Information management for long-term maintenance of technical artifacts
- Requirements on traceability in technical information

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ABSTRACT

Technical artifacts with a long lifetime put special requirement on management of technical information. The information need to be managed and maintained to keep it understandable and valid for as long as needed and this put high requirements on effective information management because it is necessary to keep track of which technical information that is valid for which variant of technical artifact. This article is based on a study where requirements on technical information was in focus and especially requirements that concern traceability. Seven requirements have been identified and it have been concluded that those requirements basically concern between which object that the traceability concern, that it matters if a requirement is put from internal or external need or if the requirement concern objects from different information systems. The conclusion is that a requirement is harder to reach if the connections between objects are separated in different information systems.

Keywords: traceability, requirements, technical information, maintenance

INTRODUCTION

Technical artifacts with a long lifetime put special requirement on management of technical information [5, 6, 23, 27, 28]. Technical artifact could be everything from a simple device such as a trailer, relay interlocking plant or engine to complex systems with embedded sub-systems e.g. a lorry or a container dedicated for medical treatment (attendance) used for aid contribution in turbulent spots. The documentation that is needed to be able to introduce, use, maintain and phase out a technical product in other words technical information could be anything from technical descriptions, user guides, installation guides, repair guides to advanced user manuals. Traditionally the documentation has been paper based but the trend is that the documentation to a high degree consists of modules including multimedia, such as videos, text, sound and animations. This technical information need to be managed and maintained to keep it understandable and valid for as long as needed. The situation today with complex products, high variety of products and introduction of changes faster and faster [27, 28] put high requirements on effective information management because it is necessary to keep track of which technical information that is valid for which variant of technical artifact.

Information management have gained a lot of research effort over the years and nowadays there exists a lot of computerized information system i.e enterprise management systems, document management systems, web content management system and content management systems [7, 16, 17, 20]. This paper concerns one special area within information management namely; traceability. It has been concluded that traceability [14, 18, 28, 29, 21] is a central issue to be able to describe the context which in turn is an important factor to reach understandable and valid information over time. There are examples of research within the field of requirement traceability. General models within this field [22, 2] have been presented. There are also examples of paper discussing different techniques to implement traceability [2]. Those could be both automatically ones and manually ones. Most of the information management system support functions for traceability such as management of versions of information, the workflow process, releases and keeping track of internal and external content types. In the product management "world" the basic needs are the same namely to manage information about the products that are manufactured. The computerized information system that often is used in this context is product management system (PLM system). Sudarsan, Fenves & Wang [29] writes that the PLM concept strives to integrate all the information that is produced throughout all phases of a product's life cycle. A central thought is that everyone (management level, technical level, suppliers and customers) that need the information should be able to have access. PLM is described as a key for e-business and digital transformation of engineering processes but many companies have failed to achieve the organizational and technological benefits [1].

The management of technical information includes both some sort of computerized content management system and at least connections to a PLM system. It should not be possible to make judgments about user guides validity or to understand it without connections between the technical information and which product it is valid for. So, there is research within domains like functionality and requirements on for example PLM systems [29] or content management systems [16] but the problem is that technical information management requires a broader view where also requirements on traceability regardless of a traditional grouping of which information system that are used product data and technical information.

The aim in this research paper is to identify requirements that are put on technical information that concern traceability. The expected outcome is a set of requirements that is put on traceability and experienced problem in reaching those requirements.

RESEARCH PROCESS

This paper is based on a qualitative study, which has an underlying interpretative approach. An empirical study was

estimated as a suitable method to grasp the kind of requirements that different stakeholders put on technical information in a requirement process. Together the stakeholders did represent all roles that take part when goods are being produced; sold and used. This strategy to collect data from different stakeholders and thereby collect data that views different perspectives are also the main argument for the selection of research sites. Besides this main argument it was also important that the research site should considered technical information as a central issue in their daily work. The interviews included purchasers, producers of technical information and end-users in six different organizations.

Description of the research sites

A.Purchasing authority that is an organization that is responsible for all purchasing needed within the Swedish defense, 8 interviews.

B.Scand Vehicle that designs manufactures and markets vehicle, 6 interviews.

C.Consultancy firm A is a producer of technical information made on commission by other companies that manufactures some kind of technical artifacts, 3 interviews.

D.Military Vehicle that designs manufactures and markets military vehicle systems, 3 interviews.

E.Consultancy firm B that works with services to companies that design use or produce vehicle, 2 interviews.

F.Electric power and district heating supplier, 5 interviews.

The data collection

The data collection was performed by semi-structured interviews following a questionnaire with the following themes; requirements, requirement finding process, requirement traceability, quality management and quality management systems, working routines and user participation. The questions were put kind of straightforward with formulations like;

- Which kind of requirements do you put on technical information?
- What kind of technical information do you need for your daily business?
- Are the requirements the same for all types of technical information?
- What kind of requirements do you put on the quality management system for the production of technical information?

The interviews were transcribed shortly after the interview was performed

Analysis

The analysis was made by reading through the transcriptions searching for requirements. An excel sheet was set up to document all identified requirements. The tables with requirements were also including a reference to which representative that has brought forward the requirement (using Purchaser, Producer and User as concepts). The data was then cleaned up from duplicates. The empirical study covered all types of requirements that are put on technical information and the total amount of identified requirements was over 80. The requirements concern language, formats, structure, use of standards, accessibility, traceability, layout, document process, adjustments to targets group just to mention a few. The study has been reported in its totality in Öberg [34]. For the purpose of this article the analyzing part was made in several steps. The first step was to mark all requirements that the interviewees named as traceability. All those requirements were then described in details. The second step has been to present if the experience is that this requirement produce problem and remain unsolved which was made by comparison with earlier research within the field. The third step was to analyze what kind of underlying common base there are between the identified requirements that concern traceability.

ANALYSIS OF REQUIREMENTS ON TRACEABILITY

The general conclusion from the study that concern requirements on technical information is that it is a difficult task. All representatives think that it is hard to set up requirements that for example concerns how detailed the technical information should be. This could partially be solved by describing the target group but not fully. Most of the requirements that are used are not measurable and even if few believe fully in measurable requirements some argue the requirement must be stated more precisely to be able to follow up and measure. Seven unique requirements on traceability have been identified in the empirical data set. They are here presented in alphabetic order.

1.Construction changes, stated by producers.

One of the companies within the study designs manufactures and markets military vehicle systems where adoptions to customers' requirements are daily issues. One of the problems that this brings on is that continuous changes in the construction put high requirements on the management of the validity of the technical information. A technical construction change is today announced by telling which part of construction is changed and that the department of technical information is responsible of analyzing eventual effects on the technical information. Due to extensive documentation this in itself is a critical job. This is further complicated by the fact that changes within the construction is made continuously meaning that some technical artifact may already have been shipped and by that two versions of the same technical artifact exists. The same situation will appear over time if a company makes improvement in one or several of the components in a product. Irrespective of the underlying reason for changes in construction there will be a traceability problem because of requirements to keep track of which technical information that is valid for which configuration of a product. In occurrence of accidents the producer is responsible for the possibilities to track exactly which information that the customer got when he bought a product. It might be the fact that the information exist in several versions due to correction of mistakes or changes within construction. Nevertheless is the producer responsible to show which information that was valid the day that the product was sold. Today the processes of construction, manufacturing and technical documentation is done as parallel activities which make this task more difficult to perform.

2.Maintenance, stated by producers, purchasers and users

During a life-time of a product it has to be maintained and the issue here could be reparations or frequent service. One example collected from the study is from a company which produces, distributes and sells electric power and district heating show the importance of traceability. A component at several of their installations exploded more often than usual. The component was order by a standardized identification number and therefore should be of equal quality as comparable spare parts. But an investigation showed differences behind the identification number and that the missing spare parts where manufactured in another country and with slightly different specifications. In this situation the company by their system find out exactly where those components where installed and could start the operation to exchange the missing component.

3. Original Source, stated by purchasers and users.

The companies in this study all have personnel that have special education and competence to work with technical information. A

simplified description of their work task is to search for product data and to refine this into pedagogical and user friendly technical information. The product data is often authored by engineering without the purpose of being useful for different user groups. The product data could be found in the PLM (Product Lifecycle Management)-system, in internal databases, in material from suppliers and so on. The requirement that have been stated here is a need of traceability between the refined technical information (a user manual, a work shop manual) and the original source. This could lead both to increased effectiveness in the production of technical information meanwhile parts of the information do not have to be rewritten. Another positive effect would be higher quality due to less risk for misinterpretations.

4. Part of relations, stated by producers and purchasers.
Products are built of structural components and this is documented in construction drawings and PLM systems. For the producers it is a base requirement to keep the traceability between the product and the components that are part of the product. The study shows that this sometimes is a requirement put by the purchaser. The opinion about the need of this requirement is divided. Some think that this kind of traceability absolutely is needed to be able to maintain the product. Within the Swedish Defence Administration some personnel put argument for the need of this kind of traceability in occurrence of invasion or some other crisis. The idea is then to start up their own production. Others are convinced that this type of detailed traceability is no longer needed. It is nowadays more effective to use contractors and outsourcing to maintain and repair products. On the other hand, some has pointed out the problematic situation in purchase such services from someone else than the original producer without detailed technical information. The law that concern public procurement makes it impossible for public organization to just choose one service provider without giving all competitors the same chance.

5.Single-Sourcing, stated by producers.
Modular documentation by separating a coherent unit of information in smaller pieces as described by Albers (2003) and Ament (2003) put requirements on traceability. The result of the modular way of manage technical information is often a need of content management system or for example special databases to keep track of which combinations that are valid and which of them that have been used in documentation which have been delivered. One of the companies in the study gives every information module a code that later on can be matched against the vehicle it is valid for.

6.Valid information**,** stated by producers, purchasers and users.
A central requirement for technical information has shown to be traceability between a specific technical artifact and the information that is valid for this artifact. The producing companies (Scand Vehicle and Military Vehicle) within the study have a selection of products where it is possible to make adjustments according to a customer's choice. This brings that a product exists in several variants which makes this requirement more complicated to reach. Within for example a user's guide a lot of the information is the same regardless of which variant it is valid for but some sections or paragraph are unique.

7.Version control and management, stated by producers.
Document process or processes are a usual component of the quality management system in all the companies in the study. The document process includes activities like review, spell-checking, glossary use check and translation and so on. Through this process it is important to keep track of different version of the document or modules of information. The same type of need for management of different versions of for example a mechanical drawing exists within PLM systems.

Comparison with earlier research
This step of the analysis was made by comparisons of the requirements with earlier research. This was done by using the identified requirements as search strings in appropriate research search engines.

Stock, Weber, Steinmeier [27] suggest a meta-data set to fill in gaps between CAD data and the technical authoring process. Reuse of data from the engineering process with computerized system could according to the authors decrease the cost to create technical information. Stock and Weber [26 p. 172] present a generic document model that is described as a "comprehensive database of atomic information packages and their logical connections". A computer system would then be able to generate a manual matching a specific product in runtime. This concept is build upon separating the content from the representation [26]). Briggs, Rando & Daggett [6] also addresses the issue concerning the need of information sharing between technical publication and product data. They present a model that aim to solve this problem. This kind of research could be useful both when it comes to the requirement that concern **construction changes**, **original source** and to some extent also **correspondence**. The research shows example of how higher level of traceability between the technical artifact and the information could be reached. When it comes to construction changes the producers have implemented supportive system where changes in constructions are communicated. But sometimes this requires extended analysis to find out which changes have to be made. The empirical data that concerns original source shows that none of the producers have implemented any kind of system to support this kind of traceability. This is a requirement that have been stated by users which is interesting. Hall et. al [15] present information system called Configuration Management Information Systems (CMIS). CMIS provides functions to control the development, approval, release and publication of all technical information during a project. The information system has been used in projects that have involved the development of vehicles for the Australian army. In 2005 Product Life Cycle Support (PLCS) a new standard was published [11]. The standard addresses the requirements for information sharing throughout the product life cycle. There are also some examples of development aiming for information sharing between different phases of the product life cycle that include the development of educational material. Gafford [12] and Lövgren [19] discuss the same type of problem background concerning construction changes. Lövgren [19] present an demonstration of a product called MiaX and according to the author one of the selling point is an integration to a common source database the allows automatic configuration control for all type of content. Dhalla & Yuspeh [9] argument that the concept of product life cycle should be forgotten. Accordingly there is a discussion about the ability to share data through the product life cycle and all requirements that somehow deal with traceability between the technical artifact and the technical information and to take this concept even further.

When it comes to maintenance it is first of all important to remark that the requirement is two folded. There is a need of traceability when it comes to **maintenance** both for the producers and the purchaser or user. The same count for **part-of relations**. The producers need it, to be able to produce, re-design, make corrections and serve their customer with service. For this internal need of information about constructions and components variants is use of a Product Life Cycle Management (PLM) system [29, 1].

But there is also an external need of this type of information. The customer needs the traceability to be able to order spare parts, accomplish repairs and so on. The hindrance is that a lot of suppliers do not want to deliver this type of information; it is seen as business secrets. Some purchasers interpret this as a way of keeping a customer close. The purchaser will decrease their chance to buy for example spare parts from the cheapest supplier meanwhile they do not know which spare part that is needed. In the cases where the suppliers choose to deliver this type of information the customer would have to put requirements on how this information should be delivered. Some issues that are important are; format, structure and language. The study have shown example of customers that put rather high requirements when it comes to this type of information and they also have a database where they store this kind of data for all their products. This is however not possible for a small or medium sized enterprise and therefore the most common solution here is that the delivery is in the format that the suppliers use. A core issues within **single sourcing** [3, 4] is to separate the content from the representation and divide the information into modules. The single source concept is needed today due to a couple of requirements. The first is the need for presentation of same information in multiple channels. It could be printed, presented on the web or in an e-learning material. The second requirement that has forced this development is the need of possibilities to reuse information. To be able to manage all modules there are examples both of standards (as S1000D) and tools (as Content Management Systems) too support this. Management of information, modules of information, and **different versions of information** is common issues for almost all types of organizations. Today it is usual to use some kind of computerized information system to deal with those issues. There are several variants of this type of information system such as document management system, enterprise content management system and content management system (see for example 7,20). Functions to keep track of different versions of an amount of information are ordinary in most of those systems [20].

DISCUSSION

The identified requirement for traceability concerning management of technical information could be visualized at different levels. Meaning that they concern different objects that traditionally belongs to two what seem to be parallel tracks of an organization. The first track is the part of an organization that design and produce a technical artifact and the other is the part of an organization that design and produce the technical information. There is also situations where two those tracks are separated in several organizations.

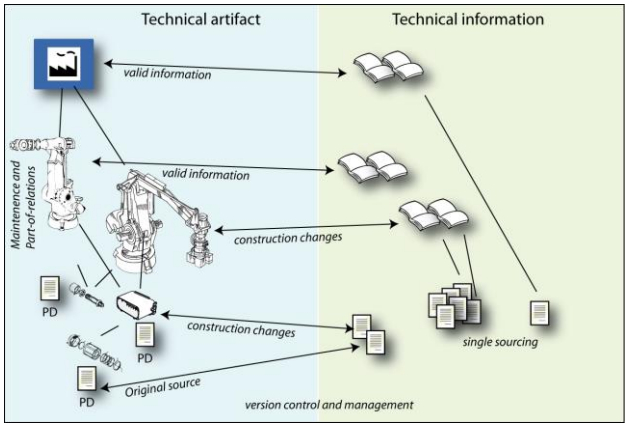


Figure 1 Visualization of identified requirements

The figure should be interpreted as a simplified example of the relationships between technical artifacts and technical information. For example would an installation of course consist of hundreds of machineries, computers, control systems and so on not only two as the figure shows. Furthermore all the lines represent needed traceability between different objects. Some of the lines are between objects that all are placed on the technical information "side" of the picture and should be interpreted as traceability that is needed to be able to manage technical information at the aggregated level (for example a user guide) down to the smallest units (for examples modules or chapters). The same count for the kind of traceability that is needed within a PLM system where it is important to keep traceability in all part-of-relations. The seven identified requirements are made italic in the figure and they are also been marked up to show where different types of traceability is needed. An interesting issue to discuss is whether or not the traceability should be able to follow from both directions. Consequently if the pointers should be from the technical information to which technical artifact it is valid for or quite the reverse. The study shows that the first is the one that is applied today. It should also be possible to have associations that are double and where both objects know which other object it is associated with. This would require solutions like the ones describe where all information is shared throughout the product life cycle. Two-way association would also give possibilities for the end-user to have a feedback loop backwards which would encourage them to report errors and maybe even to written an own suggestion for how to carry out repairs like in Wikipedia. Some of the companies in the studies work with structures to breaking down the information and or the technical artifact into smaller units. It would certainly make it easier to share information between the technical artifact side and the technical information side if they use the same standard for how to do the break down structure. The identified requirement could be summarized in some qualities that are of importance when stating requirements on traceability. It is central to describe between which objects the traceability is wanted. This study has shown variants as product data and a work shop manual or between two modules. Furthermore have the study and existing research shown that it is important to state whether or not the needed level of traceability include object within different information system. There are research that show interesting result regarding for example with construction changes. The empirical data shows that the experience is that this is a difficult problem to solve and the solutions that are used today are far from the one suggested for example by Hall et. al [15] and Briggs, Rando & Daggett [6]. This count also for the requirement about original sources none of the companies within the study has implemented traceability on this level. Another reflection is that there is also a need of deciding the level of the traceability. Should it be between a work shop manual and a product or/and between a component and a module? The third issue that influence requirements put on traceability is about if it is an internal or an external requirement. Open formats and structure could make it possible to deliver for example a product structure from a suppliers PLM system to a customer maintenance system. But is it realistic? The opinions about this are split apart some mean that it have been harder to get this information and some argument that it is approximately the same as before. Some suppliers deliver this information while some do not. There are also some that have put forward argument that point out that product of today become more complex and that a customer have no use of the technical information because it is too complicated.

CONCLUDING REMARKS AND FUTURE RESEARCH

Seven requirements namely, **construction changes, maintenance, original source, part of relations, single-sourcing, valid information and version control and management,** have been identified considered as requirements of traceability. Of those requirements is four of them common functionalities in common used software in respectively area (content management system and PLM-system). Interesting to note is that even though those requirements are common several of the companies within the study have problems reaching the wanted level of traceability. This is in accordance with earlier research within both those two types of information system and opens up for further research. Another area of future research is to investigate eventual differences between different types of technical information. One example is e-learning where technical information often is re-used. Will there be any special requirements on traceability when it comes to e-learning situations? Remaining requirements concern traceability between different information systems. Original source and construction changes are also the requirements that according to the empirical data are hardest to reach. A suggestion for further research would be to investigate further why research ideas as information sharing throughout the whole product life cycle is not used. Finally is there a need of further investigation how requirements should be stated that include stakeholders which could be internal or external. Will the internal need covers the need of external stakeholders? If not how will the external stakeholders put their requirement on this information and deal with a supplier that says that the information is business secrets?

Finally are the conclusion from this study that it is important to (even though it is experienced as difficult) to describe the requirements that are put on technical information more precise. The identified requirements in this research paper and the detailed description of them could be seen as examples of how to communicate requirements in a design situation.

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