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ENGINEERING DATA MANAGEMENT - A TOOL FOR TECHNICAL COORDINATION

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Abstract

This paper studies the basic motivations behind Engineering Data Management (EDM) in a decade long Large Hadron Collider (LHC) project with at least another decade's operational period at CERN. The main argument is that without strict managerial principles to control engineering work the exploitation of EDM becomes impossible. Structured and organized configuration management is the absolute prerequisite for an effective integration of design, manufacturing and installation work. EDM is seen to provide all collaborating parties of the project with a coherent and up-to-date view of the product specifications together with other relevant information, such as product's change log, responsibilities and status indicators during the product's whole life-cycle. It is argued that by combining simple and commonly accepted managerial principles with an advanced EDM system the outcome supports the main phases of product's evolution, i.e. design, assembly, operation and maintenance. The paper outlines the main tasks of the configuration management and the fundamental requirements of EDM in order to meet LHC-project's complexity, stringent budget, high quality and tight schedule constraints set by the CERN Council.

Keywords: configuration management, new product development, project management, concurrent engineering, engineering data management

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1 Introduction

The data generated during a design and engineering process shares multiple features and structures. The more complex the product and the longer the project the more important is the control of the product configuration data. Apart from the traditional drawings and CAD models this data includes various technical notes, measurement results, material properties, key parameters of the system, manufacturing and assembly instructions, organizational relations (i.e. responsibilities) and chronological change history of each component of the product. The role of Engineering Data Management (EDM) is to store and provide a user-friendly access to this data during the product's life-cycle according to certain predefined control rules. These rules are defined by the configuration management team of the LHC-project in collaboration with the key players of the project.

The operational environment of a project based on development and manufacturing, consists of several sub-projects with different functions and status. At a particular time each sub-project can be in a different phase: under development, performing pilot tests, in search for specification, manufacturing, assembly, etc. with all the related changes. This kind of multi-project environment is well known to most major projects, which have proven that configuration management plays the crucial role in the success of the project. The situation in a large-scale project such as the new Large Hadron Collider (LHC) at CERN[*], which, when finished and operational, will be the result of numerous multiple and parallel sub-projects intertwined with each other through the overall configuration and project plan of the system, is no different.

The development and construction of the LHC-system is a project similar in duration and budget size to a huge off-shore oil drilling platform. Yet, distinct from the oil rig, the new accelerator requires several new technological skills and, thus, the size in technological terms is much greater. This means that the applicability of previous engineering work around high energy physics devices is limited and therefore the immense design work and technological challenges to be tackled emphasize the importance of configuration management. The long duration of the whole LHC-project, including the operational period, is close to a quarter century. To maintain a *coherent view* of the system and its evolution during this period, when the human resources will change significantly, the role of EDM is that much more important.

The rest of this paper is organized in the following way. First, the basic underlying motivations for the use of EDM together with strict configuration management are underlined. This discussion also includes a brief description of the main concepts used in the field. Then we proceed to view each aspect separately, first the principles of successful configuration management and then the basic functions of EDM. Finally, conclusions are drawn together with the main principles to gain synergy from configuration management and Engineering Data Management.

[*] CERN, the European Laboratory for Particle Physics, has its headquarters in Geneva. At present, its Member States are Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland and the United Kingdom. Israel, the Russian Federation, Turkey, Yugoslavia (status suspended after the UN embargo, June 1992), the European Commission and Unesco have observer status.

2 Concepts and motivations

Advanced and competitive manufacturing units organize their production facilities in such a manner that the product can be processed in the shortest production throughput time, with minimum capital invested and according to the quality specified. To succeed in this the companies tend to place the product itself, rather than the process, in the very core of the manufacturing. The traditional process-oriented thinking is ruled out [1] and the product focused approach is now prevailing. Product with its breakdown or *bill-of-material* is the fundamental data structure which affects to all operational activities within manufacturing and design operations in a company. Correspondingly, in a one-of-kind project the product and its structure forms the starting point for the other activities, i.e. project organization formation, resource allocation, work breakdown and planning [2]. **The control of the product data, including its change history during product's life-cycle is the task of configuration management**.

Before going any further, some of the main concepts should be clarified. Product configuration displays at the time *t* a snap-shot of the design status of the product (components, equipment, parts, etc.). A version is a frozen configuration with complete technical documentation including its manufacturing instructions, specifications, technical notes, drawings, test results and responsible people. Subsequent versions are numbered and the control of their integrity is called version handling. The overall status of a product configuration is compiled from specifications of its components, equipment and parts with their respective status. This status may have several values, depending on the adapted configuration management procedures. Basically the status of a certain specification could be closed/fixed/frozen, i.e. it has been accepted and can be used, but not changed, or it may be private, i.e. under development. Other values may be assigned also, depending on the situation [3]:

- *subject to changes*, meaning that the specification cannot be processed, issued or redeveloped at that moment and therefore the previous and verified version of the specification should be used;
- *recently changed*, indicates that the specification has undergone changes which have been accepted by the configuration team, yet the changes should be studied before the specification is used;
- *pending*, implies that the specification has been changed and waiting for verification, thus, the changes may be studied but not to be used;
- *verified*, the specification is approved and its functionality and compliancy with the overall product specification is verified, thus the specification is ready to be used.

What are the motivations for configuration management? Essentially, the task of the configuration management is in the control of the flow of engineering work/information/data and to provide the project with configuration related services. The development process forms a kind of cycle during which the previous version is refined to the next version or generation of the product. In a completely one-of-a-kind product delivery the development cycle starts from the functional specifications and ends to the final assembly. Yet this process may share various versions of the end product; e.g. the current version of the LHC-system is 3.0 to be checked and the very first version existed well before the final approval of the system by the CERN Council. The following picture

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(Fig. 1) displays schematically the process of the design and engineering work from product's configuration point of view.

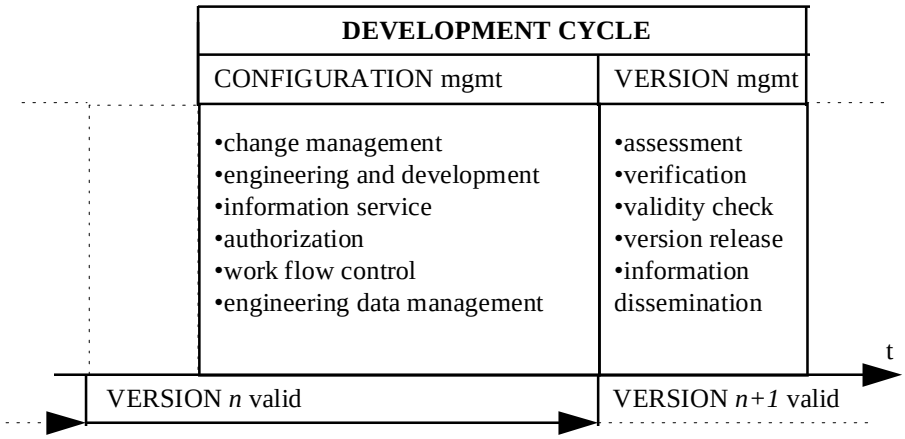

Figure 1. The evolutionary process of the development of the product configuration.

To summarize, in an environment with multiple projects aiming to produce a complex product the need for configuration management with a supporting EDM tool is justified along with the following statements:

- Several empirical studies (e.g. [4]) in project oriented manufacturing industries indicate that most, even up to 90%, of the specification changes originate in-house. Processing these changes is the cause of most of the problems, which tend to emerge during manufacturing, assembly and delivery phases, or even as late as the operational phase of the product. **The costs of correcting the mistakes will increase exponentially the later in the process they are fixed**. The very essence of configuration management is to control the specification changes in such a manner that the overall configuration maintains its functionality and correspondence with the needs.
- The underlying spirit of engineering work is to continuously develop new and advanced solutions both to old and new technical problems. This appreciated activity establishes the very core of innovations. Without control, the situation may lead to continuous engineering syndrome, when individual whims overtake the original objectives. Apart from controlling the specification changes, configuration management must control also the correspondence with the original plan. In addition configuration management is in charge to provide the organization with a flexible communication and information retrieval interface between system versions *n* to *n+1*.
- The project organization must share a common understanding of the main parameters and design principles of the product. In order to achieve this, configuration management must provide all project collaborators with an easily accessible source of information containing the current understanding of the system configuration (key parameters, measures and standards of the system, status of the various component configurations, quality requirements, responsible people, etc.).
- The documentation of product's change history is vital in long term projects, where the organization is subject to changes. Configuration management is

responsible for systematically recording and archiving all the changes, in order to provide the necessary information for the later steps of the project (commissioning, operation, maintenance). This is vital for CERN, where the age composition, with accelerating retirement rate, necessitates detailed archiving of all engineering related data and information.

In general terms configuration management, when properly implemented and focused on the control of configuration data, will shorten time to market, lower design costs, provide better quality, reduce manufacturing costs and provide means for lifelong product maintenance.

3 Configuration management - principles

Configuration management differs from traditional project, product and production management in its focus and scope. The essential difference is in the status of the configuration management team in the organization. The team provides the organization with *services* concerning the product data management, control and distribution. They mediate between various groups responsible for various systems by collecting, analyzing and keeping them informed of all changes concerning specifications, key parameters and other related modifications related to the product information. With respect to the motivations for better product data management the following practical configuration management principles can be stated to achieve high performance technical coordination in the project:

- Configuration management is a service unit within the project, whose customers are all the other departments that deal with product data.
- The main task of configuration management is to control, archive, structure and disseminate product data in such fashion that the information is verified, consistent and up-to-date.
- Configuration management acts as an interface between engineers and the product itself by providing the structured communication means to disseminate and interact around the product configuration.
- From manufacturing point of view the configuration management team ensures that each specification entering production is in accordance with the overall configuration of the project; by doing this the ground is prepared for faster production throughput times with fewer interruptions.
- For product development the configuration management team provides the latest information concerning the project and also interactively records design changes and their influence on the other sub-projects.

In practice these principles transfer into the following actions when considering a large-scale project with long duration:

1. Collect the product expertise and experience of the organization into a configuration team, i.e. assign responsible *configurator* for each major system/product of the project.
2. Provide the team with the relevant means to perform its task.

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3. Define protocols, preferably simple and visual ones, to process changes in product specifications.
4. Establish frequent meetings with the configurators to study each and every product specification change emerging during the development cycle.
5. Build an information network.
6. Provide the organization and other collaborators of the project with an easy-to-use media to transfer configuration related information.
7. Define, identify, gather and manage configuration related information into a logically centralized repository.
8. Document every change, with a reference to the original problem, responsible people and implications to the configuration.
9. Store, verify, release and disseminate product versions and maintain their integrity with customer needs.

In this respect the configuration management maintains the coherence of the product, which comprises all product related data, including whenever possible the product related tacit knowledge. Configuration management acts with the objective of preserving the project from contradictions and inconsistencies, yet, to adjust to changed circumstances.

4 Engineering Data Management Systems

In recent years, there has been a growing awareness that although computer-aided design technology and the the widespread use of computer applications to prepare engineering documents were accomplishing their objective of improving the productivity of individual engineers and designers, they were not doing much to improve the productivity of the overall enterprise. To accomplish this latter objective better methods were needed to share information between members of the design teams and other groups involved in the product life cycle[5].

Engineering Data Management (EDM) is a set of techniques and tools to organize, control and distribute all product related data during a product's life cycle (Fig. 2). They have been developed to reduce the development cycle of new products while maintaining control of the data and distributing it automatically to the people who need it when they need it.

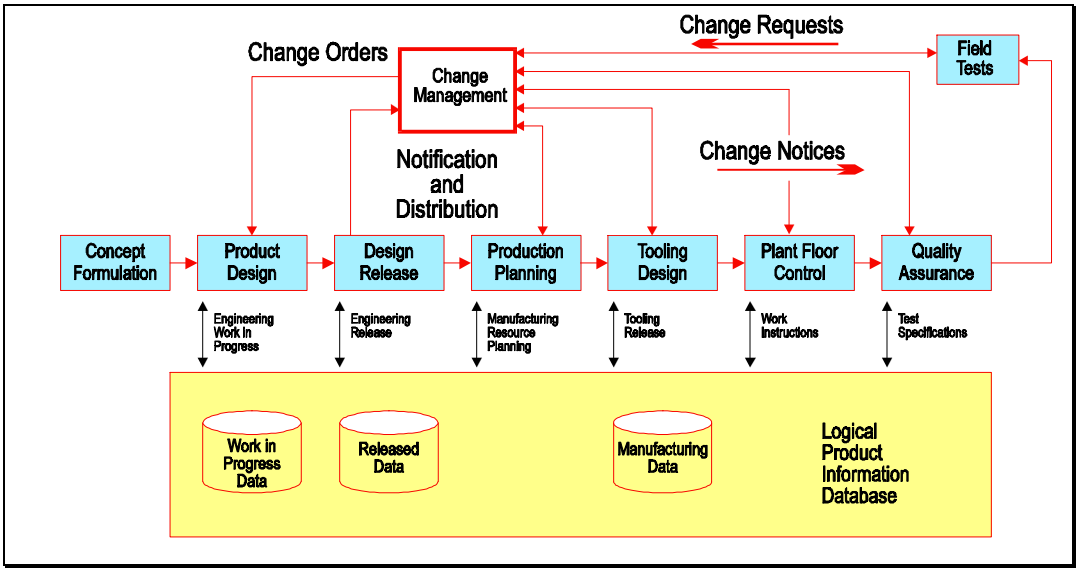

Figure 2. EDM's Role in the Product Life Cycle [5].

One of the prime motivation for EDM is the sheer volume and diversity of engineering data[6]. An exhaustive description of a part or an assembly requires a huge amount of documentation. The more complex the item, the more diverse is the documentation. The following information topics could easily be listed under the heading of the complete set of the engineering documentation of a part or an assembly:

- drawings,
- CAD models,
- part lists,
- structural analysis models,
- spread sheets,
- technical notes,
- measurements results,
- manufacturing instructions,
- assembly instructions,
- organizational relations,
- material properties,
- schematics,
- applicable standards,
- photos and shaded images.

In the near future multimedia documents, e.g. audio and video sequences, will be added to the list.

The Role of Engineering Data Management

As multiple systems are used to design, analyze and manufacture a product throughout the product life cycle, the different pieces of product data are created by a variety of tools and stored in files or databases which reside on multiple electronic media. This means that the full description of a part or assembly includes a large number of computer files. The very essence of EDM is to manipulate this data in a coherent way by establishing and

maintaining links between the documents, including their various versions, and the parts and assemblies to which they are related to. As this data is constantly being modified and accessed by various users, the basic functions required of EDM must include:

Release Management: provides a set of functions similar to a library card catalog:

- allowing users to register a set of data (files) as a single dataset, enter pertinent metadata (attribute data) about the dataset,
- check it out for modification,
- prevent other users from checking out the same dataset, and check it in after modification is complete,
- automatically creating a new version of the dataset after each check-in,
- allowing authorised users to review the dataset for approval before release according to a pre-defined release procedure.

Change Management: provides a set of function to control the change of a registered dataset:

- defining the release procedures for various types of data,
- allowing users to initiate change request against certain datasets, issue change orders in response to change request, and automatically generate change notices after the change is complete.

Notification and Distribution: provides a set of function to send messages and/or datasets to users upon the occurence of defined events:

- creating distribution lists,
- defining events,
- automatically notifying the sender when the messages and/or datasets are received.

Administration: provides a set of functions similar to database administration functions provided by a conventionnal database management system:

- assigning user access privileges,
- providing archiving/restoration facilities,
- allowing automatic back-up/recovery.

Product Breakdown and Configuration Management: provides a set of functions to maintain various configurations of the product definition data:

- creating and editing the product breakdown,
- associating datasets to parts and sub-assemblies of a given assembly,
- navigating the product breakdown and associated datasets.

The basic concept of EDM to manage datasets created by the various tools (Fig. 3) is to create a metadata layer, i.e. a layer containing pointers and summary information for the datasets being managed. The metadata itself is usually maintained in a database and managed by a DBMS. This is similar to the use of library card catalogs.

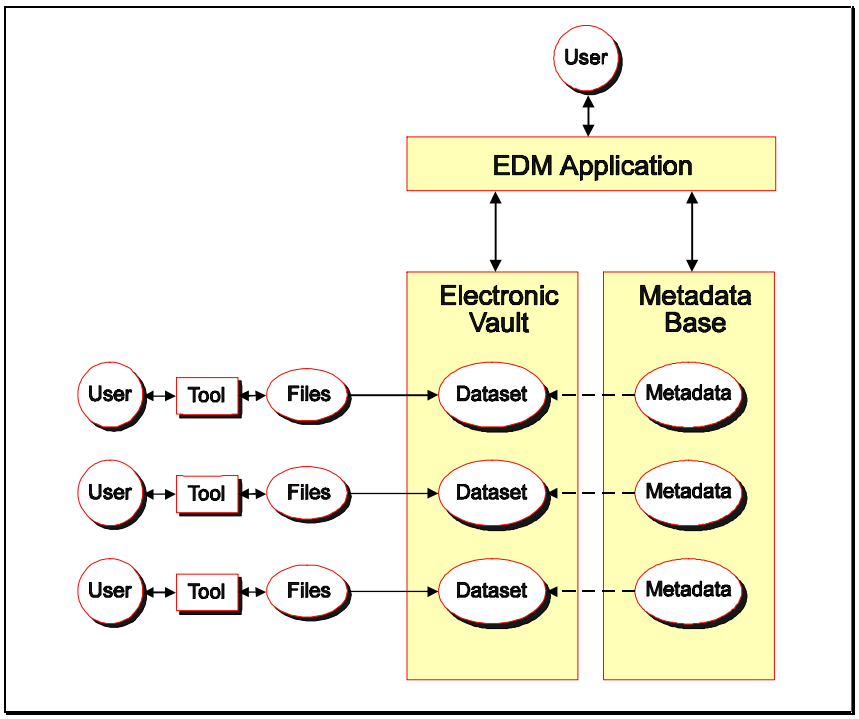

Figure 3. EDM Basic Concept [5].

Other important issues

User Interface

The undisputed number one hurdle to a successful use of EDM in an organization is "Cultural Change"[7]. Cultural Change is caused by the introduction of new ways of doing things. Implementation of such a change may face some resistance from the end users' side. The EDM team can greatly reduce the impact of cultural change by presenting tasks and the process to complete the task to the user in a familiar manner. Newly required tasks and processes should be easy to perform.

Communication

Complex products are often engineered and manufactured in a distributed manner. This fact emphasizes the system's capability to provide certain communication services to the organization. From configuration management point of view these services should include:

- basic means for technical communication between various engineering teams;
- access to the communication network, e.g. Internet and the file transfer protocols. From CERN's point of view access to the World-Wide Web is of course essential;
- communication follow-up services to provide information for the project management, i.e. capability to study how the communication frequencies have evolved and how individual collaborators have utilized the system.

Standards

While describing Product Data Management we have focused on configuration management aspects. That is only part of the story. An organization's engineering data represents its collective know-how. As such it is a major asset and should be protected and secured for its entire useful life, in the case of LHC two or more decades. Over such a

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long period it is impossible to guess what will become of the tools we use today to create engineering documents. Consequently engineering data should be stored as far as possible in recognized standard formats, rather than in the proprietary formats of the creation tools. Standards are also essential to enable electronic communication of data and documents inside and outside the organization with other Document Management System. Standard formats exists for some documents types at least, ISO STEP, SGML, HTML, CCITT to name but a few. In some cases the use of de-facto standards, e.g. Postscript, is another possibility. **It will be the role of EDM to promote the use of selected standards thereby insuring the perennity of engineering information.**

Introducing EDM for the LHC Accelerator Project

All of the above listed requirements promote the role of an EDM as a multiple linking system between people, documents, products and time together with the capability to assign various status indicators on various items and to establish rules on how they are controlled.

Introducing an Engineering Data Management solution can be done in a number of ways: selecting and buying a ready-made EDM System from a vendor, selecting and adapting a vendor's system to the specific needs of the organization, or developing an in-house solution. Whatever the choice, the successful introduction of EDM in an enterprise is a complex task involving people and technology. Key issues and preparatory activities are well documented[6][8]:

- secure the support of top management,
- create a cross-functionnal team of configurators from all groups involved to define requirements and select a solution,
- identify a short-list of possible EDM systems vendors, evaluate the products, suppliers and references,
- plan for short-term, mid-term and long term,
- test the chosen solution in a pilot project,
- implement EDM in stages, starting with areas where benefits will appear quickly.

The active participation of end-users, mainly "configurators", at all stages of the EDM selection and introduction process is essential.

5 Conclusions

The use of EDM is essentially an issue concerning the project's own capability to control specification changes and the work/information/data flow during engineering and manufacturing processes. EDM provides tools to the existing management, i.e. it does not provide the management. Thus, a successful implementation of EDM requires first the organization's agreement on the managerial issues concerning the processes around the product configuration and its evolution. The overall success in configuration management stems from administrative skills and routines supported with a sophisticated EDM system. It should be emphasized here that, although the case behind is that of the LHC, the

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message of the paper is applicable in any multi-project design and manufacturing environment.

As the LHC-project has already commenced from the beginning of 1995 the issues related to configuration management must be settled. A configuration management team should be established and the diverse requirements for EDM must be specified soon. The design and engineering work is already active and progressing rapidly, thus the engineering data is also accumulating. Configuration management is not a hindrance for the normal product development or project activity. It is merely a previously nonexistent addendum to the project organization, and its role should be seen more as a service provider to the rest of the project organization. Verified and organization-wide coherent understanding of the product configuration provides the best results with fewer mistakes.

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