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TOWARD A PROCESS AND METHOD FOR TRACING THE DEVELOPMENT OF INFORMATION OBJECTS USED IN ENGINEERING DESIGN

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ABSTRACT

The work reported here builds on the framework for EDI development presented previously by discussing the requirements for information object traceability in respect of the context-bearing information that must be associated with the design information, the nature of the information object development process and the process, requirements and activities for the traceability process itself. In order to provide a continuously updatable and accessible record of the development of an engineering design information object, authors propose the use of the 'traceability scenario'. The key characteristic of the traceability scenario is that the traceability operation is performed at certain point in a time, in order to create a traceable item from some of the elements of the underlying engineering design process. It is concluded that the greater the extent that semantics are defined for traceable activities and objects, the greater the 'intelligence' that can be brought to bear in tracing information development.

Keywords: Traceability, information object development, engineering design

1 INTRODUCTION

This paper concerns the notion of the traceability of the development of engineering design information (EDI). The engineering design process is characteristically one which uses and produces large amounts of information. At the same time the diversity of information used by engineering designers is quite large. Furthermore, the efficiency of the engineering design process is highly dependent on the effective re-utilization of engineering design information (EDI) produced during the process of earlier design activity [1]

As argued in [2] for the sorts of information commonly used and generated during the engineering design process to be used most effectively and safely, some measure of traceability of origins is required. The main motivation for enabling traceability of EDI development during the product development could be summarized through traceability objectives as follows:

- Ability to link EDI back to stakeholders' rationales and forward to corresponding design artefacts - traces of EDI development and verification procedures could help designers in ensuring of the requirements fulfilment and keeping track on the development project status.

- Ability to discover EDI development history should improve understanding of the design routes-traces of EDI from its origins, through its development and specification could help designers in understanding of the design routes as well as impacts of later changes in any product feature can be identified before a product is redesigned.

- Ability to ensure that EDI is clearly linked to its resources - traces of links between information and record could help designers in assigning the correct value and estimation of EDI relevance for particular design scenario and development episode.

- Ability of EDI traceability to support Quality Management, Risk Management, Information Management, Conflict Management, Evaluation Management create potential for improvement of overall design process and overall design project quality.

Traceability of information provides the basis for assessing the credibility of information, its better understanding and making judgments about the appropriateness of its use for a particular task. To understand engineering design information it is necessary to have contextualizing information concerning it meaning, reasoning, argumentation, documentation, choice points, critique, consequences, etc. In other words to fully understand an item of information it is necessary to know something about the circumstances in which it has been developed and recorded. Currently there is little provision for acquiring, capturing and delivering with the design information, the information that provides its development context, and few tools to support this process. In addition, 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.

The work reported here builds on the framework for EDI development presented by the authors in [2] by discussing the requirements for information object traceability in respect of the context-bearing information that must be associated with the design information, the nature of the information object development process and the process, requirements and activities for the traceability process itself. In the first part of this paper the clarification and definition of the concepts which are crucial for domain of discourse are discussed. These concepts include the information and record distinguishing (Section 2.1), development of information object (Section 2.2), traceability as a part of the information quality framework (Section 2.3), contextualization and audit trial of the information object (Section 2.4 and Section 2.5). In the second part of the paper results of the research are discussed and traceability scenario (Section 3.2, Section 3.3.) and traceability key activities (Section 3.4) are proposed.

2 BACKGROUND

2.1 Information and record

Information as a concept bears a diversity of meanings, from everyday usage to technical settings. Generally speaking, the concept of information is closely related to 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 (Oxford English Dictionary). Information is the result of processing, gathering, manipulating and organizing data in a way that adds to the knowledge of the information receiver. Transforming data into information can be accomplished by organizing it into a meaningful form, presenting it in meaningful and appropriate ways and communicating the context around it [3]. In talking about the traceability of information, it necessary to be clear about what it is that is being traced. Clearly, whilst it might be desirable to do so, tracing the development of information per se is very difficult. As is the case in the evaluation of information [4] it is not the information itself that lends itself to consideration but the physical or tangible manifestation of information. Chief amongst these manifestations of what are sometimes referred to as information-as-thing [5] is the *information object* (this is defined in [4] and represented archetypally in the engineering domain by the information object known as the document).

The International Standardisation Organisation (ISO 15489: 2001) defines a record as 'information created, received, and maintained as evidence and information by an organization or person, in pursuance of legal obligations or in the transaction of businesses. The International Council on Archives (ICA) Committee on Electronic Records defines a record as 'recorded information produced or received in the initiation, conduct or completion of an institutional or individual activity and that comprises content, context and structure sufficient to provide evidence of the activity'. Primarily the value of a record is as evidence of the activities of the organization but records are retained also for their general informational usefulness. While the definition of a record is often identified strongly with a document, a record can be a documentary object or digital information in some other form which has value to an organization. During its existence, information can become a record by being identified as documenting informational transactions or as satisfying a need for information. Much recorded information also serves to document a critical point in a process or to document an event.

The practice of records management involves all of the following activities:

- *Creating, approving, and enforcing records policies*, including a classification system and a records retention policy.
- *Developing a records storage plan* that among other things includes the short and long-term housing of physical records and digital information.
- *Identifying existing and newly created records*, classifying them, and then storing them according to standard operating procedures.
- *Co-ordinating the access and circulation of records* within and outside an organization.
- *Executing a retentions policy to archive and destroy records* according to operational needs, operating procedures, statutes and regulations.

2.2 The development of engineering design information objects

There are a number of phases which have been identified as being part of the information object life continuum. The phases and terms used differ depending on the information objects' life model concerned but they could be summarized as:

1. **Creation and receipt** deals with information object from their point of origination. This could include the creation by a member of an organization at varying levels or receipt of information from an external source
2. **Distribution** is the process of managing the information objects once created or received. This includes both internal and external distribution, since information objects which leave an organization become a record of a transaction with others (customers, suppliers, etc.). Use takes place after the information object is distributed internally, and serves for decision making, documenting further actions and suchlike.
3. **Use** takes place after information object is distributed, and serves for decision making, document further actions, or other purposes.
4. **Maintenance** concerns the information object in respect of such processes such as filing, retrieval and transfers. Filing is the process of arranging information objects in a predetermined sequence and creating a system to manage it for its useful existence within an organization. Failure to establish a sound method for filing information objects makes its retrieval and use nearly impossible. Transferring information objects refers to the process of responding to requests, retrieval and providing access to users authorized by the organization to have access to the information objects.
5. **Disposition** combines the ideas of not only 'disposal' but also 'reallocation', thus it concerns managing information objects that are no longer of value, have completed assigned retention periods or are infrequently or less frequently accessed objects. A less-frequently accessed object may be considered for relocation to an 'inactive information objects facility' until they have met their assigned retention period. Additional items to consider when establishing a retention period are any business needs that may extend those requirements and consideration of the potential historic, intrinsic or enduring value of the information records. If the information objects has met all of these needs and is no longer considered to be valuable, it should be disposed of by means appropriate for the content. This may include ensuring that others cannot obtain access to outdated or obsolete information as well as measures for protecting privacy and confidentiality.

Long-term information objects are those that are identified as having a continuing value to an organization. Based on the period assigned in a retention schedule, these objects may be held for periods of 25 years or longer (for example during the period that related products stay in service) or may even be assigned a retention period status of indefinite or permanent. There is a need to ensure information objects of continuing value are managed using methods that ensure they remain persistently accessible for whilst retained. While this is relatively easy to accomplishing with paper-based information objects, by providing appropriate environmental conditions and adequate protection from potential hazards, it is less simple for electronic format records. There are unique concerns related to ensuring that electronic information remains usable, which requires that contextual information is retained with the stored information about format and media, and that preservation of hardware able to handle the media is assured. Media is subject to both degradation and obsolescence over its lifespan, and therefore, policies and procedures must be established for the periodic conversion and migration of information objects stored electronically to ensure it remains accessible for its required retention periods. These are topics considered as a whole by the digital curation community (see for a recent overview [6]).

2.3 Traceability in an information quality management framework

The information that is needed to manage non-routine, sequential tasks of information transformation in engineering design is consequently the central object of quality-related inquiries. This engineering design information embraces three distinct areas of knowledge: it relates to knowledge about the engineering design process (knowing how to do design), the knowledge generated during the engineering design process (knowing what was designed), and the knowledge derived from the engineering design process (knowing the reason why design decisions were taken). For those parts of this 'know-how', 'know-what', and 'know-why' that can be made explicit and documented, the quality of the information is crucial to the effective knowledge transfer among knowledge workers and thus ultimately for the functioning of the knowledge-intensive engineering design process itself.

The information quality framework proposed by Eppler [7] consists of four main elements as is shown in Figure 1. The first element is a vertical structure consisting of four views on information quality that categorize crucial information quality criteria according their relation to the target community (relevance), the information product (soundness), the information process and the infrastructure. The second element is a horizontal structure, divided into four phases that represent the life cycle of information from the user's point of view as it is searched for and found, evaluated, adapted to the new context and then applied. The information quality criteria – the third element – are placed in the matrix formed by the phases and views. The quality principles identified by Eppler help to improve the quality of information in every phase.

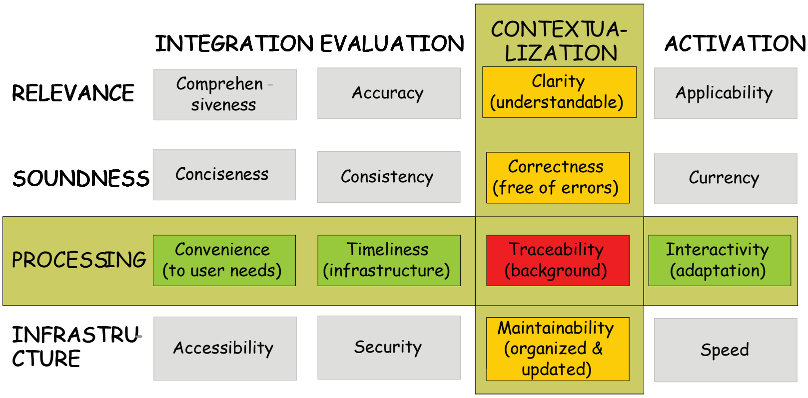

Figure 1. Eppler's Information Quality Framework [7]

The third of Eppler's information quality views – Processing – identifies criteria which relate to the content management process by which the information is created and distributed and whether that process (or information service) is convenient (for writers, administrators and users) and whether it provides the information in a timely, *traceable*, and interactive manner.

Although traceability is identified here by Eppler, it is not found universally in discussions about information quality criteria. The crucial role of traceability to assure information quality has, however, been highlighted also by a team of information quality researchers and professionals which implemented a knowledge management system at IBM Global Service Consulting Group [7].

> *'In addition to the data quality, every step of the information extraction and information fusing need 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.'*

Traceability is thus a prerequisite for the credibility of the information. It also enables a more comprehensive evaluation of the information because its sources and the methodology of its development can be established. In Eppler's model the third phase, of *contextualization*, intersects with the quality criterion of traceability. By providing a context or environment that acts as the information's background, the information becomes clearer and its limits become more apparent. The traces of information development become visible and the information can be more easily updated or otherwise modified, or deleted if necessary.

They are two main perspectives explained in our previous research [2] that should be applied in order to establish the framework for enabling the traceability of the development of information objects in engineering design:

- The **Contextualization of the information object** (related to information quality principles defined by Eppler [7]) to enhance understanding and support the correct adaptation of the information object through considering origination and use (where the information object comes from, why and to whom it is important, and it how should be used). There are two particular points of interest when considering contextualization of the information object: the circumstances of information object creation; and relations of the information object to its environment.
- The **Audit trial of the information object's life phases** (from the information quality management view defined by Eppler [7]) which has the purpose of relating to the information the information content management process by which the information object is created and distributed and whether that process (or information service) is suitable (for agents that have a role in the information life process). There are two particular points of interest when considering an audit trial of the information object: the phases of the information object's life from creation to disposition; and the relation of the information object life phases with the environment.

2.4 Contextualization of the information object

According to the Oxford English Dictionary, the term 'context' has two primary meanings: (i) the words around a word, phrase, statement, etc. often used to help explain the meaning; (ii) the general conditions (circumstances) in which an event, action, etc. takes place. In common with this definition is one drawn by Berry and Schamber [8]. They distinguish between an internal context (describes the circumstances of its creation like purpose, underlying assumptions, number of revisions, sources, author, date, etc.) and an external context (which relates information to its environment such as owner, location, usage history, demand for information object, access rights, etc.). These elements of the internal and external context of information objects are summarized in the Figure 2.

One reason why context is important for the information object in the design process is that it enables information object users to understand and adapt its content to new contexts appropriately and correctly. The provided context clarifies the intended meaning of the information object content (what it is about), its appropriate application (where the information can be safely applied and where use will lead to error), its traceability (where it comes from and how it was originated) and its maintainability (for what and how it can be appropriately updated). Thus, this contextualization principle establishes that for information to be of high quality the information object must bear contextualizing information both about origin and use. The engineering design group can also better assess value of the information objects by meaning of whether the information content holds true for a new application context and if it is correct even under different circumstances.

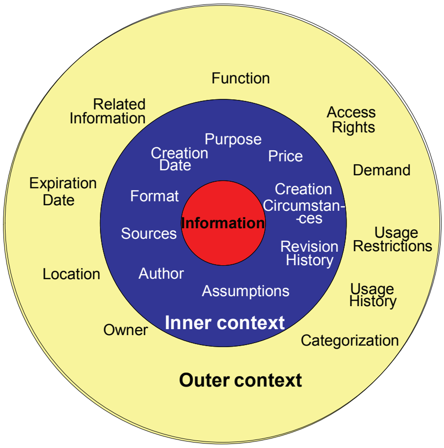

Figure 2. Berry & Schamber's inner and outer contexts and associated information quality criteria [8]

2.5 Audit trial of information object's life phases (recording of design work)

Cooper and Press [9] contend that there are two types of design audits done, on the one hand grounded in standards and regulations, on the other originating in organizational management. In fact, there exists a significant difference between these two types. The former focuses on the adoption of standards or regulations for improving design, while the latter first focuses on the design agenda, then develops audit criteria, and finally utilizes the results of the design audit to direct the management of design. In today's business world, 'auditing' is a commonly used term. In addition to its traditional application in finance, an audit can also refer to other types of inspection [9]. The British Standard Institution (BSI) defines the design audit as 'a systematic and independent examination to establish whether arrangements for design activities in an organization have been planned and implemented effectively' [10]. Accordingly, the design audit is a systematic, independent, and objective inspection of the design activities of an enterprise [11].

Work done by Ramesh and Jarke [12] relating to establishing traceability models in software development, where case studies were analysed from twenty-six companies, resulted in a number of reference models, including that shown in Figure 3. This distinguishes between product and process objects, each of which have distinct attributes and relationships related to traceability, together with two traceability links unique to each object. Though based on software component traceability, the model lends itself to consideration of information object traceability as discussed below.
The product-orientated traces describe the attributes and relationships of concrete information objects describing design/product. A high-level product-related information object defines goals or constraints that need to be satisfied by a number of product features described in product-orientated information objects on a more fine-grained level of modelling. The process-orientated traces represent the history of actions that led to the creation of the product- orientated information objects. Two link types exist between process-orientated information objects: *evolves-to* which describes the temporal evolution of a lower-level product orientated information object towards a higher level, and *rationale* which captures the reason for this evolution. The integrated presentation of the product and process traces in this meta-model symbolizes the fact that they cannot be reasonably separated as one strongly depends on the other. It is also necessary to record and connect the sources which contain and display the information objects.

The recording of product-oriented traces is partially realized inside the tools already commonly used in the engineering design environment 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]. Special steps need to be taken for recording and relating process traces and their supplementary information like arguments and decisions. It is necessary to enrich the engineering design environment with tools to enable a consistent automated and partially manual trace capture [12].

3 RESULTS

3.1 Traceability of the development of the information objects in engineering design

Based on the background research done, the following statements can be derived in order to describe the engineering design information object development space:

- Information that is important in a given context according to the engineering design practitioner is recorded in one or more information objects during the information transformation-intensive engineering design process. The purpose of the record is to provide information necessary for the realization of the product/design.
- Traceability refers to process which combines the contextualization of information objects with an audit trial of the development of the information object in order to make explicit and visible the information object's background, sources and foundation.
- The contextualization and audit trial of information objects in engineering design is carried out in order to allow assessment of the credibility of the information objects during the processes which result in their creation.
- Information object development refers to the information object life described as intentional informational transformation performed as a cognitive activity by the engineering design practitioners which result in a change in information object content.
- Information content is characterized by its quality and quantity that are assessed by quantity (maturity, complexity, etc.) and quality criteria (correctness, clarity, etc.), among which is traceability.

A framework for tracing the development of engineering design information objects should define those elements and the characteristics of such elements, necessary, for the implementation of traceability over information object development in a specific engineering design process episode. The authors specify the requirements for a traceability framework as follows:

- To reflect best practice in traceability incorporating that which, by experience, has shown to be successful.
- To provide a formal language to communicate traceability, allowing in such way description of information object development
- To enable easy implementation in existing engineering tools, in so doing maintain or improve the usability level that the existing engineering tools provide.
- To provide templates for different traceability episodes and scenarios.

3.2 The traceability scenario - capturing information object development

In order to provide a continuously updatable and accessible record of the development of an engineering design information object, authors propose the use of the 'traceability scenario'. It is important to emphasise that traceability scenario evolve in parallel with information object development itself, resulting in a corresponding step being recorded. In common with the author's own experience in encouraging the uptake of knowledge management tools in industry, Leite and Breitman [13] demonstrate that a decisive factor in getting stakeholders committed to keeping traceable information is providing through a recording mechanism that is both easy to use and easy to understand. Such tools should add the least investment in time possible additional to the design task being undertaken.

The strategy of using traceability scenarios is based on the idea of using a customizable traceability framework that allows for, on the one hand, the capture of traces between underlying activities and events and, on the other, the simultaneous capture of information objects generated as by results of those activities and events during specific engineering design episode. Combining both activities in one tool will minimize extra resource investment. The scenarios provide an intuitive representation that facilitates communication among different stakeholders who are interested in traceability of the information object development in engineering design. The use of scenarios throughout information objects development as an alternative representation could enable communication and validation of information objects with stakeholders. Because we propose a validation and approval process based on traceability scenarios, maintaining traceability to the correspondent information object and its life process is paramount in assuring overall consistency.

3.3 Explanation of the traceability scenario

In order to enable traceability among underlying process, in this particular case – the engineering design process – it is necessary to define what the process of information object development looks like, and what traceability paths should be traced in a given traceability scenario [2]. The information object development process should be considered from the two viewpoints relevant for traceability as is shown on Figure 3.

First, information object development refers principally to the development of informational *content*. The content of the information object is subject to transformation activities, as a result of which it changes during the information object life process. The textual document, as an archetypal representative of the information object, is considered as a complex structure constituted of information fragments (e.g. textual and numerical elements and pictorial representations) or other information objects [4]. In addition to traditional PDM features, the development of the structure of such complex documents could be traced through mechanisms like versioning, configuration and variants. The second viewpoint concerns that of the *context* of the information object. In Figure 4 the change in content is brought about by agents carrying out actions (A) on objects (O), which by so doing changes the context.

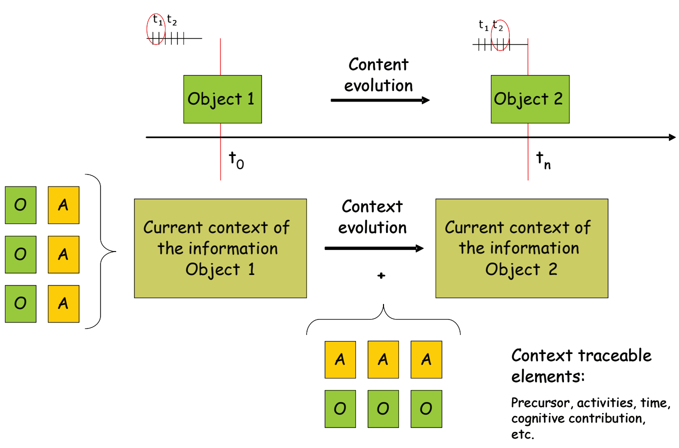

Figure 3. Information object development scenario

As discussed above, by tracing the development of the inner and outer context it is possible to provide a much richer description and deeper understanding of the information object background and in such a way establish the trustiness and credibility of the information object. This aspect of development is less well served currently and therefore is considered the greater challenge in this work. The logical model for describing the underlying process has as its focus an information object in one of its life phases. Actions take place in a space and time continuum, performed by agents, defining in such way the location of the information object. Actions are about performing rational transformation on information objects; during which the content and context of information objects are being changed as is described before and shown in Figure 4.

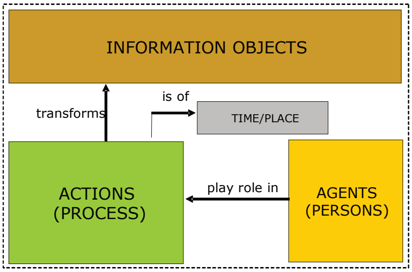

Figure 4. Underlying engineering design process logical model

Besides their associated activities, the different agents in the engineering design process have different traceability goals that have to be considered. For example, from the engineering design project manager's perspective, traceability could support ensuring that each requirement has been satisfied and that each product component satisfies a requirement. From the perspective of requirements management, traceability could facilitate linking requirements to their sources and rationales, capturing the information necessary to understand the evolution of requirements, and verifying that the requirements have been met. During the design process, traceability could enable designers and maintainers to keep track of what happens when a change request is implemented before a system is redesigned. All these different viewpoints should be further considered and their differences taken into account when developing the traceability scenarios and models.

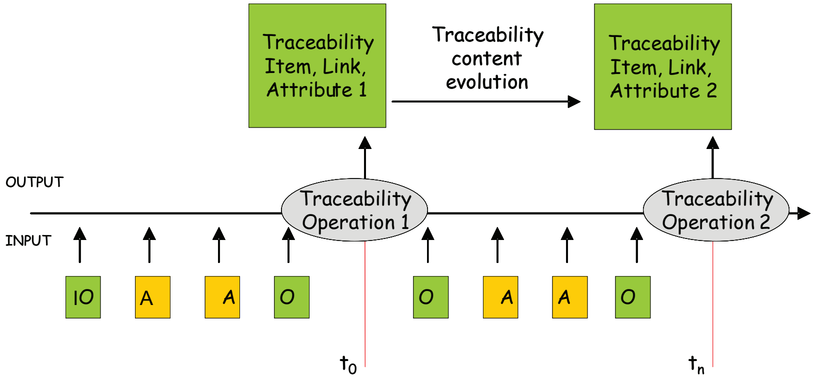

Figure 5. Traceability scenario of development of the information objects in engineering design. The inputs include both information objects and engineering activities.

The development of a traceability scenario that takes a place above the underlying process is performed consciously, with the purpose of creating traceable items from the elements of the underlying process, specifying values of the traceable meta-information and defining associations between the different traceable items as is shown on the Figure 5. The key characteristic of the traceability scenario is that the traceability operation is performed at certain point in a time, in order to create a traceable item from some of the elements of the underlying process. Since the underlying process consists of the complex set of the activities, agents and information objects, as well as complex relationships between them, on traceability practitioners is the responsibility to define what items, meta-information and associations will be captured together with its explanation.

3.4 Traceability process in engineering design – key activities

The absence of automatic techniques to assist in the identification of design routes and the lack of effective traceability support provided by tools, suggests that producing and retrieving traces would take more time than is acceptable. As can be seen from the earlier discussion, the traceability process requires the physical flow of information objects to be associated with the flow of meta-information about them. To ensure the continuity of the meta-information flow, each participant in the information object life must communicate traceability data to the next one, enabling the current user to benefit from the information contained in a trace. When considering how to achieve traceability in engineering design, the five main stages proposed in the GSI Standard [14]) on traceability in the supply chain can usefully be adopted and modified as shown below and in Figure 6:

- **Plan and organise** determines how to assign, collect, share, and keep traceability attributes. Furthermore, it determines how to manage links between traceability items. It is a prerequisite phase.
- **Align master data** determines how to assign identification to the information objects, activities, participants, locations, resources, etc. The recommendation is to align master data among participants before the underlying engineering design process begins.
- **Record traceability data** determines how to assign, apply, capture, share and store all relevant traceable items across their life continuum.
- **Request & query trace** determines how to initiate and respond to a traceability request. Any agent involved in the underlying engineering process may initiate a trace request and receive a response on this request.
- **Use traceable information** enables the use of the previous processes to take appropriate action as required different business requirements as is stated earlier in this report.

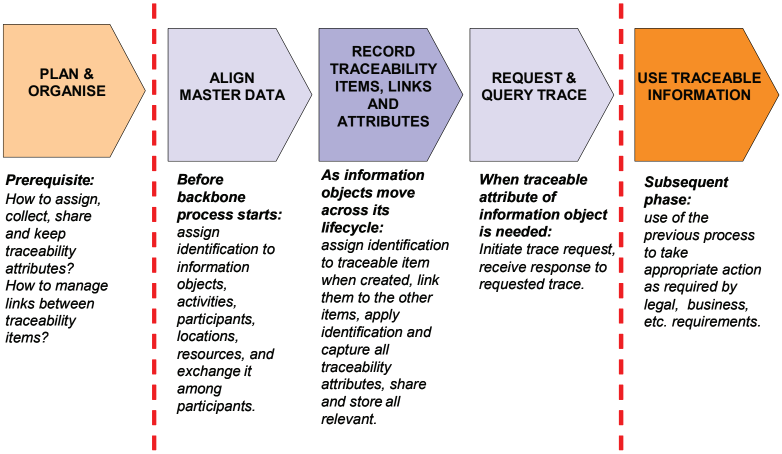

Figure 6. Traceability process in engineering design (after GS1 standard [14])

As discussed above, analysis of the concept of traceability has led the authors to the conclusion that a prerequisite for successfully traceability is a formal language for the representation of traceable items, consisting of a well-defined syntax and semantics. It is concluded also that the greater the extent that semantics are defined for traceable activities and objects, the greater the ‘intelligence’ that can be brought to bear in tracing information development. Thus, both syntactic and semantic information is needed to successfully implement tracing, because it is not enough to know only the form, it is also necessary to know the meaning of traces.

4 CONCLUSION

Consideration of the research questions relating to the traceability of engineering design information, has led closer to a fully specified framework for traceability. The following progress has been made:

- Identification of the traceability issues and understanding on the information and information objects (records) is provided
- Two-dimensional traceability space is derived including contextualization of the information objects and audit trial of the information object life phases
- Known general traceability principles from different areas provided a basis for developing a technical description of the scenarios for tracing the development of engineering design information objects
- Existing features in engineering design tools have supporting traceability based on one or two key attributes; the traceability process presented here describes traceability based on complex scenarios.

There are several directions and challenges for further research:

- To explore traceability patterns as a medium to communicate experience-based traceability best practices defined in a uniform way – of especially interest would be building research on traceability scenarios based on the engineering activities patterns for particular types of the engineering design.
- To investigate engineering design information object patterns in order to find and represent common elements of design information object structure in a form that is meaningful for tracing.
- To explore active traceability mechanisms in order to support engineers in tracing information object development with minimum extra effort, especially where tracing information can be recorded automatically.
- To investigate distributed traceability mechanisms for making information object content and context reusable across heterogeneous engineering systems.

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