RESEARCH REPORT

VTT-R-00800-15

SIMPRO

State of the art in modelling and simulation

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Confidentiality: Public

Report's title	
State of the art in modelling and simulation	
Customer, contact person, address Tekes/Matti Säynätjoki Kyllikinportti 2, P.O. Box 69, FI-00101 Helsinki, FINLAND	**Order reference** Tekes: 40204/12
Project name Computational methods in mechanical engineering product development	**Project number/Short name** 100553/SIMPRO
Author(s) Romain Sibois and Ali Muhammad	**Pages** 20
Keywords Modelling, Simulation, Data management, PLM, SLM	**Report identification code** VTT-R-00800-15

Summary

Nowadays companies are required to provide products with innovative and powerful features, and this includes more and more challenges in the development of those products. Computational methods, including modelling and simulation, have been identified as one of the key factors for success both in research and product development. Integration of software tools and management of digital models and computational data has been, and still is, a bottleneck in the wide application of computational methods. There is clear trend of research in the area of data, simulation and knowledge management. Research institutes have been already working on this topic for years, but many issues are still unsolved.

The report is a study of the current state of the art of the data management in modelling and simulation. The report is prepared considering the current state of the art and the needs of Finnish industry. This document aims to provide a better understanding of the major issues currently faced in the Finnish industry concerning modelling and simulation, and in order to be able to propose ways of improvement in the following phase of the SIMPRO project. The aim is to continue the study of these subjects according to experiences of the partners, problems and needs. Some clear aspects have to be studied in more detail especially concerning the existing software application tools, both commercial and open source. This requires getting familiar with those tools and utilising them on some case studies, which may be provided directly from the partners, in order to highlight the real issues and gaps that might be problematic for the users.

Confidentiality	Public

Tampere 15.9.2015

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Distribution (customer and VTT)

Tekes/Matti Säynätjoki, 1 original
VTT/archive, 1 original

Contents

1. Introduction

Computational methods, including modelling and simulation, have been identified as one of the key factors for success both in research and product development [1] [2] [3]. However, software and data integration, and management of the modelling as well as the computations' results data has been, and still is, a bottleneck in the wide application of computational methods.

Nowadays companies are required to provide products with innovative and powerful features, and this includes more and more challenges in the development of those products. One of the most faced issues is the increasing complexity of products, as integrating functionalities from various disciplines is a source of innovation. In parallel, companies are looking for decreasing development costs and shortening the time-to-market. Digital tools are considered essential during the design process and are becoming more and more common within the whole product lifecycle. This means that developing more complex systems, decreasing the number of physical prototypes while increasing the use of digital tools leads to increase likewise the amount and diversity of data. A multitude of data is then generated across the different teams, sometimes even spread worldwide, and the transfer and exchange of the data is of primary importance [1]. Often the data of different teams and tools is rather isolated from each other since the tools used are generally specialised. But by reducing the amount of physical prototypes, simulations are contrariwise increasing, especially multidiscipline simulations. This is particularly true within the current trend in the industry, the simulation-based product development, which consists of targeting the design process around simulations. Consequently, those simulations require collecting data from various fields, in various formats, and therefore efficient data management process is nowadays required by companies.

The report is organised as follows. In section 2, we present the goals of this report. In the first part of the section 3, we define important terms and notions which will be widely used among this task of the SIMPRO project. In addition, we present a model of computational process which will help to understand better the concept and the needs of the industry. Then, in section 4 we focus on the current state of the art in the research area, throughout academic point of view followed by European and international projects. Finally, in section 5 we will concentrate our research on the state of the art in the industry, taking into consideration the difference between small-medium and large sized companies.

1.1 About the SIMPRO project

Computational methods in mechanical engineering product development – SIMPRO is a jointly funded Tekes (the Finnish Funding Agency for Technology and Innovation) research project that focuses on the application of computational methods in the product development of mechanical systems and products. The project has the following points of view to the topic: 1) high-performance computing in mechanical engineering, 2) optimisation, design studies and analyses, 3) requirement- and customer-based product development, and 4) modelling and results data management. The SIMPRO project is categorised by Tekes as *public research networked with companies*.

2. Objectives

The purpose of this work is to study the current state of the art of the data management in modelling and simulation. The report is prepared considering the current state of the art and the needs of Finnish industry. This document aims to answer some key questions for a better understanding of the major issues currently faced in the Finnish industry, and in order to be able to propose ways of improvement in the following phases of this project. Some of the key questions can be summarised as follow:

- What are the current research trends?
- Which processes, approaches and tools are commonly used among industry?
- What are the needs and issues among the industry?
- What are the particularities of small medium-sized companies for using data management tools?

3. Definitions and background

3.1 Terms and concepts

In this chapter, we define terms and concepts that are important in the field of data management. Technical terms as well as more common notions are referenced below and appropriate data management oriented definitions are given. Consequently, hereafter all along the project, it will aim to avoid misunderstandings but rather understand better the concepts and their differences. For instance, are the product lifecycle management systems managing data, information or knowledge? Or even, what is the difference between product and simulation lifecycle management? This chapter aims to answer this kind of questions.

Data, information, and knowledge:

The definition of knowledge may vary among fields [5]. Apurva Anand et al. collected various definitions of knowledge according to a wide range of expertise areas. After selected definitions relevant to Knowledge Management (KM), they suggested the following definitions: “knowledge is considered to be information that has been processed in some meaningful ways” while “information is considered to be data that has been processed in some meaningful ways” while “data are considered to be unprocessed raw representations of reality”.

Knowledge management (KM):

When talking about management, many concepts have to be taken into account: creating, gathering, organising, diffusion, use and exploitation. KM is a notion of dissociating knowledge from the individuals but encourage spreading and providing this knowledge around stakeholders as an organisational resource. One of the main objectives of KM is to facilitate the circulation of know-how combined with basic information or processed information through the organisation for a smoother collaboration, a better efficiency, to expend skills around the personnel etc. The Engineering Knowledge Management tool is a design and simulation framework, which is aimed at hosting all simulation data, processes, and tools while maintaining a tight connection between them. [5]

Data management:

Data management consists of an administrative process by which the required data is acquired, validated, stored, protected, processed and shared. It ensures the accessibility, reliability and traceability to satisfy the needs of the data users.

Simulation-based product development (or simulation-based engineering science, SBES):

SBES is the discipline that provides the scientific and mathematical basis for the simulation of multi-scale engineered systems, from nano to macroscopic scales. SBES fuses the knowledge and techniques of the traditional engineering fields (e.g. mechanical, electrical and nuclear) with the knowledge of more theoretical fields such as computer science, mathematics and the physical and social sciences. It results to a better prediction and optimisation of the developed systems from the early design phases. [1]

In a simulation-based product development process, computational methods (modelling, simulations and analyses) are done before detailed design of the system and its components. I.e., simulation drives the development process and the objective is to use the information and understanding gathered with the simulations to design the system, subsystem, or component right from the very beginning. While the design of the system proceeds, the simulation model (the virtual prototype of the design) evolves and all the new choices are tested with the virtual prototype before detailed design. The utilisation of simulation-based product development process requires fluent data flow in the process (data flow between software applications and data management systems) and well-defined processes (e.g. utilisation of *Systems Engineering* approach, ISO 15288).

Product data management (PDM):

PDM is the predecessor of product lifecycle management (PLM) and it provides functionalities that manage and publish product data [6]. PDM aims at managing the materials data and address scheduling issues [8]. PDM has been used for managing distributed product development data in the product process, and then it has evolved from document management systems to general data management systems with interfaces to other information systems involved in the product process. [8]. Dassault Systèmes, which has developed the commonly used PLM tool called Enovia, defines PDM as the business function within the PLM that is responsible for the creation, management and publication of product data. It includes engineering data such as CAD models, drawings and their associated documents. [10]

Product lifecycle management system (PLM):

PLM evolved from the nineties' PDM approach. PLM is a business strategy for creating a product-centric environment. Rooted in computer aided design (CAD) and product data management (PDM) systems, PLM is aimed at connecting various product stakeholders over entire lifecycle of the product from the concept phase to retirement. As a technology solution, it establishes a set of tools and technologies that provide a shared platform for collaboration among product stakeholders and streamlines the flow of information along the stages of the product lifecycle [11]. Dassault Systèmes resumes the PLM definition of F. Ameri, and supplements it: by including all actors (company departments, business partners, suppliers, customers…), PLM enables this entire network to operate as a single entity to conceptualise, design, build and support products. [10]

Simulation lifecycle management system (SLM):

SLM complements PLM by associating behavioural simulation data and processes with the digital mock-up (DMU); in essence offering behavioural-digital mock-up (B-DMU). A major objective of SLM is to transform simulation from a specialty operation to an enterprise product development enabler that spans many segments of the product lifecycle. To do this, SLM should provide technology in four fundamental areas:

- Simulation and test data management
- Simulation and test process management
- Decision support
- Enterprise collaboration

The most profound impact of SLM is that the approach can be an enabler for simulation-driven design in which analysis becomes a fundamental part of product development from early conceptual stages to performance optimisation and detailed design. This elevates simulation from a design validation tool to a decision-support solution in developing innovative product designs that may not otherwise be intuitively obvious or practical to study in any other way. [12]

Lifecycle assessment (LCA):

LCA involves the evaluation of some aspects of a product system through all stages of its lifecycle. Sometimes it is also called “lifecycle analysis” or “lifecycle approach”. It represents a rapidly emerging family of tools and techniques designed to help in environmental management and sustainable development [13]. LCA starts from the conception of product and follows through design and development, production, utilization, customer support and disposal or recycling at the end of life. Parameters such as material cost, environmental impact, energy consumption, labour, etc. can be analysed at each stage of product lifecycle. Some of the main sub-disciplines of LCA are:

- Lifecycle engineering (LCE): LCE is an effective approach to improve the design of products and reduce design changes and time to market. The principal unique aspect of lifecycle engineering is that the complete lifecycle of the product is kept in consideration and treated in each phase of the product development. LCE goes beyond the life of the product itself and simultaneously considers the issues of the manufacturing process and the product service systems. [13]
- Lifecycle costing (LCC): The lifecycle cost of an item is the sum of all funds expended in support of the item from its conception and fabrication through its operation to the end of its useful life. [15]
- Lifecycle simulation (LCS): LCS simulates circulation of products in the markets over the entire lifetime of the products with a discrete event simulation technique. It enables to evaluate stochastic performances from environmental (energy and resource consumption, emission), economic (cost, revenue and profit) and process specific aspects (time to delivery for supply chain, volume collected products for remanufacturing) [16]. In other terms, LCS combines the three previous aspects of the LC (LCA, LCE and LCC).

Traceability:

Traceability is the ability to describe and follow the life of simulation models, documents and other kind of data from their origins. It also includes the mean for formulating the relations between those data [16]. The IEEE standard (ISO/IEC/IEEE 15288:2015) defines traceability as: “degree to which a relationship can be established between two or more products of the development process”. The traceability is nowadays widely used among the research community and within the industry, which takes place in the product lifecycle management although it is often included in PLM tools.

Data integration:

Data integration consists of combining data from different sources and providing to the users a unified/standardised view of these data. It comprises the practices, architectural techniques and tools for achieving the consistent access and delivery of data across the enterprise to meet the data requirements of all applications and processes. In other terms, it ensures the data to be preserved, reused and integrated with other data sets for creating a more useful and robust data sets.

Simulation integration:

Simulation integration is the notion of providing an easy transition between the phases of the lifecycle of a product [17]. For instance, providing a transition between the design phase in which preliminary analysis are performed to the testing phase reusing the analysis output as input for the off-line simulations. Simulation integration also includes the notion of reusing simulation modules and integrates different simulation tools for multidisciplinary simulation, parallel/distributed computing with Intra/Internet, and Web-based modelling and model management. [18]

3.2 Illustration of a computational process

This section presents a simulation-based design framework for developing a complex system. The process is centralised around a data and knowledge management platform whereby the data flow is circulating between simulations.

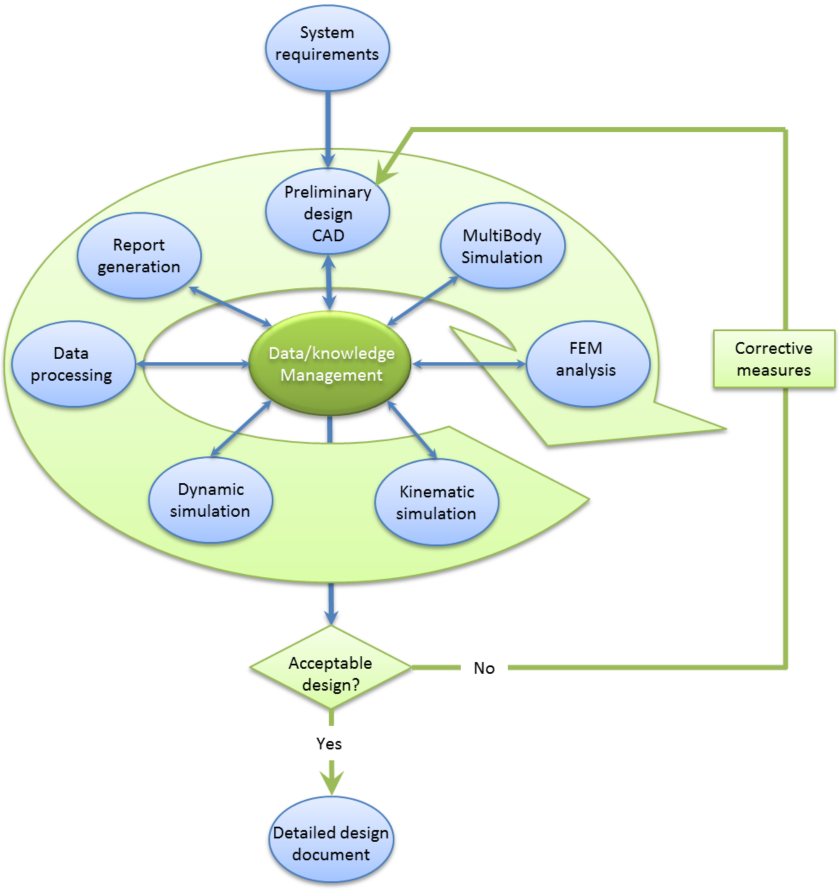

Figure 1: General view of a simulation-based product development process.

The flowchart presented in Figure 1 illustrates a general view of the use of iterative computational methods in a simulation-based product development process. It starts from the preliminary design which is based on the system requirements. The design engineer uses the requirements as input to perform the modelling activity and produce as output the early CAD models. Those models are then used as the main base for the simulations centralised around a data and knowledge management platform, which may be considered as the mean of communication between all the different tools needed. This illustration must be considered as a general view because it shows only a single layer of the otherwise multi-layered process. The number of layers is defined by the number of disciplines that is involved in the developed system. For instance, the development process of a simple passive mechanical system will have only one layer, but for a more complex system, which involves few disciplines such as mechanical, hydraulic, control system, electronic, etc. will have as many layers as the number of disciplines. Those layers are interconnected through the data and knowledge management platform which centralises the simulation input data and collects and stores the simulation outputs. In the case of multi-layer process, the management platform can be seen as spherical, around which multi-disciplines simulations gravitate. The assessment activity is always running while the simulations are performed and until the design satisfy the requirements.

The flowchart gives a good representation of the amount of data that have to be managed especially when considering a multi-layer process. By managing data, it includes collecting, storing, versioning, standardising and retrieving data. In a company, each simulation may be performed on different computers, by different persons, within different teams, and using different methods. Therefore, the data and knowledge platform can be considered as the central point of the simulation-based process and it is on which there is a clear interest of research.

4. State of the art

4.1 Research trends

Model-based system engineering (MBSE) methodology is used for supporting the modelling activities. The methodology emphasises the use of models for describing the design instead of documents simplifying the system architectural analyses. P. Graignic et al. [20] proposed a software framework based on a data model that manages complex system structure and focus on three levels of interaction. The first level considers the interaction between components simulation models, the second considers multi-level behaviours and the third interaction is between various domains. While talking about complex systems, one of the challenges is to properly manage the amount of data produced within the design process.

Simantics is an approach using semantic database system and an interactive software application framework [20]. It is a software development platform which enables to create new applications, but is not considering as an end-user application. The idea is to offer a unified user interface for modelling and simulation software applications and provide a common database for all the relevant data [22]. The database utilises semantic data representation approach, which is very suitable for simulation data management.

The data exchange interfaces have to be coded between the Simantics platform and external tools (such as finite element analysis or multibody system simulation tools). An approach has been developed to unify the process to add new interfaces and would make it easier from the external software application integration point of view [22; 23].

This approach enables to store knowledge of the domain of interest together with the modelling data. One of the general problems is the matching of concepts between software applications [24]. For instance in MSC Adams, there is a modelling element called “marker” (which is basically a local coordinate system used for defining joints and forces). In the Modelica MBS library, there is no concept “marker”, but the definitions are done using connectors and their meaning slightly differs from “markers”. This means that transforming an MBS model done with MSC Adams to a Modelica tool is not straightforward, but some data transformations are needed. In some cases, these transformations may not be unique and this is especially a problem if we expect to have automatic model conversion between software applications.

The CAD software CATIA V5, associated with the virtual product data management software ENOVIA and developed by Dassault Systèmes, has been selected by ITER as their CAE tools. The software applications are also widely used in automotive, aeronautic and ship building industries. CATIA is mainly used for mechanical and infrastructure design. In large-scale projects, such as ITER, an extensive amount of components are required to be designed by a large number of globally distributed organisations taking part in the design process. Additionally, considering the long time-scale of the project, it is of utmost importance to use advanced collaborative CAD tools to support the designers. For instance, it is of primary importance to reduce the risk of mistakenly use older data version rather than the latest one [25]. To manage such a large scale development which is distributed geographically and in time, ITER has adopted a well-defined data management process. Each component of the plant holds a unique identifier in the database along with attributes such as location of the component in the plant, subassembly that it belongs to, reversion, etc. [26]

Concerning the document management tool, ITER is using since 2004 an open source content management framework Zope. It has been considered that the main advantage of using such tools is that it is relatively easy to configure and reconfigure. The ITER Document Management system (IDM) has some advanced features, for example a powerful search capability among Word and PDF documents, it is consider as easy and intuitive to use, it includes electronic signature, versioning and traceability systems, etc. For safety reasons, the transfer of data is encrypted using the standard https protocol. The European Fusion Development Agency EFDA has its own section in IDM. [27]

4.2 Industrial trends

The U.S. Department of Energy's (DOE) presented an Advanced Process Engineering Co-simulator (APECS) for high-fidelity design, analysis and optimisation of energy plants [27]. They stated that continued progress in co-simulation technology will have profound positive impacts on the design and optimisation of high-efficiency, near zero emission fossil energy systems. The APECS tool is innovative software for providing efficient platform for model-based decision making within the product design process. This technology has the advantage to use commercial simulation tools which are coupled together by using open source based software. While using co-simulations technology, it is obviously necessary to deal with various data resulting from different simulation software applications. In their approach they store initial data and simulation outputs in a database that operates using the ANSYS Engineering Knowledge Manager (EKM) tool. One of the advantages of the APECS using EKM technology is that the system deals with different tools, which are not basically designed to cooperate between each other. The EKM, based on open source software technology coupling simulation software, enables engineers to design and simulate using software already in use within the company, basically on which engineers have achieved a certain advanced level of knowledge. This technology seems to be an appropriate solution for SMEs in the area of design and simulations. Additionally, the APECS technology can allow a process engineer to adjust his strategy in order to allow a certain trade-off between the speed and the accuracy while performing simulations. For example, it allows using networking simulation systems in order to execute parallel and distributed simulations on different computers within the company.

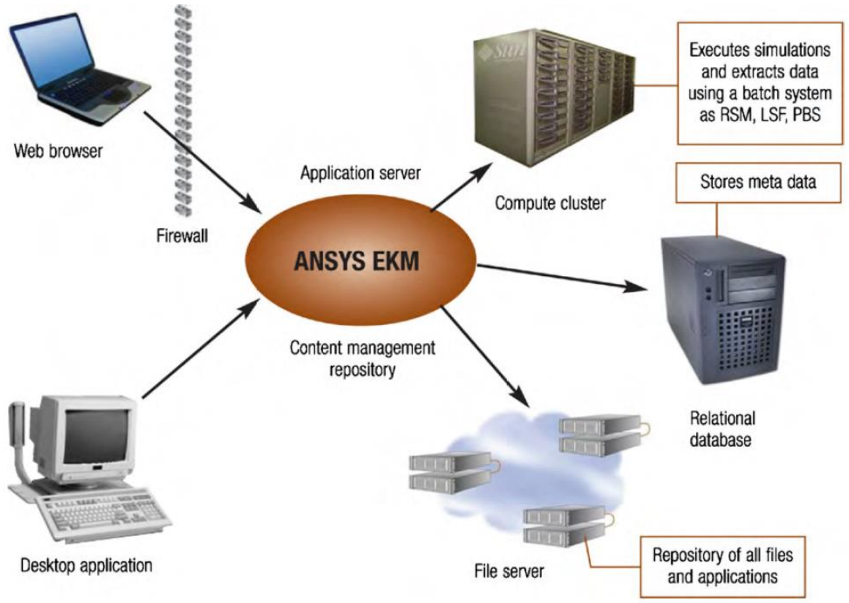

Figure 2: ANSYS® Engineering Knowledge Manager Environment [27].

Today in the industry, limits occur in the management of the product complexity and with the exploitation of the CAD and CAE tools. A better integration of simulation within the design process is required, and a key requirement is to improve the management of complex systems information. Models are validated with regards to their intended use, which means that rough models are enough for some simulations whereas detailed models are required for fine simulations [20]. Multi-physics simulations (between different domains such as aerodynamic and mechanical or fluid dynamics and thermal activities) are becoming more and more common in the industry. This increase significantly the amount and the variety of data that have to be manage for an appropriate and efficient use.

Simulation-based design is based on the design analysis integration concept, and defines simulation as the core activity to validate the design studies at each step of the design process. The environment which manages such a method is called Simulation Environment for Engineering Design.

In the case of Finite Element Analysis (FEA), both in research and in industry, there is an intense flow of data resulting from FEA especially during the design process of mechanical systems. Therefore, it is a key requirement to ensure that data is used in an efficient way right after the simulation as well as later on for further design modifications or any kind of postponed decision making. It is important to differentiate FEA resulting data to other design outputs such as CAD models, due to the complexity and range of information including in the output of a finite element analysis. For example, it is hardly possible to convert a FEA model to any common standard formats without losing any information. Most of the simulations are computed according to the intended use of the model for a given time but might always be used later for any design modifications or as inputs for advanced simulations. Consequently for an efficient use during the design process, it is important to study an efficient way of storing and the capacity of reusing such specific data in a non-processed format. For instance, one type of data can be used for various simulations and at a different time within the design process, and can also be used by management for analysis and optimization of higher level processes. Especially for smaller companies, it is difficult to utilise only one type of standardised tool which deal only with one type of standardised format. One of the expectations in the industry, especially concerning SMEs, shows a real interest in the use of similar tools but with an appropriate interoperability.

Traceability is currently an important issue faced in the industry. As said earlier, various form of data is created all along the product lifecycle, and between the first modelling phase of the product to its disposal, several years may have passed. At any time of the lifecycle, some data may be needed for e.g. optimisation or modification and have to be recovered from the archives. The versioning of the data has to be taken into account in order to provide to the user the certification of using the latest version of the document or other simulations.

4.3 Commercial tools

DOORS by IBM is a tool for requirements engineering and it is a well-known in the industry. The software tool helps for the optimisation of requirements communication, collaboration and verification within the different teams. Requirements are linked to design items and test cases which allow an appropriate traceability [29]. However, it might be quite expensive solution for SME’s, since it is a commercial tool specially oriented requirements management, therefore it needs additional compatible solutions for the design and simulation processes.

Reqtify from Dassault Systèmes [30] is a similar solution for requirements management. It provides compatible interfaces with various office and engineering software, from the most common ones, such as Microsoft Word or Adobe Acrobat [1], to generate reports to some more specialised tools, such as Matlab, for instance to perform analysis.

Teamcenter Systems Engineering and Requirements Management [32] from Siemens PLM Software is focused on the lifecycle management by a close communication with customers to better identify their needs and problems. It provides interfaces with the most common communication tools such as Microsoft Outlook for instance, or others CAD tools, but requires the standardisation of data.

The Dassault Systèmes V6 [10] software application, using the RFLP-approach (Requirements management, Function analysis, Logical design and Physical design), provides a user friendly integration in a virtual environment. It enables to link the requirements to CAD models and other simulation tools. Usually the most common limitation of Dassault Systèmes’ tools is the interoperability with other software from different companies. The cost of such solution is usually based on the needs of the company by providing only the licences of the needed tool. However, the cost can rapidly increase in the case of purchasing the full V6 package including the use of servers for a networking utilisation.

ANSYS Engineering Knowledge Manager (EKM) [33] is data management based system, which integrates the simulation process. It provides a wide range of interfaces with other software tools since it is based on modern open standards. This tool allows the user to manage simulation data and model archiving and retrieval processes keeping a tight connection between them.

SimManager from MSC Software [34] brings together people, process and technology to streamline simulation operations. It manages CAE data and provides a Web-based engineering portal and reporting tool. It focuses on managing artefacts from simulations and provides a solution to track any changes in the simulation while modifying the design. It allows also the management of similar simulations for instance rough mesh and fine mesh for the same model. The general aim of SLM tools is to provide the capability to automate the simulation process.

5. Industrial perspective

A lot of research has been done around the topics of PLM and SLM for various kinds of applications in many different fields. However, there is always the common conclusive statement that there is still a clear trend of research in this area [33].

P.G. Maropoulos [36] asserts as a conclusion that the development of enhanced PLM capabilities, in terms of codifying and capturing post-design verification data and knowledge, will be vitally important for the successful adoption and implementation of new design verification and validation methods by the manufacturing industry.

Zheng [35] states that the key priority is to provide feedback to “close the gap” between the physical and digital world in the context of PLM. Integration is expected to become easier over time with the increasing emphasis on open standards for data exchange.

5.1 Needs of the industrial partners

In the following phases of the project, meetings with the industrial partners have been scheduled in order to share their experiences and discuss about ways of improvement. A consequent list of questions has to be answered during those meetings in order to have a more appropriate idea on the needs and expectations of the industrial partners. Below is a generalised list of some main questions:

- What process, approach and tools do they use?
- How do they use simulation in the design process?
- How do they manage information, data and knowledge within the company and with their customers and suppliers?
- What are their problems concerning simulations and data management?
- What are their needs and main expectations?

Discussions about the above list of questions have been organised with some of the designers from industry, including industrial partners of the SIMPRO project. First of all during the discussions, it has been highlighted that there are real needs concerning efficient simulation and data management solutions. Currently, systems used are mostly related to data management applications, oriented around a product-based design process. The companies use a wide range of simulation tools, and the range is getting wider with their subcontractors, which might use some other tools as well. Currently industries do not have well developed tools and processes for managing the data especially related to simulation outputs for reuse. What simulations have been done?, who did them and when?, are relatively common questions among the simulation engineers.

Management and traceability of measurements have also been highlighted as a possible area of improvement. Measurements on physical prototypes are numerous and need to be properly managed for further use.

The notion of automation through data and simulation management tools would be considered as a great improvement, in order to reduce laborious manual work such as model and data creation, traceability and restoration together with the simulation applications.

With large software packages such as from Dassault Systèmes or ANSYS, the expensive licenses are another highlighted issue. The engineers are required to share few licenses and need to wait in case all the licenses are in use.

5.2 Requirements for SMEs

Aziz et al. [38] describe the use of open source PLM in the industry and detaile the difference from small to medium and large enterprises. He states that large companies have been the target of software developers, while SMEs have been left out of the developments in PLM and knowledge management. Software developed for large sized companies are often beyond the means of small to medium sized companies. This inherently affect the ability of SMEs to manage their knowledge, reuse existing data and collaborate with large companies which are often their customers and which use higher scaled PLM solutions. In that case, it is also reversibly true that larger companies face difficulties to collaborate with their suppliers, since they do not always use the same tools.

According to above statements, it is quite clear that SMEs have special needs concerning the PLM tools. The tool has to be available for project managers as well as knowledge workers within the company, to create and manage knowledge within their domains. Data and knowledge created shall be easily reused and transformed into new representation according to the use of the individuals. And finally, the PLM tool has to be able to communicate and transfer data from the SME towards the larger company and reversely.

6. Future work

The next step of this task in the SIMPRO project is first to fructify the state-of-the-art all along the project, in order to collect as much information as possible to target the real needs in the industry, especially from the industrial partners. Meetings are of primary importance for the success of the project task.

The second step focuses on the identification of problems faced by the design engineers during modelling and simulation of machines. The question of the accessibility of design data directly from simulations must be studied, as well as the exchange of data among computational tools. To assess this step, some SLM tools have to be experienced and applied to some defined case studies.

The third phase of this project focuses on the study of the utilisation of simulations over the product lifecycle. It consists of studying the use of models, simulations, and simulation data after the design phase of the machine. How data can be utilised in other phases of the machine lifecycle, such as commissioning, operator training, task planning, maintenance and decommissioning.

Finally, all along the project the development of optimisation and solutions will be analysed alongside the other tasks and case studies of the SIMPRO project. This aims to receive and give feedback among the partners concerning modelling, simulation and data exchange needs.

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