10 TRACEABILITY OF THE DEVELOPMENT OF 'INFORMATION OBJECTS' IN THE ENGINEERING DESIGN PROCESS

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This paper introduces an engineering design information traceability framework. Maximizing the value of engineering design information is partly dependent on trust partly on its proper understanding, both dependent on knowing where the information has come from, the reasons for its generation and so on. This knowledge is reliant on the traceability of the information and its development. Hitherto traceability has been an ad hoc process. The research reported here relates to the early stages of the development of a formal framework for engineering design information traceability. This consists of a traceability model and a language for describing the traceability entities and associated process, and a means of representing traceability instances.

Keywords: Traceability, Uinformation object, Uengineering design.

1. INTRODUCTION

The result of globalization is that product development companies are facing fiercer competition. Survival depends on decreasing development and product lifecycle cost, at the same time improving product quality and customer satisfaction. In response to this, the traditional engineering and manufacturing industry business model — based on delivery of the product — is beginning to be replaced by one where the emphasis is shifting progressively from supply of the product to product supply and provision of support services throughout the product's service life. This has been referred to as the product-service paradigm.[1] This trend is observable across a wide range of different industries including the automotive, aerospace, shipbuilding, construction, healthcare, and defence sectors.[2]

As the emphasis shifts towards the provision of product-service, the realization becomes stronger that engineering design information, much of which is inefficiently used, is the key to continuing competitiveness. In particular much information that is currently lost (either because it has been discarded or is not 'accessible' for reuse) can aid both product life cycle support and the development of new products.[3]

The shift in emphasis from product delivery to product-service delivery means that the 'provider' becomes on the one hand more intimately concerned with the product over its life-cycle and on the other becomes involved with the product over a longer time span. This in turn requires that engineering design information (EDI) development has to remain traceable (so that the EDI is made more accessible, understandable and reusable) throughout the decades that a product remains in service.[4]

Currently, support for EDI traceability is hampered by the lack of methods and tools for 'capturing' and documenting useful aspects of the development of information.

Traceability is required, because without it the trustworthiness, understandability and appropriate reuse of the information cannot be guaranteed at the point of use. This has been explored in earlier research.[5] In order to understand and reuse existing engineering design information contextual information concerning meaning, reasons, arguments, documentation, choices, critique, consequences, etc. is required, which for its provision requires advanced EDI traceability methods, models and tools. Currently these are lacking.

Little is currently understood about the requirements for information traceability in engineering design and there are few methods by which effective traceability can be ensured. There are a number of methods which contribute to the traceability of information development, but the emphasis here is either on description of the product or on through-life information maintenance rather than the explanation of development and data on information antecedents, i.e. PDM/PLM systems like Enovia SmarTeam — [www.3ds.com] or PTC Windchill [www.ptc.com]. In order to redress this, the research presented here has been aimed at better explaining and understanding the requirements for traceability. The work includes the development of an exploratory framework for traceability in the light of the dynamics of EDI development throughout the product life cycle. This provides the foundation upon which to build a working environment in which the resulting traceability tools and methods can be made operational.

2. TRACEABILITY OF EDI DEVELOPMENT IN ENGINEERING DESIGN

Traceability of EDI development could be viewed as one quality criterion of a product development environment with the main goal being to ensure that EDI is clearly linked to its background, origins and sources during its development.

In the research presented here, it is the engineering design information that is seen as the main subject for which traceability should be achieved during product life. The design information has a central role in product development: it describes and documents the constitution and behavior of the design and product; it drives the product development process and is the object of verification and validation procedures. By providing a means for tracing the development of the EDI a means is provided, in effect, for making the product development process itself traceable.

The foundation for this is a means by which the EDI can be linked in a complete, correct, consistent and error free manner. Traceability information provides a 'context' by which the information it contextualizes can be better interpreted. The details of the 'context' can be obtained from two different viewpoints. The first one is the context of capturing EDI including the recording and explanation of the conditions around EDI development activities. The second one is the context of using recorded EDI trace information that includes providing a basis for identification and understanding of the captured EDI. These viewpoints highlight the possibility that the two main parties involved in EDI development traceability (i.e., those in a position to make it possible and those who require it to assist their work) could have conflicting problems and needs that should be considered when traceability is planned to be implemented in their working environment.[6]

Some problems faced by providers:

- Perceived as an optional extra (and of low priority), so the allocation of time, staff, and resources is often insufficient.
- Imbalance between the work involved and benefits gained.
- Information cannot always be obtained, and the quality of that which is varies. Deliverable driven cultures can discourage gathering certain information.
- The documentation of required information is no guarantee of its traceability. That which is structured, so it is traceable in many ways, provides no guarantee it will be up to date.
- Poor feedback regarding best practice, and little dedicated support (be this clerical, procedural, or computer support), perpetuates the same problems and restricts advances.

Some problems imposed by the end-users:

- The quantity, heterogeneity, and depth of detail of the potential information required, precludes predefinition.
- Inability to predefine how any access to information, and its subsequent presentation, will be required.
- Reliance on personal contact, as there is always something that is out of date, undocumented, inaccessible, or unusable.
- Each end-use context exhibits unique information, so problems will exist if end-users do not have the ability to filter and access the information accordingly to their particular preferences.

3. TRACEABILITY MOTIVATION IN ENGINEERING DESIGN

Based on collected experience, previous work on handling of design information[7–11] and existing traceability practices and standards (e.g. GS1 — Global Traceability Standard[12]), it could be said that traceability is about how various origination steps of an information object can be traced back to original sources in order to provide its credibility. As such, traceability of engineering design information development might be measured by:

Purpose (defined in terms of what traceability should do) — the capacity of the traceability method to conform to the project development scope, role of the engineering design information among the product development, legal, quality and other key requirements that have been introduced in the organisation.

Solution (defined in terms of how traceability is achieved) — the capacity to trace development from one information object to another based on given semantic relations between them and constrained by existing tools for supporting everyday engineering working practice.

Information content (emphasizing a traceable information record) — the capacity to link between different levels of product/design abstraction such as requirements, functions, detail description, as well as description of the activities, events and resources involved in the engineering design process.

Direction (emphasizing traceability direction) — the capacity of the traceability method to provide support for following a specific information object at input of a particular phase of the product lifecycle to a specific information object at the output of that phase.

3.1. Traceability Difficulties in Engineering Design

Why is the achievement of EDI development traceability in modern highly-automated product development environments, still so difficult? The authors contend that the reason has as much to do with processes and human factors as with issues of heterogeneous tools and distributed teams. However, the current engineering design environment frequently militates against traceability since people exchange engineering information across corporate and discipline boundaries, they reuse existing information in new and unpredictable contexts and often information is transposed from one format to another during which information loss occurs. Furthermore, because of lack of the formal representations of the complex engineering design information, these exchanges still partly occur informally. As a consequence, retrieval of the engineering design information objects (e.g. with respect to format, type, and contents) as well as correct interpretation of its content (due to the specific domain context) is hindered. This, amongst other things, impedes product innovation and produces unnecessary development iterations.

Current approaches and studies give no guidance on which EDI traceability information must be captured, which traceability category exists and are the most feasible, useful and reliable, nor how to assure quality in traceability of EDI development.[13]

4. RESEARCH AIMS AND METHODS

The work presented in this paper has been built on state-of-the-art developments in the exploration of ontological principles for EDI management and has incorporated the formalization of the EDI objects, sources, stakeholders, rationale, and space/time dimension into an EDI development traceability domain.

The existing practice of recording the outcome of the engineering design process is almost exclusively based upon highly formalised model of the product, in the form of computer-aided engineering models, bills of materials, engineering change orders, etc. However, the detailed process, activities and rationale by which the design has been created and the EDI developed are — to the extent that they are recorded at all[14] — are recorded largely in an informal manner. A consequence is that is difficult to retrace or audit the engineering reasoning that has taken place during the process of EDI development without extensive work to assimilate and digest design documentation, and that identification of relevant parts of the information records within the documentation requires significant skill and often an intimate knowledge. Again, this can only be done where, in fact, the required information is available for this process.

It is the central proposition of this research that more useful traceability of EDI development may be obtained by formal description of the different EDI development dimensions. Consequently, the main goals of the research presented here are:

- Development of the concepts associated with traceability and incorporation of them into a number of explanatory models of traceability practice in engineering design.
- Building of the formal language for description of the information objects' development traceability in engineering design. This constitutes ontology.
- Development of the tools and methods for visualization and communication of information objects' development traceability using the proposed formal language.

5. RESEARCH RESULTS

Progress has been made in the above research in a number of areas, discussed below.

5.1. Information Objects

As reflected in the entry for the noun information in the Oxford English Dictionary[15] the concept of information embraces the notions of communication, control, data, form, instruction, knowledge, meaning, mental stimulus, pattern, perception, and representation related to the act of informing, or giving form or shape to the mind, as in education, instruction, or training and so on. Thus, information in many interpretations concerns a thing of abstract form. Clearly, this presents practical difficulties in terms of information traceability. Such limitations do not, however, concern information in its more tangible form, that is to say, as items of recorded information. For the purposes of this research traceability concerns the development of these information items or rather 'information object' as they are termed by the authors.

The term information object is widely used in a number of disciplines. Its use, however, is generally quite informal although definitions do abound. Rather than add a further definition here, the concept is illuminated descriptively. The authors see an information object as being a collection of information — purposefully assembled, often by convention — together with context-bearing information — such as the title, provenance information, date information, affiliations and 'physical' form. These together identify what type of information it is, and by doing so, how to interpret it. The archetypal 'information object' associated with engineering design (and indeed engineering in general) is the document, although such things as CAD representations, simulations and so on are equally representative. The idea of 'information object' embraces not only physical objects, but also electronic analogues of physical object (electronic document files) electronic objects with no physical analogue (e.g. 3D representations of parts) and dynamic as well as static objects (e.g. video streams and simulations).

The notion thus embraces all those items of recordable information commonly associated with the engineering process.

5.2. Traceability as an Information Object Quality Criterion

The main scope of the information quality studies as is defined by Eppler[16] is information transformation processes that are heavily reliant on the professional knowledge of the participants or actors in the process. The knowledge that is needed to manage non-routine, sequential tasks of information transformation is consequently the central object of quality related inquiries. The key role of traceability to assure information quality was highlighted by a team of information quality researchers and professionals which implemented a knowledge management system at IBM Global Service Consulting Group.[16] They stated that:

> *In addition to the data quality, every step of the information extraction and information fusing needs to be accounted for with reasons so that a human can trace back the whole process if needed. Since the information or knowledge generated by the customer knowledge management process will be highly summarized, credibility will not be established without such tracing facility.*

Based on the state of the art development in traceability research, two main perspectives have been recognized in research presented in this paper as necessary to establish the framework for supporting information object development traceability in the engineering design field:

- *Contextualization of information objects* so that they can be correctly understood and correctly adapted as a result of considering their origination and use; that is, where the information object came from, why is was originated, to whom it was important, how it should be used, and so on. There are two particular points of interest when considering contextualization of the information object: the circumstances of information object creation; and the relations of the information object to its environment.
- *Provision of an audit trail of the information object life continuum* from its creation to disposition, in order to record the information content management process. There are two particular points of interest when considering the audit trail of the information object life process: the phases of the information object's life continuum; and relation of the information object life continuum to information object environment.

5.3. Traceability Language Specification — Overview of the Concepts

As a part of the modelling the traceability process, it is necessary to know what information is expected from a trace model or what kind of information is of interest about the transformation of an ED information object during its life process and thus what is worth preserving. A well-specified language for modelling traceability should be complete enough to enable a record to be made of all the trace data necessary to its understanding and effective reuse. To solve the trade-off between completeness and simplicity of such a model, its design should be driven by the envisaged purpose of the traceability that is, tracing the development of information objects in the engineering design process. Accordingly, the main building blocks of the traceability language have been defined in presented research as follows:

- **Traceability Elements (TE)**
  - Traceability items — elements of the underlying information development process that are objects of the traceability process.
  - Traceability attributes — meta-information about traceability items.

  - Traceability links — links between traceability items that can be result of underlying information transformation activities, or can be computed based on existing traceable items, or can be statistically inferred — i.e. based on the usage history of the traceable items.
- **Traceability Operations (TO)** — performed based on the rules and rationale
  - On attributes — operations like copying, transforming, or converting.
  - On items and links — operation like creation, linking, search, retrieval.

During engineering design process that is traced it is necessary to create *traceability items* and *links* that model the input and output information objects involved in the underlying information transformations. *Traceability items* record the objects of traceability which in addition to representing information objects themselves could represent activities of the information transformation process or agents included in the entire traceability scenario. *Traceability attributes* record the whole set of traceability items' meta-information associated with a given transformation in order to contextualize the information object in its life cycle process. *Traceability attributes* are further classified as follows:

- **Description** — any information that helps to identify and describe the content of the information object. This would specifically include:
  - ID
  - Coverage/scope
  - Purpose/motivation
  - Assumptions/target group
  - Categorization
  - Format/medium/structure
- **Context** — information that documents the relationships of the information object to its environment, and helps to explain why the content of the information object was created and how it relates to other information objects existing elsewhere. This would specifically include:
  - Author/owner/participant
  - References
  - Creation/expiration date/time
  - Related information
  - Source/file location
- **Provenance** — information that documents the history of the information object. This might include information of its source or origin, any changes that may have taken place (e.g. migrations), and a record of the chain of custody. The assumption underlying the principle of provenance is that the integrity of an information object is partly revealed by tracing from where it came. This would specifically include:
  - Usage history
  - History of origins/sources/creation circumstances
  - Revision history
- **Fixity** — information that documents the particular authentication mechanism in use with in a particular repository.[17] If the content of an information object is subject to change or withdrawal without notice, then its integrity may become compromised and its value as a dependable record would be severely diminished. Changes can either be deliberate or unintentional, but either type would adversely affect the integrity of information object content. This would specifically include:
  - Access rights
  - Usage restrictions

Traceability links record different kinds of dependencies between different *traceability items*. In order to model and keep the records of operations performed on the elements of the underlying process with the purpose to create the *traceable items*, the concept of the *traceability operations* is invoked.

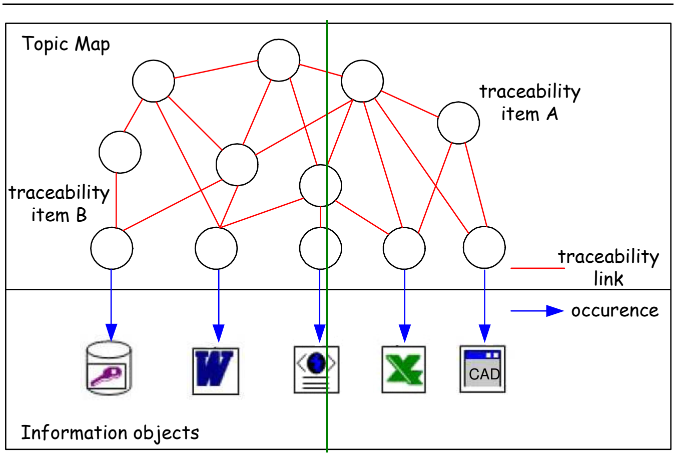

Figure 1. Mapping of the traceability language building blocks to the Topic Maps' features.

5.4. Traceability Visualization and Communication — Reusable Framework Using Topic Maps Based on an Engineering Design Ontology

The Topic Map[18] is a means of visualizing the logical (but often informal) relations between abstract and concrete entities. Topic Maps enable multiple, concurrent views of sets of meta-information — in this case traceability information related to EDI development traceability.[19] It is intended by the authors that this standard be adopted for the formal representation, exchange and manipulation of the traceability model, process and scenarios as Topic Maps.[18]

As a case study, the authors have implemented the previously proposed traceability language by mapping its elements to the Topic Maps' features as follows (Figure 1) in order to trace development of the research project outcome. The elements referred to in Section 5.3 are not included in this figure for clarity, but will be dealt with in a subsequent paper.

- A traceability system has been created with a primary navigation window using topic maps as the enabling technology.
- Traceability items, their attributes, and links between them are displayed and organized using Topic Map views.
- Each traceability item and attribute are represented as a topic
- Links between traceability items and attributes are represented as Topic Map associations.
- The locations of the information objects are implemented by Topic Map occurrences.
- A query function was used for filtering and sorting the traceability items and their attributes in the Topic Maps, as well as for extraction of the traceability links of interest.

6. KEY CONCLUSIONS

This paper describes research on an EDI development traceability framework — comprising a traceability model, a language for defining traceability process, and traceability scenarios — as a medium for communicating traceability practice defined in a uniform way for the engineering design domain. The main contributions can be summarized, thus:

- Known general traceability principles from different areas of human interests were converted into a technical description of the Engineering Design Information (EDI) development traceability process.
- Instead of adopting the current practice in engineering design practice of marking the information objects by labelling for data exchange, the access to the full information object development process becomes possible.

- A common formal vocabulary for EDI traceability and the framework allowing complex traceability scenarios has been proposed.

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