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Knowledge Capitalization in a Concurrent Engineering Environment

Summary Report

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DLR

TURQUOISE TECHNOLOGY SOLUTIONS INC.

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Applicable Documents

[AD 1] "Statement of Work, ESA Directorate of Technical and Quality Management, Ref: TEC-SYE/200742/GSC"
[AD 1] Klaus-Dieter Thoben, Frithjof Weber, PACE '96 A Practical Approach to Concurrent Engineering, Verlag Mainz, Wissenschaftsverlag, ISBN: 3-89653-093-3
[AD 2] Romberg, O.; Braukhane, A.; Schumann, H.: Status of the Concurrent Engineering Facility at DLR Bremen, DGLR-Congress, Darmstadt, September 2008
[AD 3] P. M. Senge: "The Fifth Discipline: The Art and Practice of Learning Organisation", Doubleday Buisiness, 1st edition (1994)
[AD 4] Satwiksai Seshasai, Amar Gupta: Knowledge-Based Approach to Facilitate Engineering Design, Journal of Spacecraft and Rockets, Vol. 41
[AD 5] M. Maier, E. Rechtin: "The Art of Systems Architecting", CRC Press, 2006
[AD 6] D. McNabb: "Knowledge Management in the Public Sector", (2007), M.E. Sharpe, Inc.

Reference Documents

[RD 1] Michael Wunram "Practical Methods and Tools for Corporate Knowledge Management – Sharing and Capitalising Engineering Know-How in the Concurrent Enterprise", Verlag Mainz, 2003
[RD 2] James Doane, "A Knowledge Management Architecture for JPL", Jan. 15th 1999, JPL, California Institute of Technology
[RD 3] Web page: http://www.livescribe.com/

Detailed reference documents lists can be found in the following technical notes:

[RD 4] CDF-KM-TN-01 "Review of New KM Techniques and Methodologies for Space Applications"
[RD 5] CDF-KM-TN-02 "Architecture Document"
[RD 6] CDF-KM-TN-03 "Implementation Plan"

Acronyms and Abbreviations

AD	Applicable Document
AOCS	Attitude & Orbit Control System
BMM	Basic Metadata Module
BS	Business Search
CDF	Concurrent Design Facility (ESA)
CE	Concurrent Engineering
CEF	Concurrent Engineering Facility (DLR)
Comms	Communications
CoP	Community of Practice
DAD	Domain Advancement Diagram
DARC	Digital ARChive
DB	Database
DHS	Data Handling System
DLR	German Aerospace Center
EBOK	Engineering Book of Knowledge
ESOC	European Space Operations Centre
ExTra	Expertise Transfer
FAQ	Frequently Asked Questions
GS	Ground Segment
GUI	Graphical User Interface
H/W	Hardware
IAP	Information Access Platform
IDM	Integrated Design Model
IM	Innovation Management
ITT	Invitation to Tender
KCP	Knowledge Capture and Publishing
KM	Knowledge Management
KMOD	Knowledge Management Overall Diagnosis
KOM / K/O	Kick-Off Meeting
KU	Knowledge Unit
LP	Langragian Points
MoM	Minutes of Meeting
MTR	Midterm Review
NDE	Non Digital Elements
OPS	Mission Operations
PIMS	Project Information Management System
PM	Progress Meeting
RD	Reference Documents
RDF	Resource Description Framework
RISE	Reuse, Improve, Share Experience
S/S	Subsystem
S/W	Software
SOW	Statement of Work
STAR	Satellite Technical ARchive
TIC	Tacit Information Catcher
UI	User Interface
WBS	Work Breakdown Structure
WP	Work Package
WPD	Work Package Description

1 Summary

The treatment of knowledge, captured during Concurrent Engineering (CE) sessions then stored and organized so that it can be distributed again to engineers of other CE sessions, is the main topic of this study. The theoretical background as well as building the knowledge management system architecture and developing the implementation plan are part of the study and report.

In order to analyse the knowledge capitalization possibilities within the Concurrent Design Facility (CDF), the report first gives an overview of the different Knowledge Management (KM) aspects related to the CDF at ESTEC, ESA. At the beginning an analysis of the CE environment describes the different involved domains as well as the CE process wrt to possible knowledge management approaches. The two main KM users (NASA and JAXA) in the space sector, as well as non-space-related organisations (Airbus and Daimler) are described with respect to their knowledge management activities

An analysis of different KM tools was also performed and is displayed in this summary report. Six commercial and three open source KM tools were analysed. Seven different evaluation criteria were established in order to test them for a possible CE deployment. Furthermore, vaious missing and existing KM capabilities are derived and explained. So far ten missing KM elements could be detected by the research team that are useful for the CDF at ESTEC in order to store the knowledge, generated during CE sessions.

A questionnaire was developed including 21 questions related to the knowledge capitalization effort within the CE environment at ESTEC. Within two distribution campaigns the questionnaire was sent out to over 100 CDF-engineers, experts and scientists, where 51 filled out questionnaires were received.

Moreover, an overview about the different aspects of the Knowledge Management (KM) Architecture is given. It is developed in the frame of the contract and displays the theoretical and organizational structure of the KM prototype tool. The KM architecture is divided into the four major sections: Capturing, Organization, Distribution and Development of knowledge. Every section has several interface and software modules. In addition to this, the Knowledge Unit (KU) is introduced, within which the actual file or document will be combined with additional information in order to form one knowledge package that can be stored in the KM system.

The architecture concludes with an overview of the required and preferred hardware infrastructure, as well as an overview of the software that the prototype will be based on.
The listed implementation plan is a result of extensive discussions within the project team based on the feedback of ESA. Certain elements of the plan are also based on literature review and analysis of the questionnaire results administered to the Concurrent Design Facility (CDF) participants. This implementation plan is also is designed as a practical set of suggestions covering the implementation related issues of the Knowledge Management (KM) architecture developed for ESA's CDF. An implementation plan is proposed for two different time horizons: short-term (until the end of this project) and medium term (one year following the end of this project). Certain recommendations for long-term implementation are also provided.

2 The Concurrent Engineering (CE) Environment

In order to investigate the possibilities of Knowledge Management (KM) within the Concurrent Engineering (CE) environment it is necessary to map out a short overview of it. The following will describe the different CDF expert domains as well as the underlying CE process.
The CE-process is based on a simultaneous design and has 3 main Phases. It starts with a preparation phase followed by the study phase and ends with the final documentation as part of the study post-processing phase. The following Figure 1 proposes the timeline of these phases with regard to Knowledge Management.

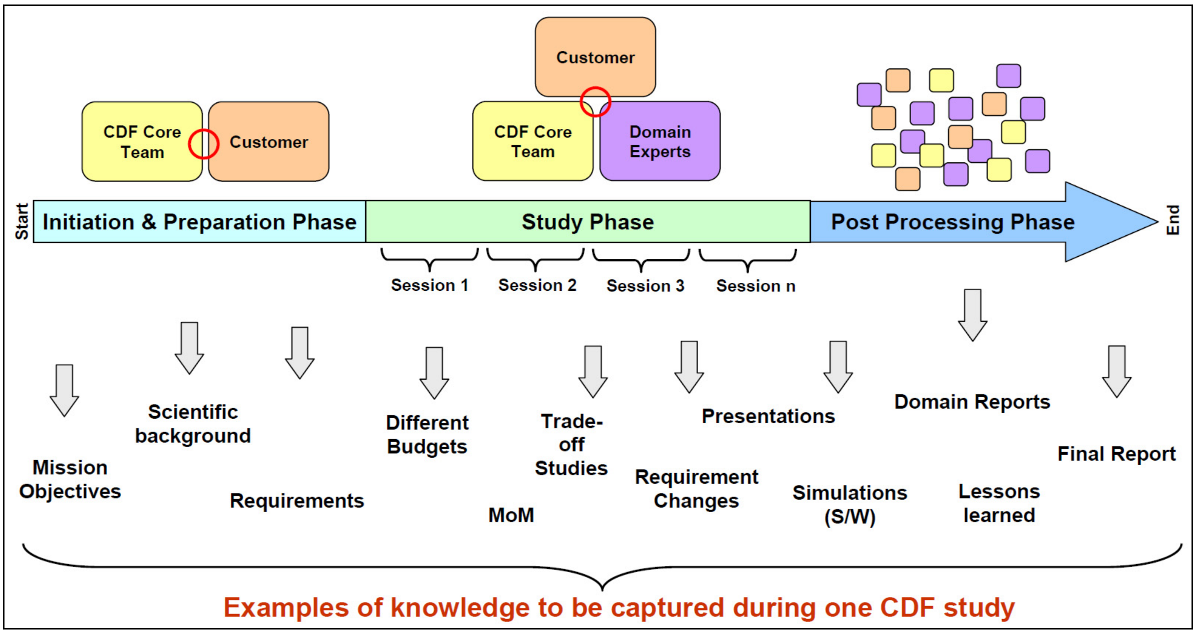


Figure 1: Concurrent Engineering Process with regards to Knowledge Management

The different phases of the design process consist of:

1. Preparation Phase (starts weeks/months before using the CDF):

- “Customer” (internal group, scientists, industry) contacts CE-team
- CE-team – customer negotiations: expected results definition, needed domain
- Definition of mission objectives (with customer)
- Definition of mission and system requirements (with customer)
- Identification and selection of options (max. 3)
- Initial mission analysis (if applicable, e. g. based on STK)
- Final definition and invitation of expert ensemble, agenda definition
- Interaction: CDF core team interacts with the customers
- Knowledge to be generated: Mission objectives, scientific background, requirements

2. Study Phase (1- 4 weeks at CE-Facility in site):

- K/O with presentations of study key elements (goals, requirements)
- Starting with first configuration approach and estimation of budgets (mass, power, volume, modes, …) on subsystem level
- Iterations on subsystem and equipment level in several sessions (2- 4 hours each); trading of several options
- In between offline work: subsystem design in splinter groups
- Final Presentation of all domains

- Interaction: CDF core team, customer and experts – all interact in a concurrent way
- Knowledge to be generated: Different budgets, trade-off studies, MoMs, requirement changes, presentations

3. Post Processing Phase:

- Collecting results (each S/S provides Input to book captain)
- Evaluation and documentation of results
- Lessons Learned processing
- Transfer open issues to further project work
- Interaction: No combined interaction between the groups, except from some splinter meetings if necessary.
- Knowledge to be generated: Simulations (S/W), domain reports, lessons learned, final report

To ensure the best results of the Concurrent Design Process, it is essential to keep all participants, e.g. subsystems, cost and risk, as well as the customer involved during the study phase. Hence an environment is required where these domains can work together.
It is necessary to place domains with strong interactions next to each other. That is why e.g. AOCS and propulsion, communication and data handling as well as power and thermal are sharing a desk within the facility. This supports communication and keeps the design process efficient and consistent.

In the following Table 1 the major tasks and project contributions of each CE domain with the software tools used by the different domains, as listed in the CDF user manual or as result from the questionnaire (blue), are summarized. Besides the listed tools all domains use MS VISIO, MS PowerPoint, MS Word and MS Excel for different tasks such as:

- General visualisation of trade-offs on possible technical solutions (e.g. different numbers of landing legs for a planetary lander)
- Creating blackbox & flowchart diagrams of mission architectures, e.g. a scenario of a Mars Sample Return Mission (SRM) architecture
- Calculation of mathematical equations wrt to the specific need of each domain
- Creating final reports of specific domain

Table 1: CDF domain description and analysis of used software

Domain	Main task	Process contribution	Specialized S/W Tools	S/W used in CE for
System	Conduct the majority of the mission design system engineering work, organize work of the other team members	Preparation and update of CDF system model, ensure convergence and consistency of the overall project, monitor interfaces between the subsystems, define system architecture, manage requirements	DOORS, MS Project, Nastran/Patran	Creating and managing requirements Keeping track on requirements changes Creating the study schedule
Cost	Design of preliminary cost estimation and a cost guided approach	Cost estimates	PRICE H, ECOM, SSCM, Think Cell	Parametric cost estimates with breakdown into subsystems and components Life-cycle cost estimates specific to long-term exploration missions General visualisation & presentation of cost categories
Mission	Definition of the mission operational orbit and navigation phases	Characterisation of trajectories and manoeuvres	EUROSIM, STK, Swing-by Calculator, IMAT, ORION, GMV ORION, MASTER, MulitiGen, Vega, Matlab & Simulink, Freeflyer	Performing mission simulations Creating mission schedule visualisations Optimizing deep space flight paths and swing-by manoeuvres
AOCS	Design of the Attitude and Orbit Control subsystem	Mass and power budgets assessment, attitude analysis	Matrix X, ASTOS, Matlab & Simulink	Performing spacecraft attitude analysis
Propulsion	Design of propulsion subsystem	Mass and power budget assessment	NAXTDI, Matlab & Simulink, EcosimPro	Propulsion system selection Planetary ascent trajectory analysis Aerothermal Re-entry Simulations Propellant budgeting
Data Handling	Design of on-board data handling subsystem	Mass, power, memory and computational resources budgets assessment	STK, Matlab & Simulink, Rapids	Creating link budgets
Communications	Design of telecommunication subsystem	Link budget and resources assessment		
Power	Design of power subsystem (generate, storage and distribute power)	Mass and power budgets assessment, A/C power and dissipation budgets assessment	PowerCap, Matlab & Simulink	Creating power budgets for deep space probes, landers, rovers and instrumentation devices
Thermal	Design and modelling of Thermal subsystem	Mass and power budget assessment	ESATAN, ESARAD, ThermXL, Matlab & Simulink, NAXTDI	Thermal budgeting Performing thermal analysis of subsystems and payload
Structures	Design and dimensioning of structure subsystem	Spacecraft configuration assessment	CATIA, Autodesk Inventor	Generation and visualization of different exploration vehicles Creating structural designs, configuration and accommodation layouts of e.g. deep space missions, landers and rovers Creating a visual basis for all participants of the study
Configuration	Integration of payload and subsystem equipment, system design	Accommodation assessment and design recommendations		
Mechanisms	Design of on-board mechanisms and mechanical device interface	Mass and power budget assessment		
Instruments	Payload definition	Payload requirements and interface definition	ZEMAX, ASAP, FRED, IGOR PRO, Matlab	Scientific payload & instruments analysis; trade-offs between different instruments
Ground Systems	Design of ground segment infrastructure	Mission operations assessment	-	-
Pyrotechnics	Definition of pyrotechnics device requirements	Analysis of safety related aspects and resources assessment	-	-
Radiation	Analysis of mission environment and radiation aspects	Radiation estimation	-	-
Risk	Analyse risk	Preliminary risk assessment	Access, Matlab	Performing risk analysis, probability distribution
Simulation	modeling and visualization of the mission phases	Simulation data	STK, Mathworks, SimVis, EuroSim	modeling and visualization of the mission phases
Programmatics	Management and assessment of the overall program schedule	Preliminary spacecraft AIV schedule and assessment	-	-
Documentation	Compilation and consistency check of domain documentation, recording decisions and evolution during the design process	Study report	-	-
Expert / Scientist	Support study	expertise	IDL, Astronomy software (IRAF, MIDAS,etc)	Misc. tasks

3 Knowledge Management within CE Environment

3.1 Theory

Within the design process during mission analysis as well as system/ subsystem design in a CE environment, scientists create a huge amount of information. Corresponding data are only to some extent handled with respect to the transferability for following CE-studies, other projects, other institutions, departments or domains. In order to capture the knowledge produced during CE studies three different types of knowledge have to be taken into account [RD 1].

Explicit knowledge

Any information that can be described or depicted, stored on a media and transmitted to others without loss of data or information is explicit knowledge. In the CE environment, e.g. tables, pictures, diagrams and the final report are part of this category.

Implicit knowledge

Knowledge that is stored within a product is called implicit. An example is a CATIA drawing. Having such a drawing, it is possible to build the corresponding product without in depth understanding of how and why the drawing was made that way.

Tacit knowledge

Knowledge that can not be easily articulated, depicted or written down by the owner of the knowledge is tacit, such as procedures, processes and experience. Examples are riding a bicycle or, regarding the CE environment, the know-how of a study participant, who has worked for many years in a specific technical area.

Wunram [RD 1] describes the creation of knowledge in a pyramid structure (see Figure 3, left). Transforming unsorted *signs* by giving them a certain way of structure and syntax creates *data*. By interpretation of this *data*, *information* is created. This *information*, when correlated with other information packages or by setting it into a broader context, transforms *information* into *knowledge*. This simple algorithm is helpful when explaining how knowledge is generated. The different types of knowledge can also be displayed in a so called *knowledge cube*. Here knowledge is categorized not only by tacit and explicit, but also in know-why, -how, and -what categories, as well as throughout the organisational structure of a group (individual, collective and external).

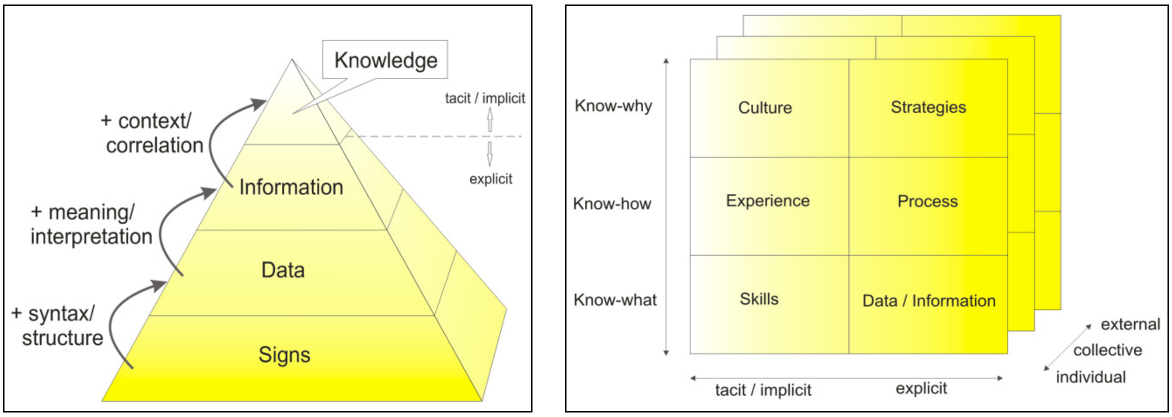


Figure 2: Left: Knowledge pyramid; Right: Knowledge classification framework (Knowledge Cube), [Wunram, 2003]

Thereby a strictly defined knowledge is more tacit and implicit and usually complex and has a short period of validity. On the contrary the explicit knowledge consists of standard content that is easier to handle. The explicit knowledge is definitely already captured in a CE environment whereas storage and access should be optimized. Figure 2 shows a classification framework for knowledge with its categories, which are defined in Table 2.

Table 2: Knowledge Content/Location and its Definition

Content	Definition
Know-what	basic information about the fulfillment of known tasks.
Know-how	Information about *how* to fulfil a specific task, under what circumstances and about the ability of adapting to new situations.
Know-why	Information about *why* problems are solved in a specific way. Drivers are cause-effect relationships, contextual development, tradition as well as cultural background.
Location	**Definition**
Individual	Knowledge is located at an individual's working place, either in the persons mind (tacit/implicit) or saved explicitly (e.g. on PC, books or other).
Collective	Information is accessible by a larger group
External	Information is located outside the working institution and has to be made accessible

3.2 Questionnaire

The questionnaire was designed to initially gather input concerning Knowledge Management from engineers involved in ESA's Concurrent Design Facility (CDF). The questionnaire consists of 21 questions, which are sectioned into the three categories:

- General Questions
- Knowledge Management
- Details of a future KM tool

The questionnaire was sent out to over 100 CDF participants, domain experts and customers of whom 51 replied. Figure 3 depicts the distribution over the different domains. The majority of returns came from the Systems Engineering domain (12 returns), followed by Customers (11 returns) and Scientists/ Experts (7 returns).

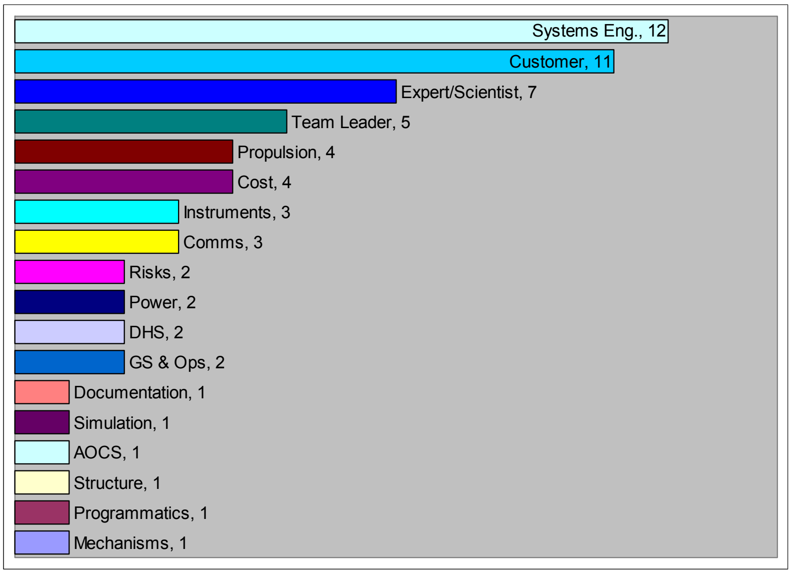
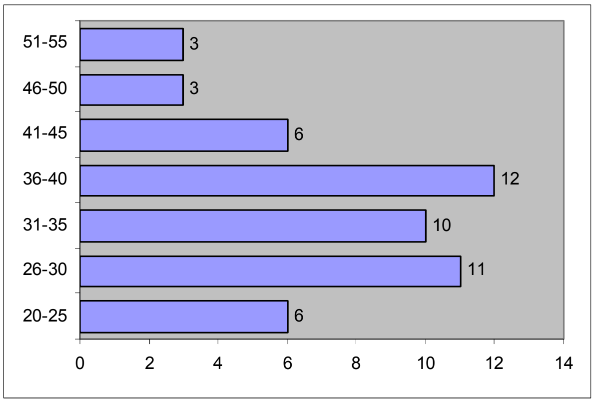


Figure 3: Questionnaire participants per domain (Total of 51 returns)

For an in depth analysis of the questionnaire results (for possible Knowledge Management activities), the over-represented domains Customers and Experts/Scientists might have to be discarded. Together they form 28.6 % of the total returns. The normalization process might be important, because the study goal is to - among others - analyze the knowledge capturing possibilities of CDF domain experts. For the time being, the returns of these two groups were considered as well.
The age distribution among the participants more or less shows a Gauss-distribution pattern. The majority (33 participants) is between 26 and 40 years of age. The average age is 35.4 years. Figure 4 (left) depicts the detailed age distribution for the questionnaire participants.



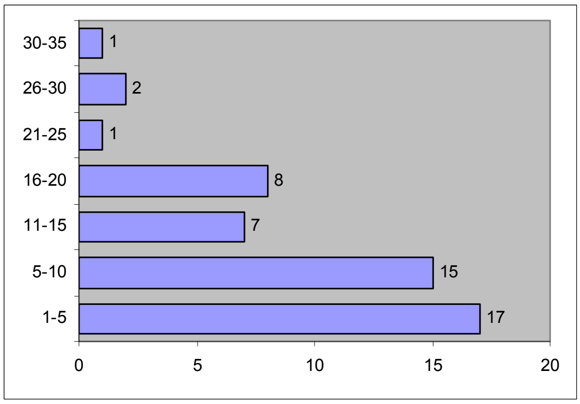
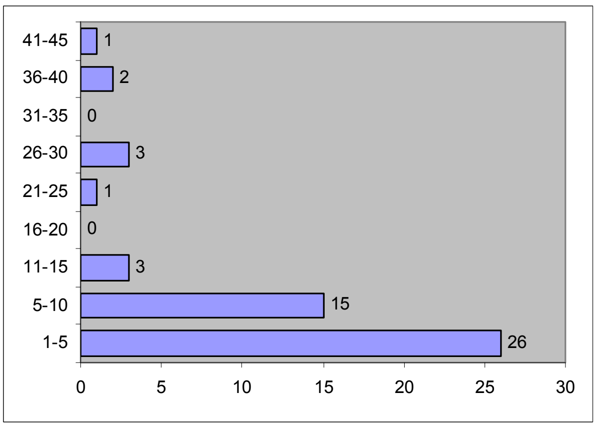


Figure 4: Left: Participants grouped by age; Right: Participants grouped by years of work experience

Concerning work experience the majority of participants has between 1-5 years of work experience (17 participants), directly followed by 15 participants that own between 5-10 years of work experience. The average work experience for this questionnaire results are 10.6 years. Figure 4 (right) shows the detailed distribution.

If we look at the specific Concurrent Engineering experience, the majority of participants has performed between 1-5 CDF studies (26 participants), followed by 15 participants that have performed between 5-10 studies. The three participants in the upper end of the scale (30-40 conducted studies) is an interesting finding but don't carry much weight for the overall findings. The average CDF study experience is 9.4 carried out studies among the participants. Figure 5 (left) shows a detailed distribution of CE related experience.



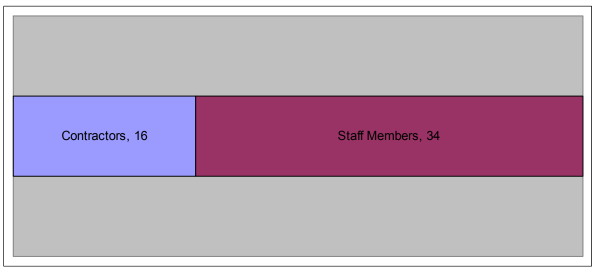


Figure 5: Left: Participants grouped by number of performed studies; Right: Associations of CDF participants

Among the questionnaire returns, there are 34 ESA staff members and 16 contractors (see Figure 5 (right)). The difference between those two groups is interesting with respect to knowledge silos and the willingness to share knowledge. This finding will be analyzed further more in the implementation plan.

Within a CE study trade-off analyses regarding different technical options are performed. These trade-offs are only fragmentary included in the final report as only the results are included. Trade-off tables are a very important knowledge element, because they *display the decision and selection process* during a session. Question 9 of the questionnaire ("What kind of knowledge generated during previous studies is most helpful when preparing for an upcoming study?") affirms that trade-offs (as well as the final reports and presentations) are the most used knowledge sources for CDF engineers in order to prepare for upcoming CE studies. See Figure 6 for a detailed distribution.

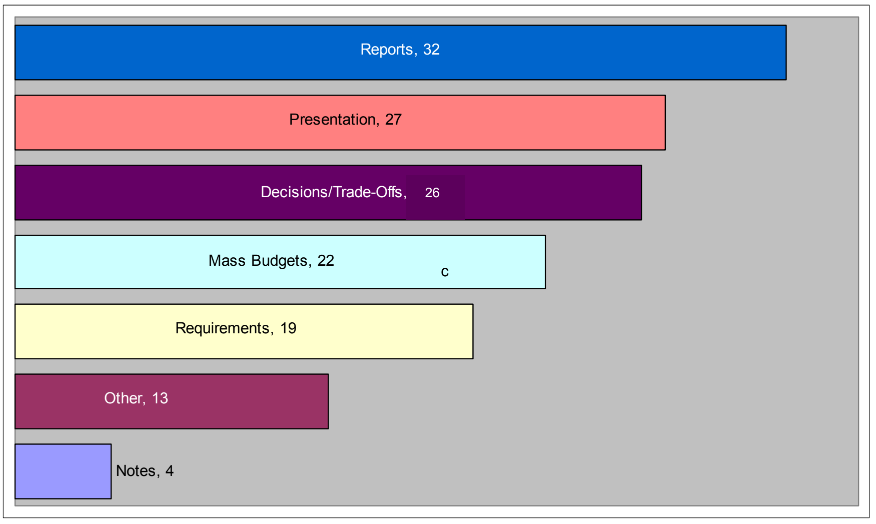


Figure 6: Question 9: Most useful knowledge generated during previous studies

Entering additional data in a KM system brings up another very important aspect, asked for the desired time commitments that the CDF participants are willing contribute for the KM system. The well defined CDF process gives the engineer already a lot to do so that time for supplementary tasks is sparse. Thus the KM system should be easy to handle and not draw too much time off the actual job. An optimal time commitment for submitting knowledge in the KM system should be between 10 - 30 min (see Figure 7).

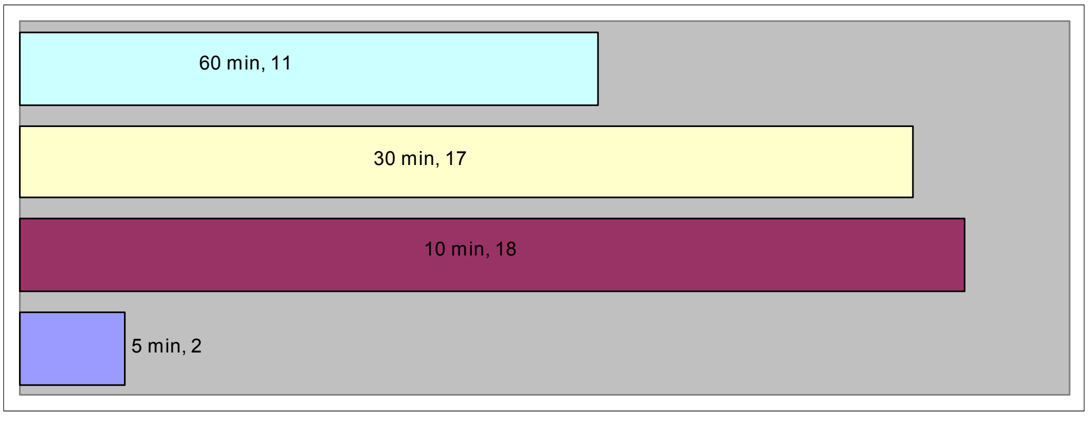


Figure 7: Questionnaire results: "One of the common impediments of a KM system is the lack of user contributions. In your opinion, which level of time commitment is optimal for you to make contributions for one CDF session?" (Question 18)

KM software tools were analyzed to search for features to be included in the Concurrent Engineering KM solution. The following analysis helps to create a set of criteria and preferences that the desired CDF KM architecture should have.

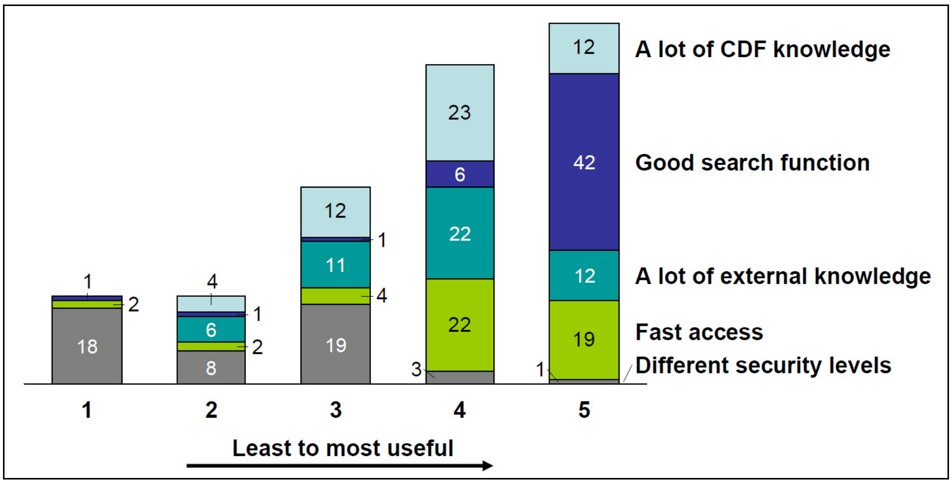


Figure 8: Questionnaire results: "What would you say is the most important attribute of a KM tool?" Question 20

Figure 8 depicts the different desired features of a future KM system. The CDF participants were asked what kind of functionality is important for a CDF KM system. The overwhelming answer (with over 40 votes) was the attribute of *good search function*. The second most important attribute is *fast access*. Both attributes are important for accelerating the work process. Furthermore, if both are implemented successfully, the additional work of capturing knowledge, needed for the KM system, should be an acceptable trade-off between current and future productivity.

4 KM Architecture Survey

The basic knowledge management concepts of other space agencies are analysed. For this, three different types of knowledge were defined to then be able to describe what kinds of KM elements exist within the environment of the Concurrent Design Facility (CDF). Concerning the basic architectural design in the space sector knowledge management solutions of both NASA's and JAXA's were looked at. In addition the KM architecture of EADS/ Airbus and DaimlerChrysler was analysed to look for different approaches in not space-related businesses.
All analyzed KM systems mainly focus on spreading knowledge company - or institutional wide. This knowledge is restricted in format and usability, meaning that only knowledge classified and sorted as resourceful is stored in the KM System. At NASA the KM steward and at Daimler the book owner is responsible for this decision. The format of the knowledge underlies restrictions.
The KM programs also focus on storing the knowledge in defined categories with no link between different files. For the CE environment however, it will be necessary to link files in different categories to connect them to one study, without violating the taxonomy.
Most of the investigated KM systems, used by the industry, make sure that the knowledge entered into the system is 100% valid. The validating process includes discussions and routings to managers, therefore taking a lot of time. In the CE process the knowledge gets validated through the discussion of the study members and through a ranking and linking option thus achieving an in-system-validation.
Generally it can be stated that personal intensive KM solutions focusing on the preservation of results are not recommendable (e.g. personal interview capturing). In the CE environment an easy to use and handy tool seems a lot more amiable. Also, the KM solution should be able to record all kinds of files and information at any time. Experience has shown that the decision making process, one of the most important elements of a CE study, cannot be recorded retrospectively so that a real-time solution is required.

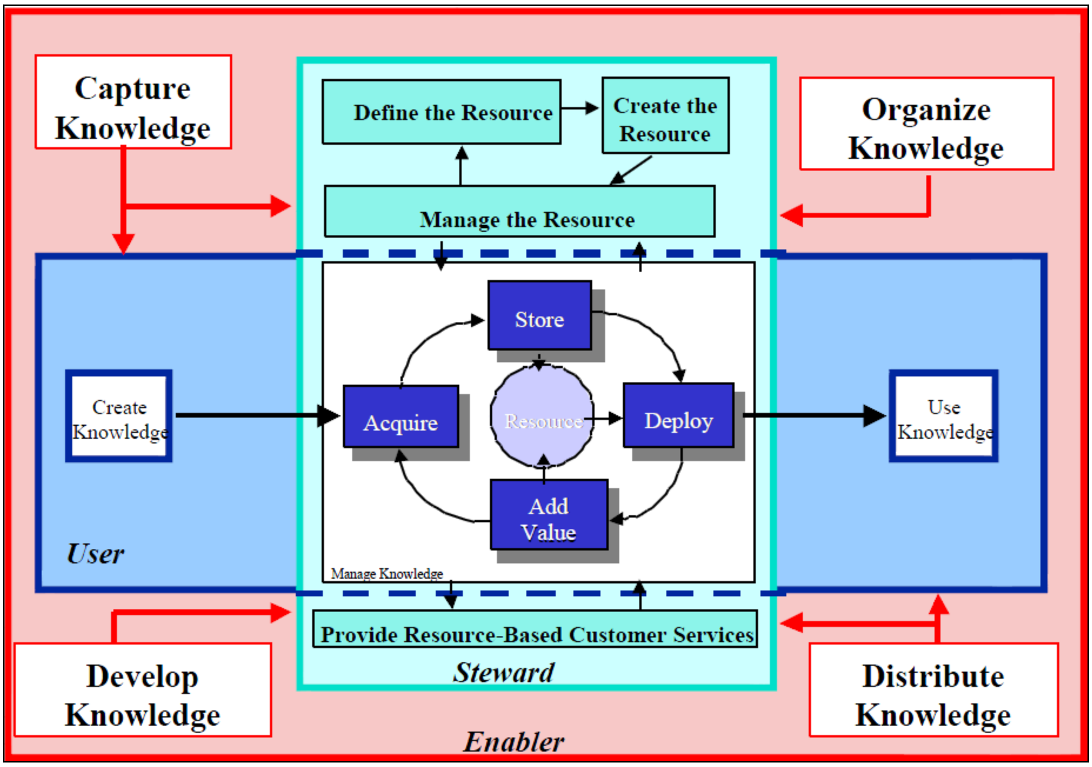


Figure 9: NASA Knowledge Management Architecture

NASA's experience with knowledge management showed that a successful KM system needs to implement the following four factors: Culture, Supporting Services, IT Infrastructure and knowledge architecture. Of the four, the knowledge architecture is the most important in respect of this investigation comprehending of methods "helping people do their work more effectively". The knowledge architecture consists of three components (from [RD 2]):

- *Process*, guiding and governing how people share knowledge through the use of policies and procedures
- *Services*, staffed by people that can assist projects and individuals
- *System*, a federated arrangement of both centralized and locally controlled systems, tools and technologies that follow similar procedures and standards for interoperability and information exchange

As most knowledge management solutions, NASA has segmented the process into the four categories Capturing, Distribution, Organization and Development (see Figure 9).

NASA has 11 departments and institutes, each with up to several hundreds of employees, contributing into their knowledge management system so that the size of the database resulted in the need to establish an expert-position - the so-called "Steward". The steward has access to the whole knowledge management system and is in charge of approving whether or not a "User", respectively the engineer, gets access as well. He is also the person responsible for uploading data into the system or making requested information available for the engineer.

5 Knowledge Management Tool Analysis

Different knowledge management tools are analysed in order to either find a tool and extend its capabilities and functions or define properties that a KM software should have in order to create an optimal program. To be able to analyse the different KM tools, a set of criteria has to be defined. The tools were examined concerning some key points, for example:

- The **Graphical User Interface** (GUI) is one of the most important parts of a program, since it is the direct interface to the user. A well structured and easy to learn GUI can save a lot of time and motivate the user to use the program. Closely related to the GUI, navigation should be easy. The user must know at any point where he is and knowledge should never be more than a few clicks away. The program should also animate the user to surf in the content and add knowledge.
- The tools should also be analysed on which **Metadata** can be added to an e.g. document and how this Metadata is handled.
- How is **linking** realized in each of the tools? Can the user link information actively to another information and/or does that happen automatically?
- **Search:** This is one of the most important features. The tool should help the user to find what he is looking for by providing an easy but complete and accurate search.
- On which **programming language** is the tool based? This is important to estimate whether the program can be extended easily and what personnel are needed.

Different commercial and free tools are analysed and compared concerning the key points just mentioned. Two minus (--) indicate that the function does not exist at all. One minus (-) could mean that the function is only partly implemented or rather complicated to execute. A plus (+) is a good evaluation with some restrictions on e.g. functionality. A function with a double-plus (++) is complete and easy to access by the user, those solutions are good candidates to be implemented into the program.

Table 3: Commercial and Free Software Tool Evaluation

	Commercial Tools						Free Software Tools		
Program / Category	Zylab	Hyper Test	Confluence	Docushare CPX	DOORS*	SMAR TEAM	Protégé*	Mendeley*	Open Steam
GUI & Navigation	+	-	+ +	+	+	+	+	+ +	+
Metadata	+ +	+	+ +	+ +	- -	+	-	+ +	+ +
Versioning	+ +	+ +	+	+ +	+	+ +	- -	- -	- -
Links	- -	+	-	- -	+	+ +	+	- -	+ +
User Groups	+ +	+ +	+ +	+ +	+ +	+	- -	- -	+ +
Search	+	+	-	+ +	- -	+	- -	+ +	+ +
Pricing	- -	n. a.	-	- -	n. a.	-	+ +	+ +	+ +
Adaptability	-	+	- -	-	- -	-	+ +	- -	+

* Those tools are not complete knowledge management tools. However, they are good examples on how to implement specific features.

In Table 3 the different investigated programs are compared, regarding the introduced key points. One more category is added, adaptability. This is important to estimate whether the program can be extended easily and what personnel is needed to do so. Adaptability is an important feature, since it strongly influences the decision on extending the program.

Since storing knowledge in documents is the most common way, the majority of tools were especially concentrating on document management. Lacking features of search, taxonomy

and general information processing, i.e. processing of drawings and multimedia information, excludes all candidates from being used in a concurrent engineering environment. The investigation also showed that most commercial tools are not adaptable or can only be changed by the resellers of the program, which would results in additional costs.
None of the above tools fulfils all requirements envisioned for knowledge management in a concurrent engineering environment, thus using one as a stand alone application is not recommended. However, most tools are using technologies or features which should be inherited for our knowledge management solution. These technologies and features of interest of each tool are listed in Table 4:

Table 4: KM Tools with Technologies and Features of Interest

Tool	Technologies and Features of Interest
Mendeley	Extracting and presenting metadata from PDF-files; software can serve as template to implement its features into the knowledge management system; source code is not available, functions will have to be emulated
Confluence	WIKI technology; good solution for correcting, adapting and providing suitable content for a certain subject; collective intelligence can be recommended as a technology for administrating information content; confluence lacks suiting document management options (linking of documents / metadata) excludes tool from usage in a CE environment
Open Steam	Uses so called “backpacks” to share documents and information to other clients in the system; usage of main bus for communicating with the server, presentation of other client’s documents can be provided by sending a server message including the data as well as the recipient; server is able to present needed data to the client; usage of API enables third party applications to use services of the server; API is not standarddized: problems for third party applications to understand and use it
Docushare CPX	With Confluence’s and Open Steam’s interesting features (described above), Docushare does not offer additional functions worth mentioning.
DOORS (Dynamic Object Oriented Requirements System)	Not a knowledge management solution; database with sophisticated versioning options; working with own Objects: text associated with the object can be searched for changes; accurate changes presentation: changes in an object can be easily viewed and archived, each user is able to easily understand what exactly was done with the document
Zylab	Uses XML-Storage to maintain compatibility to other systems; format is structured, compliant to public standards and easy to understand for other applications: possibility to communicate with the same set of data through different systems; with usage of XSL technologies, data can be presented individually, suited to the clients needs; XML is known to produce high overhead, using it as a data storage can lead to resource insufficiencies; technology is only recommended for interoperability and collaborative functions, not for data storage
HyperTest	Specialized on the management of documents rather than on files in general; provides advanced pool of search functions that can go through text-based documents themselves; supports extensions through Java-based add-ons; cannot be recommended to build the intended KM solution on top of it, user interface does not allow fast & easy navigation
Protégé	Not a management tool itself; but a program to develop ontology maps; possibility to extract the ontology into standardized formats such as RDF and the algorithmic for building the ontology itself; cannot be accessed from third party applications, since it provides no API; features could be implemented by building an application around it; could serve as a basis for a future KM system.

6 Current KM Status at CDF (ESTEC)

There are many Knowledge Management (KM) elements within a CE environment. In order to investigate what kind of KM capabilities/elements are presently available and which are missing at the CDF, KM elements respectively KM capabilities are defined. Within the present study we refer to a KM element/ capability as a document (explicit) that describes or displays a certain knowledge or skill. The following categories of KM elements within (Table 5) and missing in the CDF can be defined (see Table 6).

Table 5: Investigated existing KM Capabilities

KM Element	Description
Report	• Knowledge gathered during one study • Every CDF domain is involved • Most important KM element within CE environment
Presentation Slides	• Kick-Off (K/O) and Final Presentation (FP) • Every CDF domain is involved • Important findings, decisions or requirement changes are communicated via presentations
Trade-Offs	• Very important Knowledge Element • Displays the decision and selection process during a session
CDF Internal Database Folders	• Integrated in CDF infrastructure • Collection of different folders (>Taxonomy) • Each topic folder inhabits various documents, collected by the CDF participants
Minutes of Meetings (MoM)	• Protocol of the main topics and results (e.g. of splinter meeting session)
Integrated Design Model (IDM)	• Offers technical parameter and budgets • Equipment lists of different systems
"Miscellaneous" Folder	• Knowledge gathered during one study • Mostly unstructured cluster of documents
CE Infrastructure	• The CDF principle itself • Media enhanced systems (Web conferences, etc.) • Interconnected systems
CE Process	• Well defined concurrent design process • "Process knowledge"
CE Experts	• CDF participants are domain & systems experts • Lot of experience • Tacit knowledge (Know-how to do s.th.)

In general it can be stated that the already existing knowledge management elements have one major disadvantage: even though they represent good sources of knowledge, the access to this knowledge is still a burden. To access information the engineer either has to know the content of the file he or she is looking for, rely on recommendations of other engineers or trust the nomenclature of the files and folders. What is still missing is a database supplying information about the information that is already existing (e.g. a short summary/comment or tags), making the search for it easier.
Also the connection and the integration of already existing knowledge databases through a single and easy accessible CDF KM system are missing.

Table 6: Investigated missing KM Capabilities

KM Element	Description
Requirements Change Log	• Final Report shows the final study requirements • Not shown: Development and History of Requirements
Personal Logs	• Very important Knowledge Element • Source for Tacit Knowledge • Helpful: Visual and audio capturing
Decision Mapping	• Capturing of big design decision • Also small & specific decisions • Questionnaire indicates *Decision* capturing as very useful
Lessons Learned Directory	• Storage and organization of different *Lessons-learned* • Questionnaire for fill-in procedure • Implementation of existing *Lessons-learned* Systems
Handling of Software Files	• Proper tool for storing software files • According to Domain specific demands
External Domain Databases	• Implementation of different ESA databases for extended knowledge search • Various domain databases within ESTEC
Handling of Notes (digital and non digital)	• Questionnaire indicates high demand • Remarks, Drawings, Formulas, etc. • Digitalize => Capturing & Storing
Visual Recording of Presentations	• Presentation of slides together with the remarks of the author • K/O-, Midterm-, Final- Presentations, but also Trade-offs • Source for tacit knowledge • Very important knowledge element
Specialized CDF Wiki	• Almost every KM architecture offers Wiki (IAC) • Threat: Contribution from participant necessary!
Experts database - Ask an Expert	• Ask an expert • Yellow Pages of “ESTEC” wrt CDF domains • Expert profile is needed

7 KM-System Architecture

This chapter gives an overview about the different aspects of the Knowledge Management (KM) Architecture developed in the frame of the contract and displays the theoretical and organizational structure of the KM prototype tool.
The present layout of the architecture represents the total 100% of the desired system. Not all of these suggested interfaces (& modules) will be selected for the later prototype system.
Also not all presented functions will be implemented at once. There will be a introduction phase, where the different features of the modules will be implemented in a step-by-step approach. Highest requirement during Phase II, which will be the prototype development phase, is the design of an intuitive, simple and easy to handle Human-Machine-Interface (HMI).

7.1 Taxonomy

Taxonomy is the practice and science of classification. Typically this is organized by supertype-subtype relationships, also called generalization-specialization relationships (parent-child relationships).
The taxonomy refers to the access procedure a CDF engineer will have to select before he or she can submit a KU into the KM system. In addition to this the possibility exists to use this categorizations method to search through the different KUs within the distribution section, when the engineer is looking for certain knowledge. A third characteristic of the developed taxonomy system is to visualize the full data model that should be established for each up coming CDF study (see Table 7).

Table 7: Investigated taxonomy system and the full data model

Domain	Category	Sub-Category	Knowledge Data Type	
System	Launchers		CE Session Documents	Final Reports
Cost				Presentations
AOCS				MoMs
Propulsion	Earth Observation			…
Data Handling			Software Files	Excel Calculations
Communications				CAD files
Power	Navigation			Simulation files
Mechanisms			CE/IDM Results	Mass Budget Developments
Instruments				Power Budgets
Ground Systems	Telecommunications			System Ratios
Risk			NDEs	Calculations
Programmatics				Books
Documentation	Human Spaceflight	Human Exploration		Remarks
Team Leader		ISS Utilization		Drawings
Expert / Scientist		Cargo		…
Mission	Science & Robotic exploration	Astrophysics	Hardware	Assemblies
Thermal		Fundamental Physics		Subsystems
Structures		Solar System		Components
Configuration		Robotic exploration		…
Pyrotechnics	Infrastructure & Technology	System of Systems	Reference Documents	Dissertations
Radiation		Security		Surveys
Simulation		ISS infrastructure		Thesis
Customer		Technology developments		Reports

7.2 System Overview

The fundamental design of the Knowledge Management system is based on the key elements, which are also used by NASA, JAXA and other technology intensive organizations: Capture knowledge; Organize knowledge; Distribute knowledge, and Develop knowledge.
The four sections of the knowledge system are in relationship to each other, so that a feedback loop can be described as seen in Figure 10.

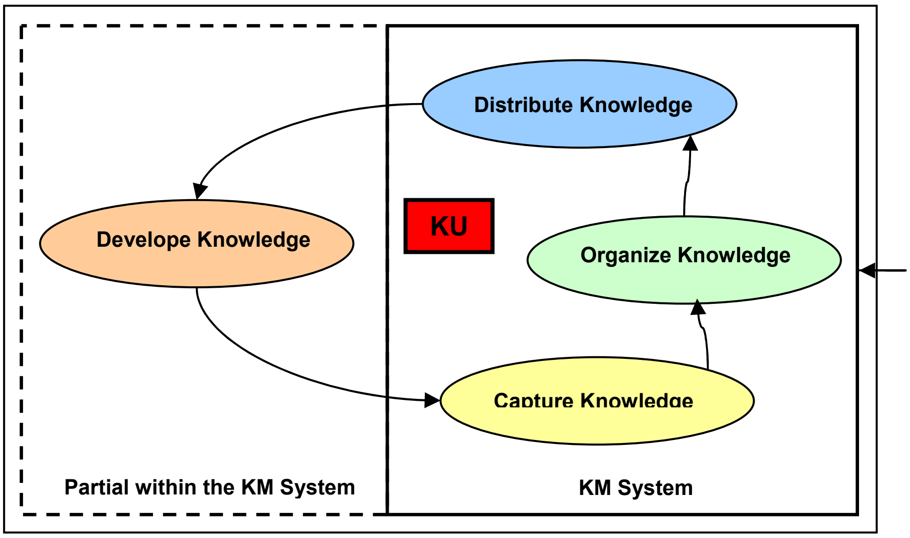


Figure 10: The four basic elements of the KM system: Capture, Organize, Distribute, Development.

As shown in Figure 11, the *capture section* organizes the interface towards the engineer and the procedure to submit knowledge towards the main KM system. Once knowledge is entered to the KM system the different knowledge contents have to be saved and stored, back-uped, and organized so that the various content items are linked in a semantic manner.
These tasked are executed within the *organize section*. The *distribution section* basically deals with the delivery of knowledge towards the engineer. Search functions are the main features in this section. The *development section* gives the engineer the possibility to alter the knowledge in the KM system as well as to enhance & add new knowledge aspects to the existing knowledge. As a result, the *development section* is only partial included in the KM system, the main contribution in this section comes from the engineer her- or himself.
Additionally to these four sections, a fifth element is introduced: the Knowledge Unit (KU). The KU is interacting with each of the elements. The Knowledge Unit is the smallest unit, where data can be stored to. Every knowledge package that is uploaded to the system is stored in a KU. Figure 11 depicts the different data flow relationships between the described sections, the KU and the knowledge submitting engineer.

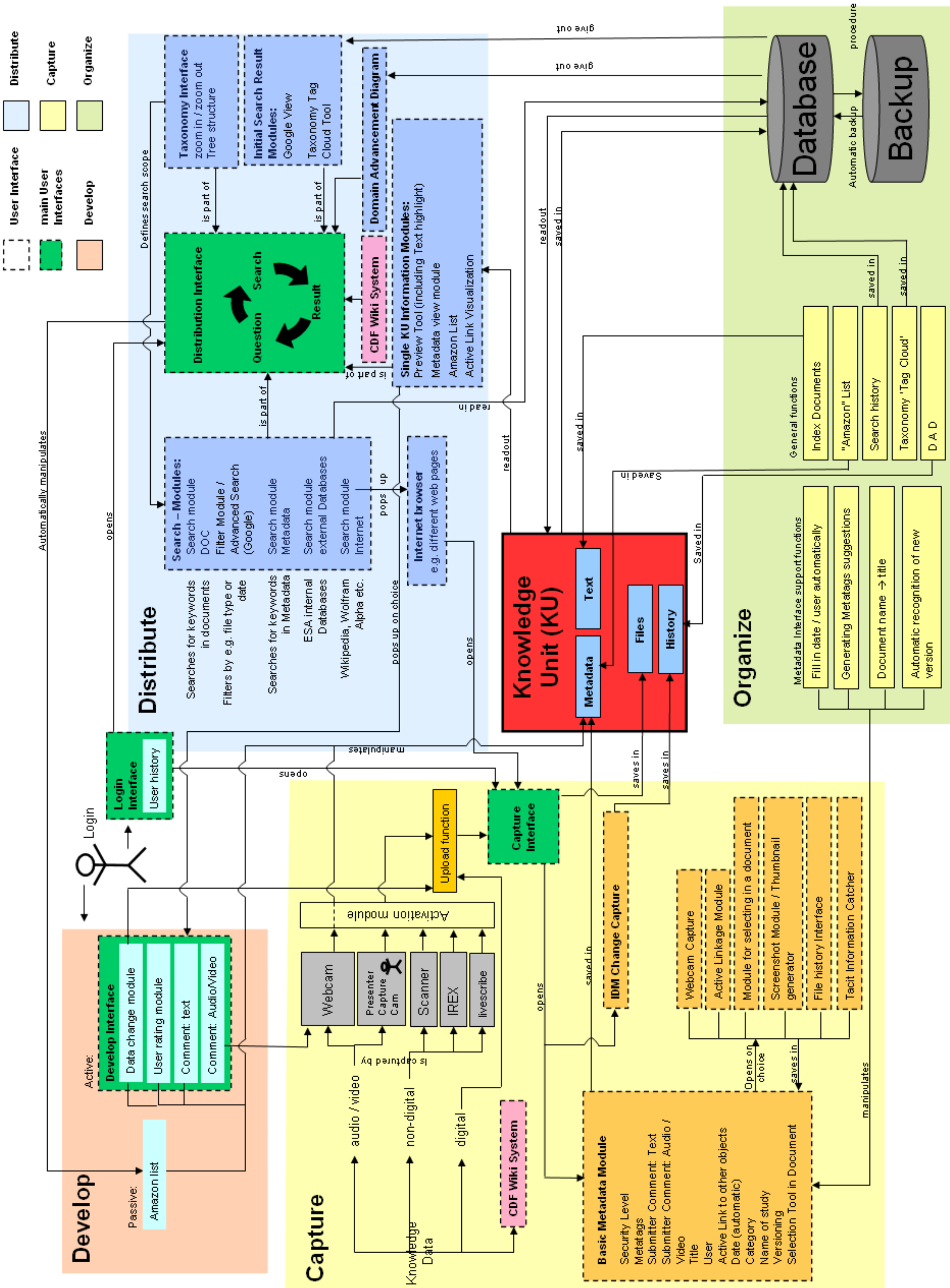


Figure 11: Proposed KM architecture map with the four sections: Capture, Organize, Distribute and Develop

7.3 Knowledge Unit (KU)

The Knowledge Unit (KU) is the major element of the proposed KM system. The idea behind the KU is to ask the submitter (here: engineer/expert) to add information about the knowledge, currently uploading into the KM system. As seen in Figure 12 we refer to this procedure as giving *information about information*. This information is also called Metadata.

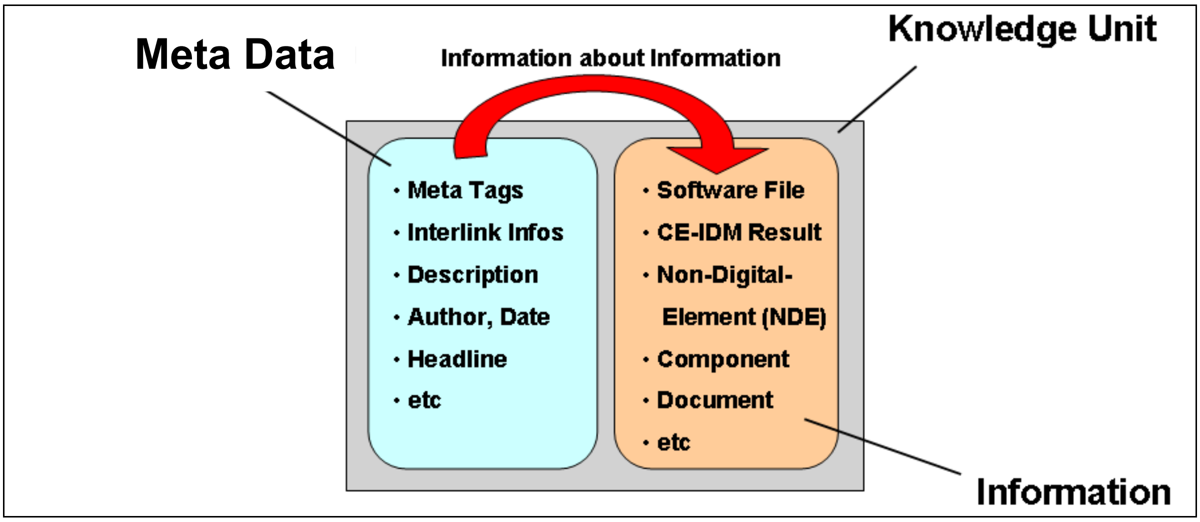


Figure 12: The basic Knowledge Unit (KU) theory

A typical KU consists of three elements: the file; metadata and text (indexed content). The 'File' is a digitized version of the knowledge to be captured. There are many different file sources. Basically, the file of the KU is the actually information or knowledge that shall be stored in the KM system.
In this context the Metadata captures the additional information about the submitted file. The information within the Metadata section will in parts be completed by the KM program itself. To assure that the metadata is generated, the KU is implemented on top of the capturing process. Whenever a new file is uploaded into the system a pop-up directly asks the submitter to enter the needed metadata. When searching through the database (distribution section), the metadata categories are offered as possible search-fields. The KU also consists of data, which is delivered by the *development section* and the *organization section*. Examples are the video or user comments.
The third part of the KU is the "Indexed Text". If the submitted knowledge is a text based document (e.g. final report in pdf or word) the 'Text' indexes all words and stores the text as a so called *string* within the KU. This way a fast access by the search function can be allowed.

7.4 Capturing

The capturing of knowledge (see Figure 11) is one of the most important elements of the KM system. A lot of knowledge is generated during a CE session (e.g. documents, messages, S/W files, scans, Decision Making Process).
The capturing process starts with the user log-in and execution of a Java-Application available as an always accessible task. This application serves as tray to 'load knowledge in'.
This can happen either by "drag & drop"-ing a file onto the task-icon, by opening a selection menu from within the application or by starting the 'Activation Module' to access peripherals like a scanner or webcam. Independent of the selected method, a KU pop-up window opens afterwards, asking the user to fill in the Metadata categories. With capture devices like webcam, scanner, IREX, livescribe pen, together with the normal upload function for already digitally available files, the knowledge can be added to a KU. A confirmation button completes the upload process. Table 8 shows all offered capturing interfaces.

Table 8: Capture Interfaces

Capture Interface	Description
Basic Metadata Module (BMM)	• collects all Metadata, necessary for the completion of a KU (predefined by the KM program, entered by the submitter) • BMM will be the central interface for submitting knowledge
Screenshot Module	• generates a thumbnail/ preview of a file (later: *icon* of the KU) • uses different KU icons for the pictured Taxonomy Tag Cloud • for PDF / DOC files the first selected page is displayed as an icon
Active Linkage Module:	• links a new KU to already existing • provides user with a history of personally uploaded or accessed KUs. • shows all uploaded KUs of one session, for linkage of KUs • creates knowledge map that helps the user to find useful other KUs that are related to the present KU
Webcam/ Microphone Capturing Module	• records video & audio sources • uploads recorded video stream "tag" together with the KU • offers an additional way to add tacit knowledge (module is also used in the distribution section, when comments on other KUs are appropriate)
File History Interface Module	• keeps track concerning different versions of the same KU • highlights the latest and newest version of the KU
Tacit Information Catcher (TIC) Module	• helps capturing tacit information/ knowledge • is interlinked with presenter- & web cam of each domain client server • records PowerPoint presentations in combination with presenter cam • indexes the different slides • combines the PowerPoint slides with the spoken words (+ video stream) of the engineer • captures decision-making processes by recording the discussions of a trade-off table • user can jump to a certain slide & video stream
The IDM Change Capturing DAD (Domain Advancement Diagram)	• documents the changes that were made from one session to the next monitors whether or not components were added or removed • monitors the changes made to the different technical system features (mass, temp. etc.) • saves IDM changes as 'History' in an adapted KU - allows to give comments on the changes. • captures and stores the decision process that occurs during the study evolution (displayed in the Domain Advancement Diagram (DAD)) • Links KUs with different IDM interations

7.5 Organization

The main tasks within the organization section (see Figure 11) are the storage of the different KUs and the back-up procedure. Several recording functions (see Table 9) are implemented that record the search behavior of the users in order to establish a semantic knowledge map. With such a map the search capability of the KM system can be increased. Other tasks of the organization section are the different fill-in support functions (see Table 10) for the BMM (Basic Metadata Module).
The database will be based on MySQL which is a freely available (GNU General Public License) database management system.

Table 9: Semantic recording & organizing tasks within organization section

Semantic Recording	Description
Taxonomy Tag Cloud (TTC)	• arranges knowledge, depending on how often words are requested by users (in regard to the topic), appearance is accentuated through font-size • topics are represented through the categories of the taxonomy circle. • depicts Knowledge Units with a thumbnail or the title of the enclosed knowledge in the 'cloud', sized according to the request frequency • results of these generated TTCs are displayed in the distribution section
"Amazon (Search Record) List"	• Amazon provides a list of additional products which were bought by customers who also bought the selected one, the assumption is that both past and present customers share a similar field of interest • envisioned KM solution will record which KUs were accessed subsequently to the selected one (the deeper the taxonomy level goes - thereby narrowing the field of interest - the more accurate this assumption will be)
Search History Log File	• eases future queries - search history is recorded for every user • averts searching for the same topics over and over again and also avoids search results getting lost.
Index Documents	• able to index common text-based documents like PDF or DOC files • access and save the documents content - making it searchable by the program itself index document will be stored within the KU
DAD	• organizes the IDM-specific KUs • manages the change-log, saved in the KU history, and connects them with related Knowledge Units (KUs)

In order to speed up the capture process several BMM (Basic Metadata Module) support functions are also implemented (see Table 10).

Table 10: BMM Support Functions

BMM Support Functions	Description
Fill-in date/user automatically	• records elements like the User/Submitter or the date that do not change during a session • program offers automatic suggestions to speed up the capture process.
Generating Metatags automatically	• some documents (PDF, word documents) already offer the possibility to include meta-information. • program will access and import them into the KU automatically.
Document Title	• algorithm code detects the document title (Metatag or first row of a text-based document) and automatically upload them into the KM system.
Automatic recognition of new version	• program compares content of uploaded file with already existing files • updates of old files are marked as those and get the same metadata.

7.6 Distribution

Unlike the capturing process (see Figure 11), the log-in on the dedicated KM website does not open an additional window. The main elements within the distribution section are the Distribution Interface; Taxonomy Interface; Search Modules; Initial Search Result Modules, and Single KU Information Modules.

The distribution interface is the main interface for search requests. Within this interface all search procedures are executed. Regarding the distribution of knowledge, all in the following described interfaces and modules are implemented into the website.

The taxonomy interface is a main part of the distribution interface. It is used to control the scope of a search by enabling the user to define on which taxonomy level the search shall be performed. The interface will be designed in a dynamic way which allows the user to *scroll* in and out with a specific search request. This way the search scope can be adjusted in a dynamic fashion.

The following search modules are planed to implement in the KM system:

- Keyword search in documents
- Filter Module/Advanced Search
- Keyword search in metadata
- Keyword search in external databases
- Keyword search in Internet

The initial search result (Multiple KU-Interface) view modules help to visualize the search results. Therefore, different techniques will be used:

- Google-View
- Taxonomy Tag Cloud (TTC) Tool (see Table 9)

Once the user has made a decision on a certain KU, it will be displayed in detail within the Single KU Information Module. This module/ interface displays the different Metadata information of the present KU as well as the software file or the document itself. The following tools are used:

- Preview Tool
- Metadata View Module
- "Amazon List"
- Active Link Visualization

The DAD distribution User Interface (UI) will be offered in addition to the before described solution. While the other interfaces allow the user to browse through all Knowledge Units (KUs), this view is centred around the different versions of the Integrated Design Model (IDM) that is generated during different study sessions.
After selecting or searching for a study, the user is presented with the "Domain-specific study timeline". The timeline gives an overview of the iterations the IDM ran through (for the selected study). After selecting an IDM state (iteration) in the timeline, the lower left side of the screen depicts the documents related to the changes that were made to this version. The lower right side depicts the changes and presents the notes given by domain expert who uploaded the file.

7.7 Development

The development is the ongoing process of uploading knowledge into the database, rating it through methods like direct 'User ranking' or by passive search recording like the 'Amazon List'. The development section is rather more located on the engineer and expert side than within the KM program.
The development Interface will give the user the opportunity to interact with the knowledge provided in the system. Basically the development interface is build up of two functions:

- User Rating Module
- KU Comment (Text or audio/video)

Located in the distribution section but belonging to the development section the *User Rating Module* will allow the user to rate a certain Knowledge Unit (KU) with respect to its usefulness. This rating will affect not only to some extent the "Amazon list", but also the general ranking of selected KU.
The comment module allows adding certain comments to the selected KU. The comments are stored within the Metadata of the KU. The Comments can either be text based or audio/visual, recorded over a webcam/headset combination

8 Hardware Evaluation

Figure 13 (left) displays the different additional hardware items that are intended for the Knowledge Management architecture. Important to mention here, with respect to limited budget resources, are that not all hardware items have to be purchases for the proposed KM system. The hardware evaluation rather gives an overview of desired media and system hardware structure (see Table 11).

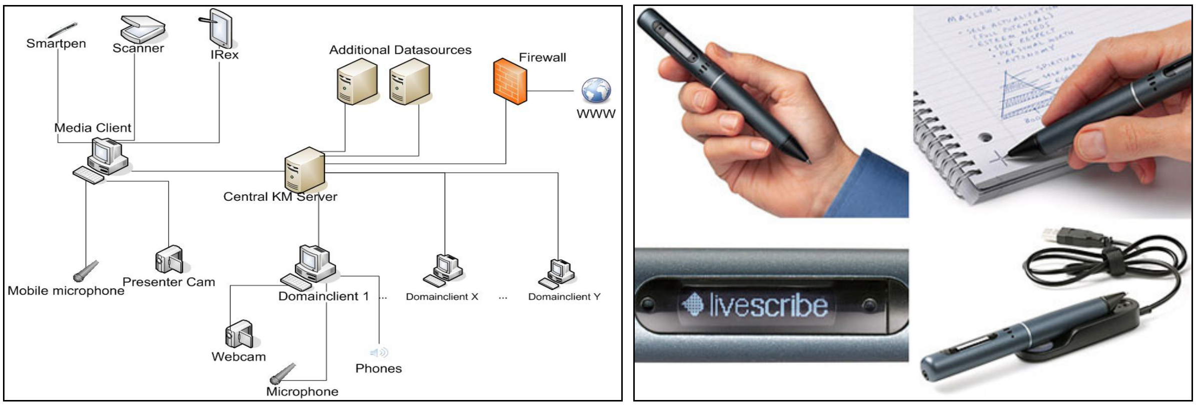


Figure 13: Left: Hardware infrastructure of the proposed CDF KM system; Right: Livescribe pen is digitalizer for handwritten notes as well as audio [RD 3]

As an example for the additional hardware items, the Livescribe Pulse Smartpen is described. This device works on special paper manufactured by Livescribe itself and is able to digitalize notes and associate them with audio information, recorded while the notes were made. [RD 3] Due to these abilities, the pen can be used to monitor decision-making processes (compare Figure 13, right). Furthermore, it provides a development kit, enabling customization of the pens behaviour and the development of applications which suit the needs of a concurrent engineering environment.

Table 11: Hardware Evaluation

Hardware	Description
Central KM Server	heart of the KM system; CPU: minimum 2 CPUs with each at least 1,4 GHz; Memory: minimum 2 GB of RAM; Hard Disk: minimum 120 GB
Media Client	digitalizing and capturing of knowledge; equipped with special media recording hardware like the Livescribe pen or scanner; functions as a media docking station, providing the engineers the proper tools for capturing different types of knowledge
Presenter Cam & Mobile Micro-phone	Recording of presentations; adds the visual data to the captured audio information with the PowerPoint file; a mobile microphone is used; pre-senter carries this mobile phone on his/her body; indexing process will be executed via the TIC module
IRex / Ipad	digital reader; able to present documents and information on an easy-to-read e-Ink display; touchpad provides the ability to digitalize notes and transfer them to the media client
Webcam & Headphones	capturing video & audio information from each domain client; webcams are mandatory for every client in the system; user has possibility to make video comments on different KUs
Scanner	digitalize complete documents; enable the capitalization of knowledge
Livescribe Pulse Smartpen	works on special paper manufactured; is able to digitalize notes and associate them with audio information, recorded while the notes were made

9 Implementation Plan

This implementation plan document is a result of discussions within the project team based on the feedback of ESA. Certain elements of the plan are also based on literature review and analysis of the questionnaire results administered to the Concurrent Design Facility (CDF) participants. This report is designed as a practical set of suggestions covering the implementation related issues of the Knowledge Management (KM) architecture developed for ESA's CDF. An implementation plan is proposed for two different time horizons: short-term (until the end of present project) and medium term (one year following the end of present project). Certain recommendations for long-term implementation are given. An overview of the existing IT infrastructure of the CDF is also provided, as it relates to the implementation of the KM tool.

9.1 Implementation Schedule and Plan

9.1.1 Short-term Implementation Plan

The short-term implementation plan focuses on the prototype tool to be installed at the CDF. The planned implementation stages for this task are shown in Figure 14. The first element of this plan, the development of a KM architecture is already completed. This plan foresees selecting a set of initial features for the prototype tool based on the priorities of ESA as well as the specifications of the existing IT infrastructure at the CDF.

Once the IT solution is developed, it will be first installed at DLR's CEF, and it will be tested in this environment. Following the review of this implementation, modifications will be made and the prototype tool will be adapted to work efficiently in a concurrent engineering environment. This iterative implementation approach will increase the chances of success for the CDF installation. As part of the installation process, a training session will be provided. This step is envisioned to be the "training of the trainers" which will ensure that the people who will be directly responsible of the KM tool to get a formal training regarding the capabilities, limitations and benefits of the KM system. Basic functionalities of the prototype tool, the user manual and other relevant information will be explained. After this stage, as the prototype tool becomes operational at the CDF, future implementation steps can be taken.

Figure 14: Prototype Implementation Plan Note: Completed elements are highlighted.

9.1.2 Medium-term Implementation Plan

This medium-term plan starts with the activation of the prototype version at ESA CDF and the beginning of the operational use stage. In contrast to the short-term implementation plan, this time the objective is not only testing, but also ensuring operational use of the KM system. In the meantime, existing (explicit) knowledge of the CDF (e.g. in the form of past study reports) will be transferred into the KM system to ensure that there will be relevant content for the CDF participants. This is a very resource intensive task, as it will require organizing many files (with different file formats) and creating a logical data structure. For this purpose, it is recommended that an ESA YGT is tasked with populating the database. Knowledge Unit entries will be performed by a YGT and the database will be populated by scanning through the CDF archives and entering the KUs into the database. Another way to populate the database is to connect it to existing CDF databases, which could be supported by the IT staff of the CDF. In parallel, the YGT will start giving training to other CDF members before CDF

sessions, and the CDF members will start using the KM tool as they are working on CDF studies. A cycle of 2-3 studies are recommended at this stage, each study preceded by a training session given by the YGT.
After this initial experience gained through the operational use of the tool, an evaluation phase is scheduled. During this short evaluation phase, comments of the core CDF team will be collected using interviews and a brief analysis of these comments will be performed. The results of this evaluation can be used to fine-tune the subsequent steps of implementation.
Following the initial operational use, the KM tool will be ready to be activated as a "full version", although it will still be at the prototype stage. Further improvements in the software and hardware components are expected before the tool can achieve its first official release ("version 1"). In the meantime, additional activities are proposed to better integrate the tool in CDF's day-to-day activities. Some of the possible incentive schemes include internal recognition (e.g., "knowledge worker of the month") and external recognition (e.g., sending top knowledge contributors to conferences and workshops). The exact nature of the incentives can be determined by the KM officer and the CDF core team. Another step in the evolution of the KM tool is increasing the amount of accessible information by connecting to other ESA databases
At this stage, a more formal evaluation is recommended, which will include a questionnaire. During this phase, the feedback of the CDF participants will be collected and potential issues will be identified. The usability and benefits of the system will also be assessed. The results of this analysis can be used to further improve the KM tool.
When these additional stages are completed, the KM tool will reach an important milestone: Joint Evaluation Meeting. During this meeting, the performance, usability and benefits of the KM tool will be evaluated, and the necessary steps to reach the code maturation stage will be planned. The KM system will have evolved into a fully-functioning tool with plenty of documentation and user experience. This step will also signify the end of the prototyping stage and the release of version 1. Furthermore, the core CDF team will have gained significant experience in using the tool and be capable of planning its future. The exact timing of this evolution is based on CDF's preferences, available budget and other considerations. Therefore a prediction is quite difficult. (See Figure 15)

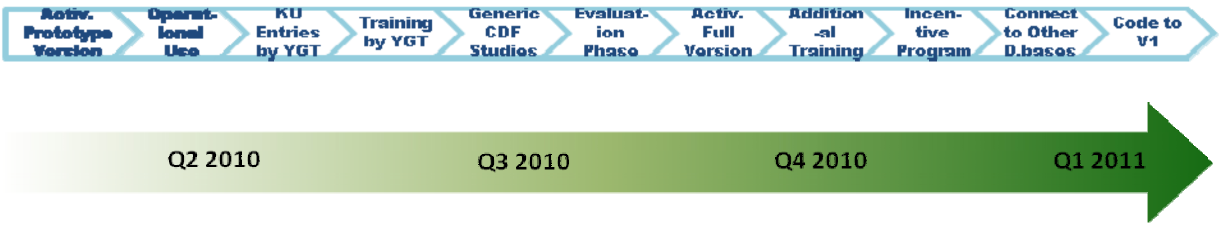


Figure 15: Full project implementation plan

At the end of this medium-term implementation, a fully functional KM system will be achieved, which is capable of sharing past knowledge, as well as recording and archiving new knowledge generated by the CDF.
For a detailed schedule of the medium-term implementation plan, please see Figure 16, which shows this information as a Gantt chart.

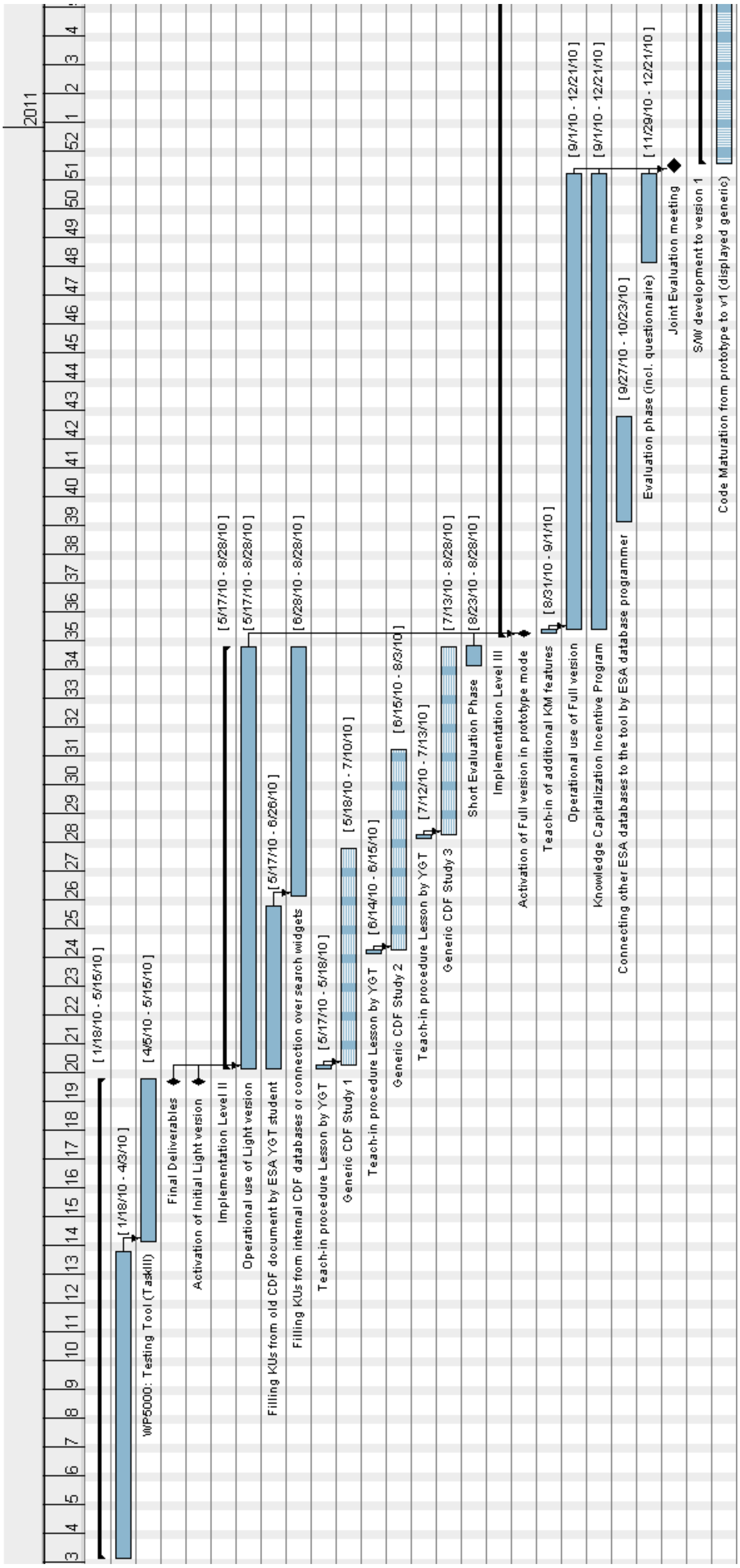


Figure 16: GANTT chart of medium-term implementation

9.1.3 Long-term Implementation Roadmap

For a longer term outlook, we propose a roadmap, shown in Figure 17, which includes the previous two stages, as well as future steps required to implement a successful KM system which will enable preserving and sharing the knowledge within the CDF.

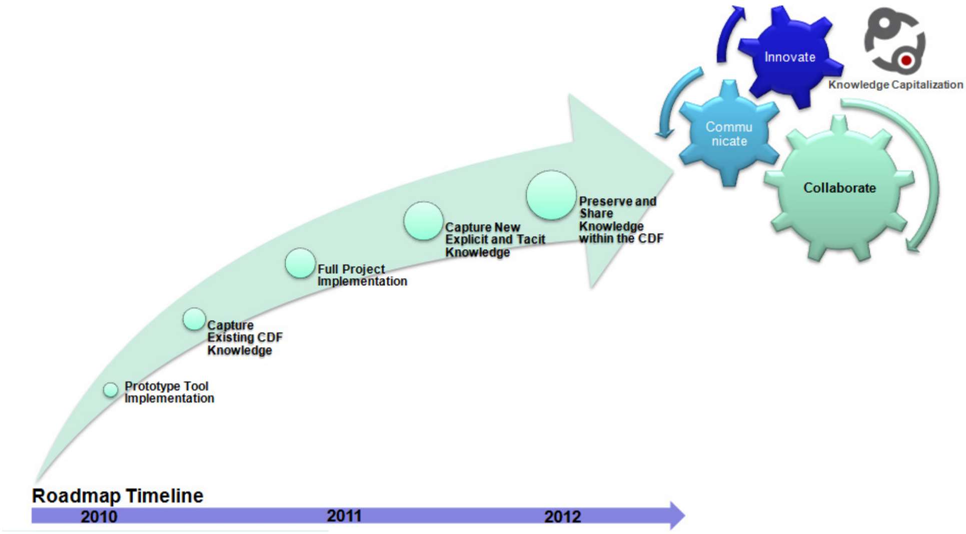


Figure 17: Long-term Implementation Roadmap

As shown on the roadmap, the successful implementation of the KM system can bring a number of benefits, including increased communication and collaboration, which in turn will create a very fertile environment for good engineering practices and innovative ideas and designs.

9.2 Recommendations

From present point of view some of the best advice for the CDF is likely to come from within. With this guiding principle in mind, some of our recommendations are preceded by a quote from the CDF team.

A "Start Simple" Approach

“Don't be too ambitious from the start with a tool supposed to collect and manage all kind of knowledge. Start with something well identified, on only one aspect, with limited data to enter and fast access to them. Once the users are convinced and are actually using the tools, then it would be easier to expand it and benefit from the lessons learnt on the initial limited scope.”

- *a CDF participant (questionnaire result)*

We propose a modular implementation approach which is designed to maximize user adoption of the proposed KM system by starting with a simple version of the KM system. When it comes to usability, the integration of the KM system with the ongoing processes at the CDF (such as design studies, reporting) is a key factor. In other words, KM system should give the users the confidence that their time is not wasted, and there will be concrete benefits for the individual or for the team as a result of a well functioning KM system. KM should not be seen as a chore or an extra task to be completed without a clear value.

Some specific implementation recommendations are as follows:

- Start simple, concentrate on the functions identified as top priority by the CDF team

- Create a culture of ownership for the system by communicating the value of the system through training and exploring non-financial incentives, such as peer recognition
- Communicate why this system is being implemented and its potential benefits
- Ask the KM system users for structured feedback to develop lessons learned
- Develop a modular investment approach by determining the benefits of each implementation step before investing more resources

Integrate KM into the Training Program of the CDF
"It would be useful to deliver introductory lectures for each subsystem explaining the basics of its design and the way it is assessed in the CDF."
- *a CDF participant (questionnaire result)*

We recommend integrating the KM system into the training program of the CDF, so that newcomers are introduced to the KM practices right from the beginning and perceive it as part of the corporate culture. This can provide multiple benefits, including faster integration into the team through socialization and building commitment to KM very early on. Another benefit of a KM system is the support it can provide to training new participants in a group. However, the KM system has to be designed and implemented with the existing training practices in mind.
For existing CDF participants, a series of dedicated KM training activities should be designed, so that they are introduced to the system and start using it as part of their regular CDF tasks.

Developing a KM system as an integral part of training can provide many benefits. For example, a system engineer with the potential of being a Team Leader can benefit from participating in CDF studies as an engineer and observe how the team leader handles various challenges during the study. This on-the-job training is an effective way to transfer tacit knowledge from the team leader to the system engineer

Benefit from the ESOC Experience
ESOC has made significant progress with their own KM initiative, and their know-how can be valuable for the CDF. In addition to the transfer of their tacit knowledge of KM implementation, more specific issues such as obtaining a license of their KM tools should be investigated (e.g. Logica).

Explore Incentive Systems
"…a possible incentive could be both internal and external recognition by means of
- *conference papers, interviews and/or ESA-wide internal presentations"*
- *a CDF participant (questionnaire result)*

We recommend exploring the applicability of non-financial incentive systems, such as creating opportunities for recognition of most productive contributors to the proposed KM system. These incentives can start as simple as establishing a "knowledger worker of the month" program, and incorporate other activities such as giving opportunities for presentations at workshops and conferences.

Leading By Example
"…If a team leader regularly requests team members to fill in the database, especially after solving an important problem, this would be the best change of getting valuable inputs."
- *a CDF participant (questionnaire result)*

Even though the Team Leader may not be able to manage the operational aspects of KM, s/he should still feel responsible for the proper functioning of the KM system. To this end, s/he has to see the long-term value in the KM system for the CDF, and understand that capturing knowledge is for the shared benefit of the whole CDF community. Given the resource constraints at the CDF, a logical division leadership roles should be explored between the Team Leader, System Engineers and Document Manager.

Audio/Video Knowledge Capture
This particular form of knowledge capture was not rated very highly by the CDF participants: only 7 respondents identified it as a must-have feature [AD 1] (TN1 p.74). The reasons behind this result should be investigated further before any investments are made in video capture technology.

Specialized Approach for Younger CDF Members
CDF experts who participated in multiple studies (the "veterans") are an especially important source of tacit knowledge. Their expertise is not only about their particular domain, but is also about their understanding of resolving conflicts, trade-offs and making hard decisions. Even if a well structured mentorship program is not feasible, pairing the veterans with newcomers to the CDF environment can be a useful way to transfer tacit knowledge. Given the high enthusiasm of younger CDF members for mentorship, we recommend investigating the feasibility of a CDF mentorship program.

Partnering with Other Agencies
Taking part in the ongoing KM discussions can increase the chances of success of the KM system as it will enable CDF representatives (e.g. Team Leader, Documentation Officer, etc.) to be in direct contact with their peers in other agencies, tackling similar challenges.

In particular, we recommend CDF leadership to contact the IAA Knowledge Management Working Group and actively participate in the 3rd International Conference on Knowledge Management for Aerospace (hosted by ESA) in 2010.

Objectives of the IAA working group are:

- Define the organizational and inter-organizational issues that support or inhibit knowledge sharing amongst aerospace organizations (including capturing knowledge of our key experts and aging workforce)
- Identify and recommend standards for knowledge management activities and initiatives to promote interoperability of key systems (such as lessons learned or publications)
- Create, through consensus, a position on the recommended approaches for an aerospace organization to investigate to excel at knowledge management

Dedicated Staff Members for Populating the KM System
As indicated in [AD 1] TN1 (p.50), the CDF already has an internal database of documents which can be used to populate the KM system. It is essential that this database, currently in the form of a folder-based hierarchy, should be incorporated into the KM system. This is a repetitive and time consuming task, however it can result in significant short-term benefits, as it will make the KM system relevant right from the start. It is important to note that, updating the KM system with newly generated or found documents is an ongoing task, and it should be standard practice as part of CDF sessions.

10 Conclusion

Main elements (as seen in Figure 18) for a successful introduction of a KM system within the CDF are:

- The CDF structure & participants
- Core KM Architecture & Prototype
- KM Hardware infrastructure
- KM responsible person & User Manual
- Implementation Plan

The successful knowledge capitalisation within the CDF depends on a coordinated implementation approach. Here, one has to be careful not to overload the participants by providing too many KM functions or other time consuming obstacles right from the beginning. Besides the necessary KM hardware infrastructure, the core KM program architecture is of essential value. Not all recommendations that were stated during the initial system analysis phase of the project could be implemented in the software prototype. Still, different semantic software modules such as the so-called ‘Amazon List’ should be implemented, where semantic knowledge algorithms speed up the overall search process.
Also a customized Concurrent Engineering Wikipedia (Wiki) system is a desired feature for future prototype upgrade developments. The time commitment for a growing Wiki system is significant, because full articles have to be written and interlinks between the different technical terms have to be drawn. An interweavement between different contents from the internet-based Wiki system and the CEF Wiki system is conceivable and should be examined further.

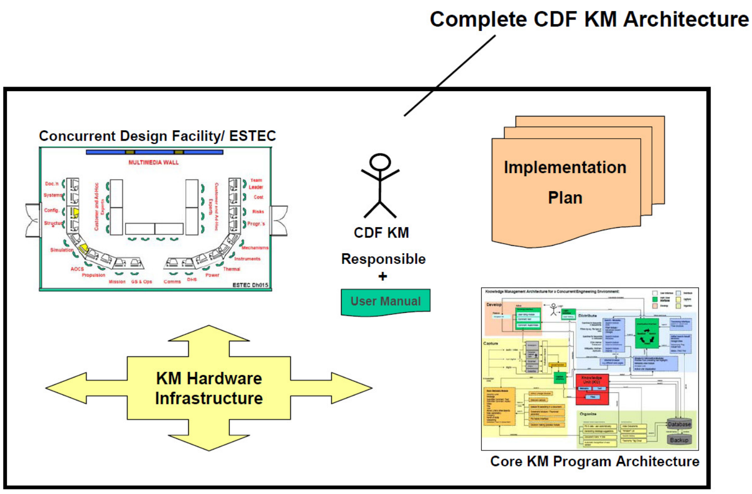


Figure 18: Main elements for a successful knowledge capitalisation within the CDF

Not only important for a successful introduction of the KM system, but furthermore essential for a sustainable maintenance of the KM system, a KM responsible person has to be determined. For this spectrum of tasks not a new CDF position has to be determined, but existing domains might be able to cover this scope of tasks. Possible domains might be various assistances towards the Team Leader position or the documentation position or even YGT positions.