF in later phases
d) Application of the new process(es) in a test case (upcoming project)

The initial survey on user experiences, working methodology, user demands, expectations and recommendations was conducted in two different ways:

- Document-based questionnaire open to complete institute (+ interested externals)
- Face-to-face interviews of selected key personnel from DLR who have experience as systems engineer and/or project manager in space projects` later phases

The questionnaire inquired about the user`s familiarity with CE, experiences in later project phases, specific challenges and major tasks in Phase B projects, the work environment / setup, expectations and specific demands for Phase B studies, as well as a conclusion.

The interviews were led as open conversation tackling some major operational aspects of Phase B projects such as:

- Frequency of “multidisciplinary” meetings
- Usual issues that can be attributed to not working collaboratively
- Complications derived from lack of communication between domains
- Recommendations for best way of using the CEF

In addition, specific questions regarding the projects’ documentation management and typically used tools were raised and discussed.

4. Results

The results of the survey are presented in this chapter. The quantitative results from the questionnaire are depicted in diagrams. As the answers and also the focus during the interviews varied, such a graphical representation of the interviewees’ contributions is not possible. Instead, word-maps for the different main topics have been created automatically using the unmodified interview protocols as input. The font-size represents the relative frequency of words mentioned during the interviews, and thus, global trends and common thoughts (i.e. keywords) could be interpreted. In the following chapter the diagrams are supported by these word-maps, where suitable. The results are derived from an absolute number of nine completed questionnaires and seven conducted interviews with key personnel.

4.1 CE experience

As evidenced in Fig. 2, the feedback of the respondents in regards to their CE experience is positive. Most of the respondents answers sponsored a number of positive views about a CE study (i.e. enjoyable, team-building, benefits and result quality). The one negative point that some respondents noted is in regards to the difficulty to include a CE study into their regular work-schedule and/or the impact to other projects.

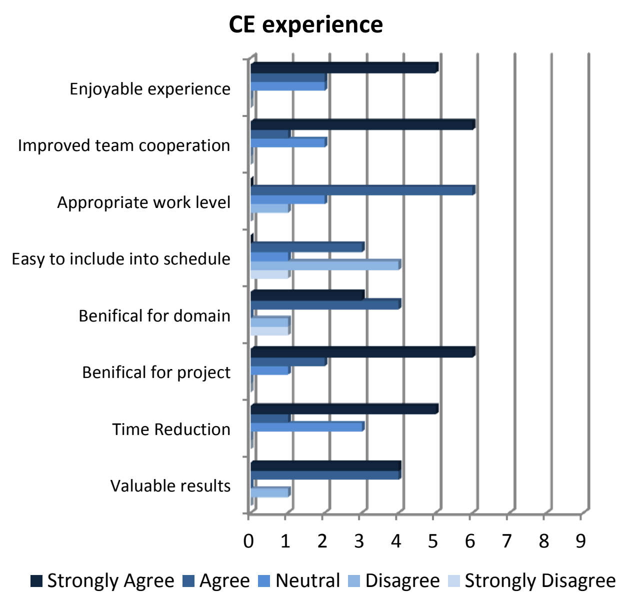

Fig. 2. Evaluation of the user`s personal CE experience from former studies

Another aspect evaluated by the respondents was the main advantages of CE studies when compared with traditional methodologies, i.e. centralized systems engineering (c.f. Fig. 3). According to the participants, the CE process is particularly advantageous in the achievement of consistent designs and achieving a common understanding of the project by the involved experts (both marking 100% approval). Additional benefits as time saving, risk reduction and other “soft” benefits as team building were also acknowledged by the majority of the respondents.

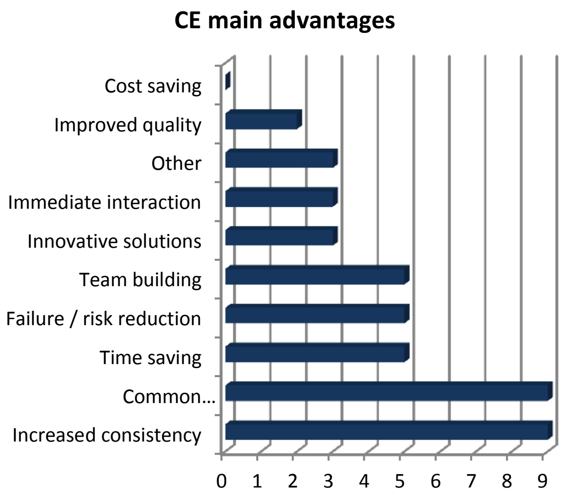

Fig. 3. Main advantages of applying the CE process as experienced by the user in former studies

4.2 Current work environment in Phase B

The first step to understand the potential of new processes is to record and understand the current work environment, in this specific case during the execution of projects in Phase B.

The average team size in projects plays an important role, especially under consideration of the limited place to accommodate project members in a CEC and the manageable group size to work efficiently. The survey showed a clear tendency towards teams with more than 25 members (c.f. Fig. 4), which makes it necessary to think about new methodologies to still make use of the benefits of CE.

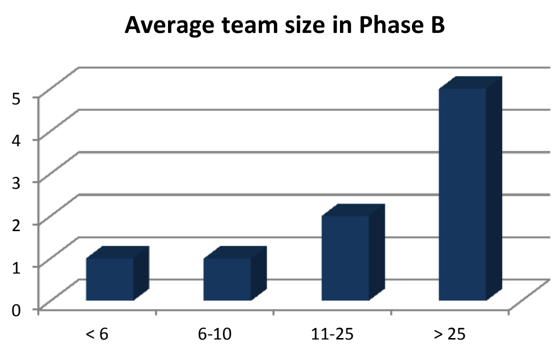

Fig. 4. Average projects` team size in Phase B

In regards to the tools used in the different projects, there was a set of tools that seemed to be commonly used in most projects according to the following categories:

- Data storage: Subversion (SVN) / Network-Drive
- Communication: E-Mail / Team site / (Wiki)
- Modelling & documentation: Microsoft Office Excel / Word / Powerpoint

The conversations showed that MBSE or integrated / central data models for now did not enter into the engineers routine work yet. Mostly, Excel-based master-files are used for budgeting and system layout (in some cases version-controlled by SVN). According to the interviewees, the system engineer is often the only person updating this master-file and must put a lot of effort into updating, consistency checking and information redistribution (i.e. following a traditional centralized approach). Even though new communication platforms (e.g. Wikis) are sporadically used, email is still the standard way of information exchange, including data transmission.

During the interviews it was made clear that following collaborative processes and new ways of data modelling could have a positive impact on future projects. In this regard, it was stressed by several interviewees that the user-friendliness of a new tool has a significant importance for the acceptance within a team. It was specified that a tool should not be too complex and only cover the most important elements of the work it was meant to do. It was also stated that for any tool to be useful, after a short training period to get acquainted with the tool, it should facilitate the daily work without putting additional work-load onto the user.

The experts were asked about the major tasks which are typically performed during Phase B. Detailed analysis, interface definition and risk assessment are the most critical tasks according to the experts, but there are a number of other secondary tasks that are important and cannot be underestimated (e.g. AIT/AIV planning, costing), as shown in Fig. 5.

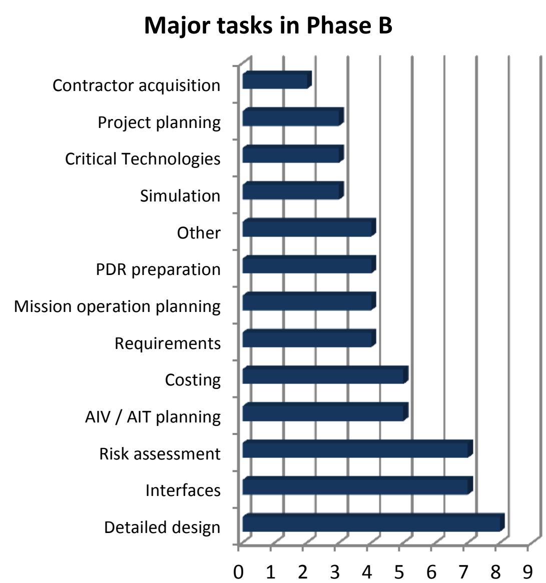

Fig. 5. Major (most important & common) tasks during the Phase B of a project

The identification of the major issues in Phase B, is helpful to define the areas which could be a promising start for first activities to support the projects by means of CE. The respondents identify primarily consistency as an issue, with other important concerns being design verification, requirement tracking and documentation (c.f. Fig. 6).

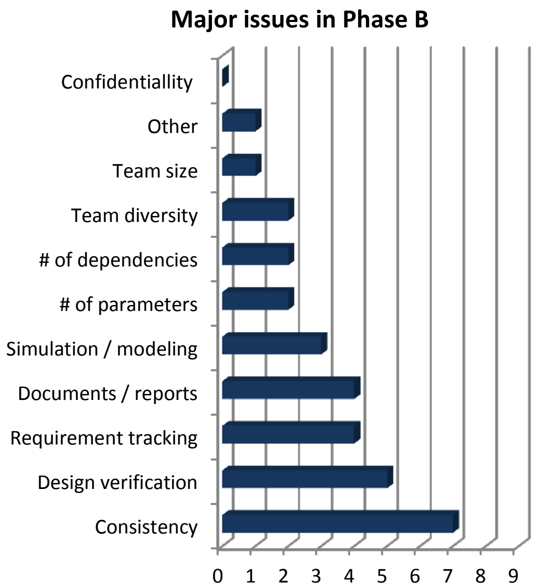

Fig. 6. Major issues experienced during the Phase B of former projects

The next important aspect to better understand the current daily routine in project work is to assess the frequency, type and typical attendees of meetings. Bi-weekly meetings are to be considered as the most common frequency for planned meetings involving the complete team, or within a subsystem team at a minimum (c.f. Fig. 7).

The interviews indicate that the types of meetings and their frequency in Phase B are dependent on the project's progress and current open tasks. Team meetings involving all the project participants, as well as CE-based design sessions, are, if even, conducted during the beginning of Phase B (e.g. to consolidate the design from former studies as common baseline). Meanwhile, as Phase B progresses, the number of participants necessary for a meeting decreases, and the frequency of the meetings increases up to a daily-basis (e.g. status morning meetings for short term planning and problem solving). Both the questionnaire and the interviews show the the tendency for a high need of action-based/ issue-based meetings involving task forces or subsystem teams to work on a very urgent topic/ solve an unforeseen issue. The importance of these unplannable meetings increases in later phases, which makes it difficult to make use of the CEF in the same way as for early phases.

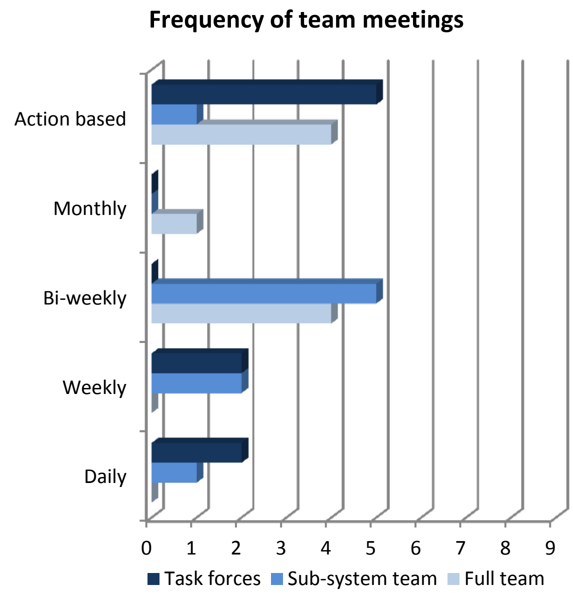

Fig. 7. Best practices for the frequency of different types of team meetings in Phase B.

Looking at the preferred work approaches, Fig. 8 shows the following tendencies: concurrent work seems to have potential in a lot of different fields as it is considered as the preferred solution for at least a few of the respondents for almost every task defined, although it is typically outranked by collaborative work.

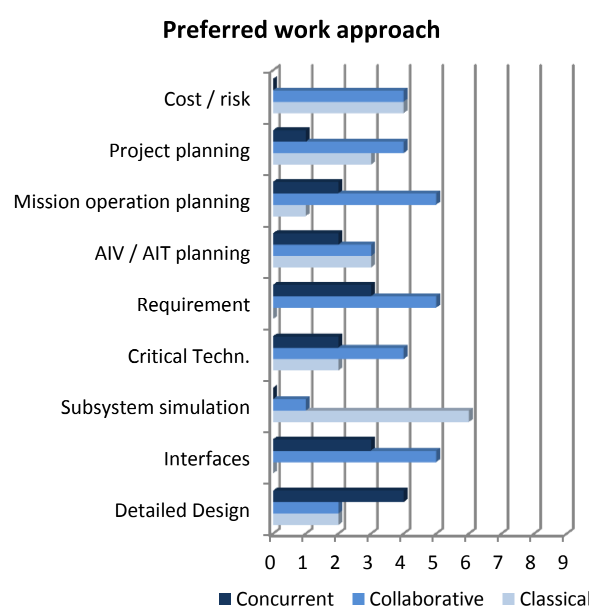

Fig. 8. Preferred work approach for different type of tasks during Phase B

Only for cost/risk assessment and subsystem simulations there seem to be no potential/need for the use of a concurrent approach. It is to be noted that the biggest group of respondents selected concurrent work for the task of designing a system. In the other fields, a big potential for collaborative work can be estimated, as it has been the approach of choice for the biggest group of respondents in almost all other tasks, except subsystem simulation. The latter is a clear task where one individual has to work independent from others (classical approach), especially in the preparation of the simulation model.

4.3 Potential applications for CE in Phase B

The final block of the questionnaire is dedicated to the assessment of the most promising and suitable tasks to be performed in a collocated manner and which of those are considered as most important and could have the biggest impact on the work routine in Phase B from the point of view of the respondents (c.f. Fig. 9 and Fig. 10).

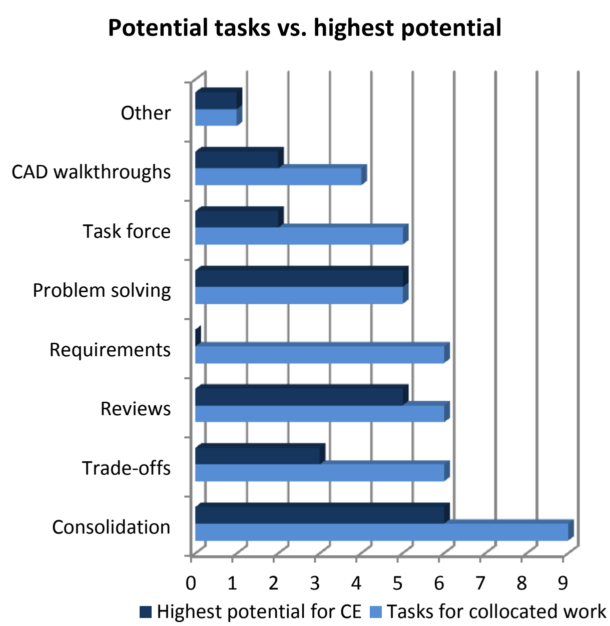

Fig. 9. Tasks during Phase B in which the use of the CEF as collocated workspace is considered as beneficial compared to the assessment of tasks with the highest potential for the successful implementation of CE in Phase B

There is a clear understanding of the potential benefit of using the CEF and a CE process for consolidation, but also for reviews and problem solving, and in a lesser way for trade-offs. The one task which respondents did not consider the CE to have a positive potential impact in Phase B is requirements definition/management. The interviewees considered that conducting a CE-study at the beginning of Phase B would be a good way to jump-start a project, and additionally serve as a kind of team-building kick-off event to introduce the project members and facilitate subsequent cooperation (especially for big consortia).

Another common impression was that the most natural usage of the facility is to conduct workshops in the manner of small CE studies to focus on specific design elements with the objective of optimizing them (e.g. wrt. mass / cost / performance). This could be done by inviting only a sub-set of technical experts whose work might be directly affected by changes on said elements.

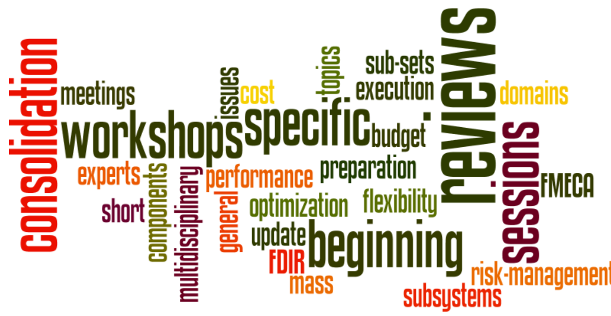

Fig. 10. Word-map representing visualizing the keywords as named for "type of activities in the CEF"

Another activity which, according to the interviewed experts, should be conducted in the CEF is to perform design consolidations (e.g. as preparation for milestones / reviews). Foreseeably this would be done at several points throughout the project to reduce/eradicate any miscommunication or misunderstandings, or to realign the current design elements and parameters.

Moreover, the CEF could be used for (internal) reviews, especially if MBSE (i.e. using Virtual Satellite) becomes the common way of modelling and documenting systems within DLR. The joint reflection of the design directly from the data model is an inherent part of CE, as wrong assumptions and inconsistencies can be noticed more easily than in a text-based documentation (especially when additionally supported by software checks) and would support the review preparation or even conduction.

The increasing level of detail is likely to lead to changes in the role of the CEF core team and the CE team leader compared to early phase studies (c.f. 2.2). The interviewees were asked about their demands and ideas for potential support for the project by a CEF core team member during the single CE activities in Phase B. The results of the conversation around this topic are visualized in Fig. 11.

The experts acknowledge the assessment that for a project-external CE team leader the detailed discussions are hard to follow without excessive effort (long preparation times or continuous shadowing of the project meetings). On the other hand the experts see the potential to use exactly this "open-minded" external actor to serve as an objective moderator (e.g. leading discussions, asking unbiased questions) responsible for the successful execution of the study (e.g. facility operation, CE process monitoring and MBSE tool support) and to take over tasks from the project manager / systems engineer during the activity (e.g. monitoring of action items, task distribution, status updates and technical budgets) to provide those domains with more time to focus on the detailed, specialized project related topics.

Fig. 11. Word-map representing visualizing the keywords as named for "support by CEF core team"

5. Discussion

In general, it has to be stated that the achieved sample size of completed questionnaires is not big enough to create a statistically verifiable result. The aim of the "CE@Phase B" activity is foremost to create a customized process for the work environment at DLR`s Institute of Space Systems. Thus, the interviews with DLR key personal with project responsibility inside this environment is a very important additional input, as those are considered to be the direct customers for the to-be-developed service (i.e. the process for CE activities in later phases). The merge of the information from the questionnaires and the interviews created a representative view, from which a set of findings with impact on the CE process for Phase B could be formulated. Even though derived from a very specific project setups and work environment at the institute, the global messages should hold true also for other organisations, while the specifics need to be adapted on a case to case basis.

The most important findings from the survey are listed as statements in the following text with a short discussion on the significance and potential impact on the process development for CE in Phase B.

Finding #1: The way work is currently performed follows a traditional centralized approach with appreciated usage of CE in the early project phases (Phase 0/A)

The overall picture generated from the survey and the interviews w.r.t. design process, applied tools and domain task distribution (i.e. role of the systems engineer) indicate that the projects follow a centralized approach with the Systems Engineer as hub and distributer for technical information. The experienced benefits of CE and the collaborative design approach using a central data model during CE studies in early project phases are not transferred into the projects routine work.

Finding #2: Later phase activities (especially if they are conducted concurrently / collaboratively) could benefit from a central data model. The central data model should at least cover the basic system parameters, budgets, interfaces and requirements.

During the interviews, the demand for tool support during Phase B has been recurrently noted as desirable supporting the hypothesis that tool and process should be developed in close cooperation.

On the other hand concerns remain w.r.t. usability of the tool for more complex designs. Based on experience from the current CE approach at DLR, the tool should not dominate the CE activity and should be intuitively usable with short time for familiarization. The assumption is that in later phases Collaborative Engineering, i.e. the continuous usage of a central data model, will take an important role and that it should be supported by one common tool. This will allow the user to get acquainted with the software in greater detail than not using it regularly in time-limited CE studies. Thus, it can be assumed that the manageable complexity of the tool can be higher. On the other hand, different domains are interested in different parts of the data in the model. Additionally, the manageable complexity during collocated work phases might differ from those with individual work. Thus, the implementation of different views onto the same data model enabled by the software tool is recommended.

Finding #3: Detailed design, interface definition and risk assessment are critical tasks in Phase B.

The individual answers to this rather specific question on most critical tasks depend on the actual domain of the particular respondent. Design, interface definition and risk assessment involve the complete team, which is why it is assumed that these tasks achieved the highest number of votes. Costing, test planning and requirements tracking, on the other hand, are more specific to single domains and therefore less prominent. It is reasonable to conclude that, since these Phase B critical tasks require the involvement of most experts in a project, they should be considered within any Phase B process involving the CEF.

Finding #4: Bi-weekly meetings seem as the preferred timeframe for project management scheduling, but a large number of action-based, impromptu meetings take place during Phase B.

Since bi-weekly meetings seem to involve the whole team, it might be a potential element of consideration for a CE Phase B process. Practical considerations would have to be contemplated, such as whether the CEF could support a recurrent bi-weekly use by a number of projects, as well as to the duration of such meetings, and the facility preparation effort required for each meeting. Action based CE sessions should also be considered, but this would require the CEF and the CE team to be both flexible, and to define a work process that can be set-up in a short time-span to accommodate projects that need it.

Finding #5: Meetings involving the full team are normally conducted during the beginning of Phase B, but as it progresses the number of participants required for a meeting decreases, and the frequency of the meetings increases (especially those that are action or issue based, and therefore unplanned).

It is easy to conclude that the way the CEF is used in later phases, and how CE is applied, must be adapted to support issue based activities. The short lead-times to "book" and setup the facility that would be required to assist such action-based activity must be considered, requiring the CE core team to be more flexible and possibly standardize how such activities would be conducted. Another relevant conclusion is that to better plan the frequency and required type of multidisciplinary activities within a project, typical milestones should be defined at those points where a collocated session would be most beneficial. This general scheduling of meetings/ activities most likely will not be defined by a specific timeframe (e.g. a date, or a period of time after some other activity), but will rather be linked to the achievement of specific milestones (e.g. mechanical interface definition freeze).

Finding #6: The most important issues to tackle in Phase B are consistency, design verification, requirement tracking and documentation.

Consistency is one of the main motivators for the initiation of this research w.r.t. CE in Phase B, as increased consistency is identified as one of the main benefits of CE in general, as also acknowledged by the respondents and interviewees. While it seems quite understandable how CE helps the team in ensuring consistency in their assumptions and to verify the design decision, for the latter issues this might not come naturally and possible ways to also support requirement tracking and documentation need to be analysed. The usage of MBSE is considered as especially helpful and required both during CE sessions and individual work to solve these most important issues.

Finding #7: The use of CE in Phase B is considered a potentially useful approach for most tasks, second only to a collaborative approach, and is identified as the most useful work approach for detailed design.

From the perception of the respondents, it seems clear that with an adequate process, a CE methodology could be useful and comfortable for a number of project tasks. It is also clear that a Phase B process which combines Collaborative and Concurrent Engineering could bring the best of both worlds. This is in line with the hypothesis stated by the CE team, whereby MBSE could support collaborative work throughout Phase B, with the model then being exported to the CEF for the execution of CE activities, and exported back to continue working on top of the changes that were made.

Finding #8: The task of "design consolidation" is deemed as the one which would benefit most of the use of CE during Phase B.

There is a clear understanding that the task of design consolidation is well suited for collocation, and also that it holds the highest improvement potential with the application of a Phase B CE process. Based on this information it could be worthwhile to consider this task as a first step to introduce CE in later phases by analysing the specific needs of such an activity and optimize the process accordingly.

Finding #9: (Task) specific problem solving is also considered a potential activity that can benefit from CE activities in Phase B.

The support of specific problem solving through CE should be looked into deeper. Collocated activities can support problem resolution due to the increased communication, but another aspect to be considered are the unforeseen problems that arise and that require action-based meetings.

Finding #10: Requirement definition and management are considered to have a high suitability for a collocated activity, but is considered at the same time to not benefit from a CE approach.

This finding seems to be a contradiction in itself. A first impression is that either the way a CE requirements review can be conducted is not well understood by the respondents, or that they consider that the means to do so are not available. There is a disconnect on the side of the users, that might require the CE team to analyse an efficient way to do these types of activities and promote it amongst the experts.

6. Recommondations

As a concrete take-away message of this paper, the above findings can be translated into a set of CE activity types suggested for Phase B which can be used as building blocks for the to be developed process. In a parallel work, a first preliminary recommendation of such a process based on these activity types has been sketched in [10]. The recommended activities can be defined by the involved team / participants and the objectives for the single activities.

The teaming for the CE activities should be selected from the list below:

- **Full team**: This type is used for activities for which it is important to have all domains and different views available. Depending on the current project phase, the group size can vary. If one domain is covered by more than one individual (i.e. a subsystem team) it might be sufficient if one representative participates in this activity type.
- **Subsystem team**: If the group size for one specific subsystem is too big to work efficiently by only using ad-hoc / direct communication, it is proposed to organize subsystem team activities to elaborate on the detailed design of their subsystem.
- **Task force**: A task force is defined as multi-disciplinary group (i.e. a sub-set of domains / work packages) which need to work on one specific common topic.
- **Customer**: For specific meetings it is important to have the customer available to be able to take direct consolidated decisions.

Even though the objective (i.e. the scope) for a CE activity is not limited in any direction, a few applications with high potential are listed as recommendation:

- **Phase-B "Kick-Off" CE study:** This activity is used to introduce the latest state to the project team, to summarize the results and recommendation from the Preliminary Requirements Review (PRR) and to actually start with technical work (i.e. to come up with / further develop the preliminary design of the system(s)). By this it is assumed to create a common understanding of the most important design drivers and critical parts of the project and additionally to achieve a consolidated starting point for the subsequent design phase.
- **Design workshops on specific topics / optimization:** The scope of such activities is to focus on one or a few closely connected aspects of the design and to discuss the different options with a group of multidisciplinary experts or to optimize the system design w.r.t. a specific performance parameters (e.g. mass, power, cost).
- **Detailed design sessions:** The proposed activity would use short collocated meetings for actual design work during which next to the involved technical experts also the systems engineer would be present for direct discussion of the system impact and constraints.
- **Design consolidation / Interfaces:** To ensure that in the progress of a project the design does not deviate too much from a common baseline and the overall team uses the same assumptions and to reduce/ eradicate any miscommunication or misunderstandings, it is recommended to conduct design consolidation meetings. These consolidation meetings would also be suited to define and freeze mutual internal / external interfaces.
- **(Internal) Reviews:** The aim of this activity is to concurrently examine the current project`s state, discuss about spotted discrepancies and sort those with regard to their assumed criticality.

As mentioned, the software and process development are mutually dependent. Based on the findings, recommendations w.r.t. the software would be to implement the possibility to apply filters and different views onto the model for the different type of activities and users. These mechanisms should not lead to a loss of information or extra work in transforming the data back and forth between the different views. Within the S2TEP project, a first concrete step into this direction has been taken by testing the work on the data model using two different views (one specifically for the work in the CEF and one for the continuous work throughout the Phase B).

7. Conclusion

This paper introduced DLR`s CE-team current research field with the aim to define processes and recommendations to successfully apply CE in later phases (taking Phase B as a first concrete step) and to assess the associated benefits by combining it with other design methodologies, i.e. Collaborative Engineering and MBSE. The described research methodology includes a mostly DLR internal survey from which valuable insight into the current work-environment of projects (e.g. teaming, tools, tasks and processes) has been gained as well as a collection of ideas / demands for potential support by the CE-team to solve some of the projects´ main issues when entering into a later project phase.

The results from the survey were discussed and 10 major findings w.r.t. the research topic have been derived leading to recommendations for various new activity types and task areas with high potential for the application of CE.

8. Outlook and future work

As a next step, the exact implementation of the proposed activity types need to be defined and to be put into a meaningful generic overall work flow to support the objectives of Phase B. The taken assumptions need to be tested step-by-step within an existing project by introducing different type of CE activities to create lessons learned in order to improve the assumptions and the process itself.

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