CONSIDERATIONS AND FIRST STEPS TOWARDS THE IMPLEMENTATION OF CONCURRENT ENGINEERING IN LATER PROJECT PHASES

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ABSTRACT

The benefits of Concurrent Engineering (CE) in early space project phases (0/A) have been demonstrated for decades. Many organizations have developed their own processes and tools, with different objectives and levels of integration into their product design cycles, and managed to execute studies in a systematic and efficient way. All of this, however, has not yet been made possible for later phases (B/C/D), of a space technology project.

For CE to be successfully applied in later phases a significant number of obstacles must be overcome, e.g. the high level of complexity of the systems involved, the distribution of industrial partners, or the increasingly large sizes of the teams involved. New tools need to be developed, new work processes will have to be established, and new ways of working will need to be enacted in organizations before CE can support these later activities. The CE team at DLR is focusing at present on the development of an internal process that could integrate the use of CE in combination with the application of Collaborative Engineering into Phase B.

A generic process can only be considered useful to a limited degree if implemented as originally defined. Any such process needs to be adapted to the specific work environment where it is to be executed. Therefore, when contemplating the development and application of a new work process in an organization, a number of different aspects need to be analysed. The particular characteristics of the organization will affect the process and vice versa. The methodology the process is aiming to follow will also impact its definition. The tools (i.e. software) that are used or need to be developed will impose its own restrictions to the process, and be influenced by it.

As part of DLR's current efforts to develop a working process for the use of CE in Phase B, an analysis of the factors that may influence the development has been undertaken. The paper will present this analysis, identifying the issues that need to be considered, as well as introducing the specific resulting CE process for Phase B at DLR.

One concrete first result for this proposed process is the identification of several CE benefitting activity types which shall be organized in a generic sequence from Phase 0 to end of Phase B. This paper presents the defined activity prototypes and a generic overall sequence flow of those activities. Finally, one possible specific implementation for an example project is sketched for clarification and comparison with a classical work approach.

1. INTRODUCTION

Organizations accomplish their work through linked chains of activities, many of which require the participation of different departments, experts, or functional groups within the company. Processes are the backbone of any organization, precisely because they provide a fine-grained description of how an organization works or an activity is performed, and therefore developing effective processes is critical when making activities consistent and repeatable. [1]

All entities have work processes that they follow, although they can differ in their level of maturity. Organizations with a high process maturity level will have efficient processes that have been designed with a clear rationale and are properly documented, while others will have processes that might have been developed organically and grown unchecked. Such inefficient processes need to be re-engineered in the pursuit of increased productivity, but it is not the only reason for the generation of new processes. The appearance of new methodologies (e.g. Concurrent Engineering, CE), new technologies and paradigms (e.g. Model-based Systems Engineering, MBSE), or changes in the structure of an organisation, are other reasons behind the re-engineering of existing processes, or of discarding them altogether and creating them anew within the new organisational model.

CE has been implemented successfully in many organizations for decades now [2] but most of these efforts have been carried out for feasibility or high-level design (phases 0/A).

To introduce the benefits already experienced in early phases in later ones (i.e. phases B/C/D), new tools and processes need to be developed, and previously established ones will need to be reengineered to work under the new paradigm or be substituted.

Efforts to engineer a process or a series of processes that can support the use of CE in later phases in DLR have led to the study of the current processes in DLR and developing a set of activity prototypes that will be presented in this paper.

2. BACKGROUND ON DESIGN METHODOLOGIES

CE is one concrete example where the process strongly depends on various influence factors, which need to be considered when trying to implement CE. For this reason, even though based on a common concept, many organizations established their own customized processes (see [3], [4]) to optimize the CE experience w.r.t. their specific needs.

The methodology of CE is common to all the processes that are followed in the different Concurrent Engineering Centres (CECs) around the world, but not all these processes are the same. How these processes are formulated and how CE is implemented will depend, primarily, on why and for what it is being adopted in the first place [5]. While in DLR a study is fully conducted typically within one week [6], other organisations choose to divide it up and spread it throughout several weeks [7], or reduce the number of sessions depending on their own needs and expectations. The fact that CE is not limited to design tasks has been proven as it is used e.g. for the conduction of Reviews by Team X [8].

The process for CE in early phases at DLR has been demonstrated successfully by over 60 studies in the Concurrent Engineering Facility (CEF) since 2008 and a lot of lessons learned could be introduced since then [6]. The current aim is now to re-engineer this process towards the implementation in later phases, primarily for Phase B (as defined in ECSS-M-ST-10C [9]).

Even though sometimes mistakenly used as synonyms, this paper distinguishes between CE (i.e. the simultaneous and collocated work) and Collaborative Engineering. The latter is used in the course of this paper to express a work approach, where the team is not necessarily working at the same time or at the same place, but uses one central shared data model to design the system and exchange information [10]. As contrast to this, the term “classical approach” is used in this paper to refer to traditional Systems Engineering [11], where the systems engineer has a central position and collects, consolidates and re-distributes the information without direct interaction of the different technical domains among each other or support by a central data model.

One important aspect of successful CE is the usage of a shared data model [12]. Such a data model and the necessary tools to access and them is an implementation of the MBSE concept, which is gaining more and more intention in order to manage the growing complexity of projects in later phases [13].

The combination of the above mentioned approaches for the development of a CE process in later phases (i.e. Phase B) is an open research task and so far there is no known precedence case. Therefore, the assumptions and conclusions in this paper are not verifiable and the actual benefit not quantifiable yet. Therefore, the recommendations given in this paper are based on the experience from work in the CEF during early design studies, results from the survey (see Chapter 5) as well as subjective opinions of the authors or common sense. The assumptions and suggestions need to be tested by applying them to existing projects in order to draw conclusions and to create lessons-learned.

3. FACTORS THAT IMPACT NEW PROCESSES

When the need arises to modify or update existing processes, the first step will typically be to define a generic high-level process, but a generic process can only be considered useful to a limited degree if it is implemented in an organisation as originally defined. Any such process needs to be adapted to the specific work environment where it is to be adopted and, therefore, when contemplating the development and application of a new work process a number of different factors that will impact its formulation need to be considered and addressed. Depending on the particular factor, it may support or constrain improvement efforts, and can have a positive or negative influence on an organization’s activities particularly in the short run.

Impacting factors can be categorized within different dimensions or aspects within an organisation, where a change in each dimension will impact the others and require consideration within the process formulation [14]. For example, the particular characteristics of a given organization will affect the process, but also need to adapt to the new process. The methodology the process is aiming to follow will also impact its own definition when introducing it to any particular team, institute or company. The tools (i.e. software) that are used or need to be developed will impose its own restrictions to the process and be in turn influenced by it (especially for in-house tools). These aspects and any number of other project traits will determine the form of the final process. One way to categorize the generic environmental and organizational factors that can impact new processes is through an analysis of which internal and external influences have to be considered (c.f. Table 1).

Internal	**External**
Company culture	Customer interests
Organizational structure	Political elements
Existing processes	Economic concerns
Communication channels	Social constraints
Economic resources	Technological considerations
Human resources	Legal limitations
Availability of facilities	Regulatory aspects
Company know-how	Shareholder preferences
	Structural elements (e.g. standards to uphold)

Table 1: Generic internal and external factors that impacts a new process [14]

A more concrete view of the dimensions and elements to consider need to be assessed when introducing CE into an organisation, or extend it into later phases. A well-known case inside the CE community is when a given organisation that works under a traditional system engineering paradigm decides to incorporate the CE methodology for early phases.

For starters, the first thing to identify is how the new process will be introduced into the work environment: will there be a clear separation between the CE and non-CE approaches? Or will later phases be carried out under a collaborative approach? The answers to these questions will affect the tools that are used. If there is a clear distinction, the CE part of the work may be carried out using a MBSE based tool, while lather phases might use the tools that traditionally have been used in the organisation; otherwise, the organisation can benefit from finding solutions that build upon the model created throughout the CE activity. At the same time, introducing CE in an organization will require certain changes within the organization itself for it to be effective [15]. E.g. a clear distinction might allow the organization to keep its original structure, as long as there is a mechanism for the CE effort to count with the necessary experts from the different departments. On the other hand a full collaborative environment might become more efficient if the organization re-organizes itself to allow experts to follow projects throughout the phases, or creates a CE workgroup with multidisciplinary experts that can support the activities and pass the information forward to the teams working on later phases.

A major issue tends to be that while management likes to see CE as a tool, from the CE-engineer's perspective, introducing CE in an efficient way requires a change in culture, and a drive towards Collaborative Engineering. This will ultimately affect the process, as any given organisation will fall within a spectrum that would theoretically go between an outright change in the whole companies work structure to accommodate Concurrent and Collaborative Engineering, and just implementing CE for a specific purpose or subset of phases (e.g. Phase 0, or Phase 0/A).

Other structural elements that will affect the process (or that will have to change to make the process as efficient as possible) will cover, for instance:

- The systems that are the target of the organisation: for example, launcher design is not easily parallelizable, and therefore an organization specifically designing launchers might not benefit as much from a CE methodology and will need to extend it over time to handle a cascade-like process [16]; meanwhile other entities that focus on systems that are easy to parallelize -satellites or landers, for instance- can indeed benefit from a focused CE approach.
- The experience level and background of personnel: CE is a very multidisciplinary-oriented activity; it requires experts for their depth of knowledge, but it needs a level of overview to channel all their expertise; systems engineers and project managers that will lead CE work must not only exist in the organization, but they need to be trained and introduced to CE and be part of the CE process development so they can adapt it to the organization and are capable of maximizing its efficiency.
- Resource management: on the one side, the organisation needs to assess how their current and future experts will be involved with the new CE work; will the CE workgroup count with their own set of experts, or will they be coming from other departments? If so, how will the finances work internally? Will the CE process be part of the design cycle, or only an optional tool that acts as a horizontal service within the organisation? And also adapt to the need of spending more and more abruptly in the early stages on a project (as the facility and personnel cost will be performed early and in a relatively short period of time, which will be seen as a peak in expenditure early on in the project when compared with other classic project management methodologies)

From a project standpoint, there are also be aspects that will need to be modified, or that will otherwise influence the process:

- The project timeframe changes, accelerating the design cycle in early phases, which means that projects must accommodate for this, and be ready to begin Phase B earlier in time. This can become a big resource problem if any necessary experts are in short supply.
- Efficient use of resources would require projects to be initiated in the CE work group, yet the introduction of it will result in an alteration in the way projects are conducted, and their work process will need to be altered to accommodate this.
- Certain projects will need a specific approach which might require adapting the CE process established by the organisation. For instance, large projects might require breaking down the original (sizable) project into pieces that can be tackled in different studies. Other projects might provide feedback into the organization or the CE process, due to oversight in the previous definition, or new elements not previously considered.

As explained by Tristan Boutros, "If the level of process maturity is low within an organization, meaning processes have not been identified or documented, the level of effort increases as significant cultural and structural changes are needed in order to formally change the enterprise to an integrated entity." [17].

While most, if not all, the aspects that have been defined in previous sections will also be applicable to later phases, other additional aspects might need to be considered too. Most organizations, due to complexity, highly differentiated subunits and roles, sometimes limited informal relationships between work units, size and even physical distance have a real organizational problem when re-engineering or introducing new processes. This is true of earlier phases, but even more so of later phases where multiple, frequently overlapping stages, require large numbers of people to be involved.

In this environment it would be a mistake to expect a single flexible process or approach to cover all, or most, scenarios. This will rarely be the actual case, and require multiple processes that, while adaptable, should already be tailored towards different types of activity. This requires plenty of forethought and process engineering, and will undoubtedly require changes in the organizational level, and on the project level.

4. METHODOLOGY FOR THE DEFINITION OF A PROCESS FOR CE IN PHASE B

In consideration of the described factors and impacts for the implementation of new processes, an internal survey has been conducted among the institute's employees (questionnaire and interviews) with the aim to fill the generic factors of Table 1 with the institute`s and project`s particularities.

This assessment led to recommendations for the use of Concurrent and Collaborative Engineering (i.e. demands and requirements for shared data models) from which a set of potential activities in the context of CE in later phases has been derived. As a starting point, the exercise focused so far on Phase B activities only, but similar activities could be analysed and defined also for the subsequent phases.

As a next step, those Phase B activity types were mapped to the major tasks for Phase B and organized into a generic work-flow to be able to fulfil the main review objectives of Phase B as defined in ECSS-M-ST-10C.

5. SURVEY RESULTS ON USER DEMANDS FOR CE IN PHASE B

The results of the internal survey [18] are summarized with a special focus on the findings w.r.t. activities (types, frequency and tasks) and potential CE applications in Phase B. Next to the collection of information on general work methodologies of the different space systems projects at DLR (e.g. average team size, frequency of meetings, documentation style), the survey pointed out that CE is an acknowledged and appreciated methodology the way it is currently applied for Phase 0/A studies. Additionally, it showed that for the classical approach during Phase B, the most critical tasks are the detailed design, interface definition and risk assessment while the biggest issues to tackle are consistency, design verification, requirement tracking and documentation.

Another finding is that even though Collaborative Engineering would be preferred for most of the tasks, CE also seems suitable for the majority and is the most preferred option for the detailed design tasks. Specifically asking about tasks with high potential for collocated (concurrent) work, the respondents named design consolidation, trade-offs and problem solving but also the preparation of reviews. The majority of the respondents see potential in the research field and would support activities in the context of CE in Phase B.

6. PROPOSALS FOR THE IMPLEMENTATION OF CE IN PHASE B

It is important to note that also applying the classical approach, meetings with specific topics and group compositions are inherent parts of any project. They normally take place at a fixed frequency (e.g. jour-fixe, weekly or ad-hoc). The difference for the proposed activities in the scope of CE is that during those activities the objectives are not only to uncover and discuss current issues and maybe define action items, but to actually work concurrently on those open points with the final aim to create a consolidated solution or major progress during that same activity. The following chapters elaborate on the proposed activities by explaining the different categories and initial ideas for the preparation, conduction and necessary post-processing. The proposed activities can be categorized by the involved team size and domains (see 6.1) and the objectives during the single activities (see 6.2).

5.1 Activity teaming

The teaming compositions are considered, and accordingly included, in the flow diagram following the colour scheme shown in Figure 1. For all of the proposed meetings at least one CEF core-team member needs to be present to support the group by operating the facility, moderation and process monitoring and control.

Figure 1: Legend for activity types as used in the work flow chart

Full Team: The Full Team meeting is used for activities for which it is important to have all domains and different views available. The group size can vary according to the project`s type, organization and status. If one domain is covered by more than one individual (i.e. a sub-system team) it might be sufficient if one representative participates in this activity type. Due to the high number of participants which need to be available, this activity type needs sufficient time in advance for the definition of a suitable date, organisation of travels and proper preparation of the activity´s contents. For the same reason, the minimal duration of such an activity to be beneficial should range between three and five days, depending on the actual objective and team size.

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 and planning activities for their subsystem. As subsystem teams normally tend to be located at one single site, this activity can be conducted with relatively short lead times (even within one day). As subsystem teams are well aware of their own current state and issues, there is no need for specific preparation aside the availability of all important information necessary during this activity.

Task Force: A task force in this scope is defined as a multi-disciplinary group (i.e. a sub-set of domains / work packages) which need to work on one specific common topic. Depending on the project`s organisation these meetings can be announced and conducted on relatively short notice, comparable to the subsystem team. If different institutions are in charge of the involved domains, some lead time has to be considered. Nevertheless, these meetings should be executed within a short timeframe. Potential solutions would be the usage of videoconferencing or a small pool of representatives per domain, to have all stakeholders available.

Customer Participation: For specific meetings it is important to have the customer accessible to be able to take direct consolidated decisions. As the customer is normally not actively participating in the project, and sometimes not even part of the consortium, these activities need sufficient lead time to find a suitable date, prepare executive presentations on the current state and the upcoming activity´s content. For this reason, customer participation is to be considered, as the presence is especially suited to Full Team activities rather than for action-based activities with short lead time.

5.2 Activity objectives

The subsequently explained objectives for CE activities in Phase B are derived from the conducted survey. Due to the peculiarities of these objectives in most cases they can be directly connected to the teaming constellations described above. Nevertheless, the objectives should be defined separately for specific projects or organizations, as the most suitable teaming for the different objectives might also vary case by case.

Detailed Design: The classical approach for the detailed design of a subsystem (or work package) is individual work of the involved engineers with either action-based or frequent status meetings. The results are then communicated with the systems engineer, who has the task to verify the design in the context of the overall system. The proposed CE activity for “Detailed design” would change that scheme towards short collocated meetings with an assumed duration of approx. one day during which next to the involved technical experts also the systems engineer would be present for direct discussion of the system impact / constraints of any taken decision.

Specific Topic / Optimization: The activities for a specific topic or optimization are to be conducted issue-based as consequence of uncovered critical items during the project`s progression. 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). Due to the difficulty to foresee the important topics in advance, the lead time and preparation effort needs to be as small as possible, i.e. in best case similar to the preparation phase of the Detailed Design activities of only one day. For the actual activity, the representatives of the involved domains / subsystems come together in the CEF for a recommended period of 1 to 3 days (depending on the problem`s complexity and number of involved parties).

Kick-Off: A Kick-off activity is assumed to be organized very similarly to what is common practice for early phase CE studies at DLR. It would start with a preparation phase with a request from the project manager or the customer towards the CE core team optimally a few months before the actual activity. The work-schedule during this activity is similar to early phase CE study, but with a greater level of detail. This Kick-Off activity would be 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.

Consolidation: 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. For this purpose, as suggested by the survey, an activity is proposed to make use of the CE advantages and to allow this design consolidation to be conducted efficiently and consistent in a reduced period of time. The idea would be to invite the full team (at least one representative per involved domain) for a duration of two to three days.

Review (Preparation): Another interesting activity, which came to attention both from the survey and common practice in other CECs, is the preparation and the conduction of (internal) reviews supported by CE approaches. With the implementation of a jury principle according to the recommendations from Team X, 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. Due to the limited time, the voting on major issues would select the topics to be discussed in greater detail during this activity with the aim to either find solutions to be implemented immediately or to formulate strategies / action items to do so in the post processing (i.e. as answer on possible RIDs).

5.3 Work flow

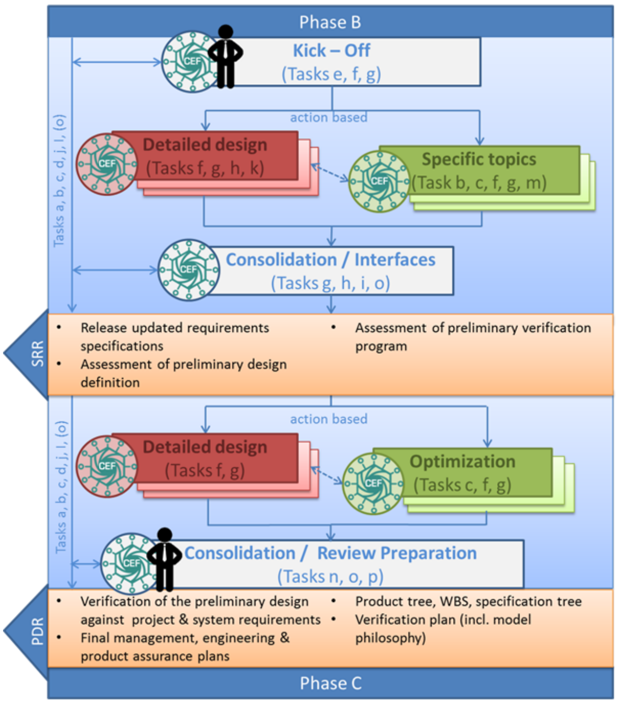
After having defined the type of activities which were assessed as suitable for the application of CE, those activities were put into a generic work flow (shown in Figure 2) to support the different phases. For the timing of the activities a difference must be made between activities which need intensive preparation (i.e. Full Team studies) and those that would be action-based (i.e. Task Force and Subsystem Team). The first activity type is proposed to be scheduled well in advance, already in the project time planning, and to be considered as a fixed milestone. For the subsequent activity types this long-term planning is not possible and therefore they are included in the work flow between different milestone activities only as placeholder without defined timing, frequency or repetitions. It is up to the involved parties to initiate those activities as needed, maybe supported by specific trigger events defined by the process.

Additionally, the figure lists the main tasks during the single phases as well as the main review objectives defined by the ECSS-M-ST-10C. It is important to remember the required state of the project before entering the next phase and its desired state at the end of the single phases to have a clear target to aim for. The work flow map the tasks to the single activity types. Bold letters indicate aspects which are deemed to have high potential in being performed concurrently during CE studies or workshop activities.

Some tasks are more suitable to be conducted outside the CEF but are also valuable input to and need to respond to the results from the CE activities, as indicated by italic letters in the activities´ list and by the vertical arrows on the left of the figure. Due to the increased complexity of the design and management effort, most of the Phase B tasks need to be worked on continuously. The CE activities are assumed to be supporting and accelerating specific tasks but are not meant to be fully superseding the classical approach or Collaborative Engineering.

The proposed work-flow to support projects during Phase B through different CE activities starts with a requested Kick-Off activity with preferable participation of the complete project team (or at least one representative per involved domain and project partner). The participation of the customer is highly recommended as to be able to immediately decide on different possible solutions to project related questions.

After this Kick-Off, the different domains and partners continue the design in a collaborative approach, using a data-model supervised by the systems engineer and project manager. At specific points in the design phase, it is proposed to conduct small CE activities with the aim to work collocated on either the detailed design of subsystems or to elaborate specific aspects which involve more than one domain. Those activities can be conducted once, repeatedly or in alternating scheme to conduct fast iteration cycles. The most appropriate



Phase B Tasks:

a) *Project management, engineering and product assurance plans*
b) Baseline master schedule
c) Baseline cost at completion
d) *Preliminary organizational breakdown structure (OBS)*
e) **Technical solution(s) for the system and operations concept(s), feasibility w.r.t. programmatic constraints**
f) **“Trade-off” studies, system concept selection, technical solution(s) for this concept.**
g) **Preliminary design definition**
h) Determine verification program, model philosophy
i) **External interfaces**
j) *Next level specification, business agreement documents*
k) Initiate pre-development work on critical technologies or system design areas
l) *Long-lead item procurement*
m) Space debris mitigation plan and the disposal plan
n) **Reliability and safety assessment**
o) **Product tree**, *work breakdown structure* and **specification tree**
p) **Update risk assessment**

Figure 2: Work flow from PRR to PDR including proposed activities to achieve review milestones

scheduling needs to be defined in accordance to the specific problem, the project`s setup (mostly internal, easily accessible personnel or geographically dispersed partners) and optimized based on lessons learned and user experience after conducting the activities (e.g. evaluation w.r.t. benefit for the specific expert). Before going to the next milestone, the System Requirement Review (SRR), approx. after half the duration of Phase B, another Full Team CE activity is proposed with two specific purposes: a) Design Consolidation and b) (external) Interface Definition. It is important that at a specific point during the project, the different design activities and streams are merged back to the baseline design to make sure the overall system design does not deviate excessively and to work with a common set of assumptions and parameters. Once the design is consolidated, the definition of interfaces (both external and internal) should be discussed and afterwards frozen.

After accomplishing the SRR objectives, the project would continue with the collaborative approach supported by CE activities for the subsystem group and task forces in a similar open schedule as described above. The main focus for the task forces could be to conduct design optimization w.r.t. specific system characteristics (cost, mass, performance).

The final CE activity during Phase B is proposed to be a Full Team activity with customer participation with the aim to consolidate the preliminary design and to prepare the external review.

7. ILLUSTRATION OF WORK FLOW IMPLEMENTATION

For the clarification of the proposed process, one specific implementation of the generic work flow shall be illustrated subsequently. As an example, an Earth observation satellite mission is used. The type of mission is assumed to influence the specific topics of the single CE activities and the order in which design steps happen typically and thus have the biggest impact on the action-based activity types (i.e. Sub-system and Task Force). The milestone activities (i.e. Full team) on the other hand are proposed independently of the mission type.

Following the proposed scheme presented in Figure 2, the first activity of Phase B is a Full Team Kick-Off activity with the goal to recap the proposed concepts from Phase A, to conduct trade-offs between different solutions and to create a common baseline design of the mission. According to the critical points, open discussions spotted during this activity, the subsequent order of CE meetings needs to be adapted and evolve in the course of the actual work progress. In this hypothetical example, one specific topic from the Kick-Off study to be analysed in more detail by a Task Force activity is the detailed definition of operation`s concept and the system`s modes of operations. This topic is optimally suited for such a Task Force meeting, as there are multiple dependencies between a subset of domains (i.e. Payload, Electric Power System (EPS), Datahandling System (DHS), Communication, Attitude & Orbit Control System (AOCS), Mission Analysis, Ground Segment) while for other domains, this topic is less important to follow (e.g. Structure, Thermal, Assembly, Integration & Verification (AIV)). If for instance, as an outcome of this Task Force meeting, the need to conduct a detailed update of the Power and Communication sub-systems` design w.r.t. the decisions being taken has been determined, this design update (e.g. antenna positions, increased photovoltaic collector size) makes a revision of the satellites accommodation / configuration necessary. This subsequent activity should be conducted as a Task Force meeting with strong usage of CAD walkthroughs involving especially the interested domains (Structure, EPS, Coms, Thermal, AOCS) to ensure that all constraints (e.g. equipment position, Field-of-view) are met. Due to the changed configuration a detailed update of the primary structure and mechanisms is necessary creating valuable input for e.g. AOCS (more precise Moment of Inertia).

Again for clarification, this illustrative sequence is only one possible branch derived from one specific topic from the Kick-Off. Parallel design streams and also iteration cycles might be necessary but for the sake of readability they are not depicted in Figure 3. All these design streams need to be merged back to a common baseline, which is done in a structured way during a Full Team Consolidation meeting, during which all domains have the chance to assess the design decisions and give comments to exclude any inconsistencies. Additionally, this meeting gives the opportunity to discuss internal / external interfaces. Another more or less unconnected task deemed useful is a Task Force meeting for the definition of a Verification program and an update of the master project schedule. The list of involved domains in this meeting should at least consist of the Project Manager, Systems Engineer, AIV Experts, Quality Assurance (QA) but could be extended to domains with specific interest / criticality (e.g. considering low Technology Readiness Level (TRL) components in their design). With this, the project should be prepared to go through the SRR.

As proposed in the generic sequence (Figure 2), after SRR there mostly should be optimization meetings. In our example, a need for power optimization could be one result of the SRR, which could be discussed in a Task Force meeting with the biggest contributors. Based on the outcomes of this meeting, the EPS engineers should revisit their design in a Detailed Design session. The outcome of this might be the potential or the need for mass savings on system level, which should be analysed in a mass optimization Task Force session plus subsequent detailed design sessions for example on the structure and thermal control. Another aspect which could be optimized in a Task Force meeting to fulfil the PRR objectives is the development plan and associated project cost, similar to the Pre-SRR activity but with a higher level of detail and assuredness. With the available information, the last deliverables for the Preliminary Design Review (PDR) could be created during a short dedicated Reliability, Safety & Risk assessment Task Force session involving Project Management, Systems Engineer, QA and preferably at least one expert per domain to update / create a Failure Mode, Effects and Criticality Analysis (FMECA). As final activity before the PDR, the full team meets to conduct another consolidation meeting and to prepare the actual review. The meeting could be already used to indicate the most critical open items (c.f. Review Preparation in chapter 6.2) and either fix them immediately if possible with small work effort or at least come up with consistent strategy to do so as an answer for the potential questions and RIDs during the PDR.

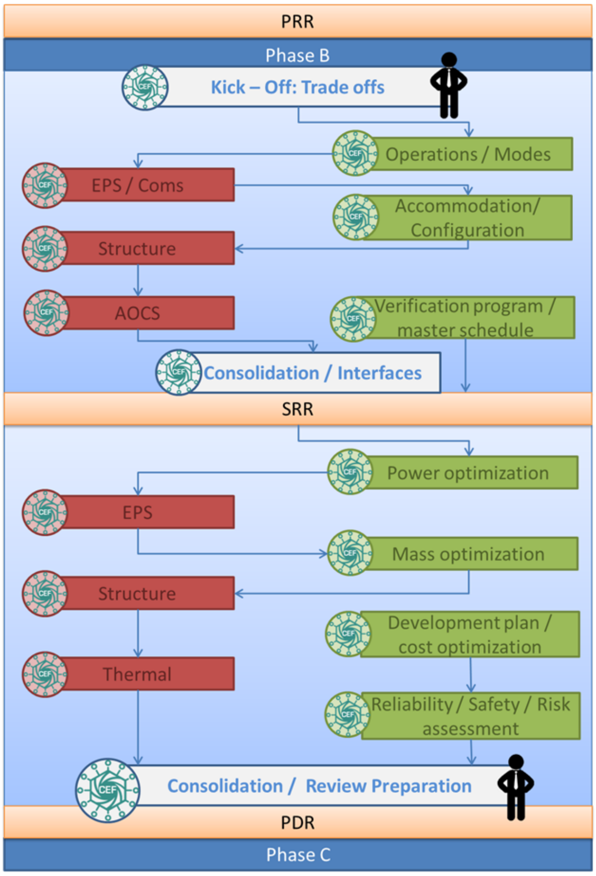


Figure 3: Illustrative implementation of the proposed process for Concurrent Engineering in Phase B.

8. CONCLUSION AND FUTURE WORK

This paper discusses general aspects and impacts for the implementation of new design processes, using as an example the initial introduction of CE into an organization, and studying the development of a CE process to be applicable in later project phases. Based on those general findings and a conducted survey about the work environment and demands for CE in Phase B, this paper presents a set of recommendations for activity types and a generic work-flow for the application of CE in Phase B. Even though there has not been the opportunity yet to test the recommendations for Phase B within an existing project, the current digitalisation efforts being made in Europe (i.e. Industry 4.0) and also at DLR (i.e. cross-sectional topic on Digitization & efforts w.r.t. the introduction of MBSE including peoples growing awareness) is a promising and supporting setup to apply first ideas under real conditions. Only by doing this, conclusions on the actual effectiveness of the different activity types can be drawn and improvements can be implemented to adjust the theoretical background to the projects` needs.

As future work, one concrete aspect which need to be analysed based on lessons learned from existing projects would be the optimal usage of the data model as design representation both for Collaborative and Concurrent Engineering in Phase B.

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