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Ontologies for Product and Process Traceability at Manufacturing Organizations: A Software Requirements Approach

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Abstract— **A Traceability business process is mandatory and unavoidable on manufacturing organizations. Customers, particularly original equipment manufacturers, require it on contracts, while governments enforce it, through rules and regulations.**

Organizations fail to create and sustain a business process satisfying traceability demands. IT departments are one of the main players on efforts to create a solution, as this process is only manageable when supported by software. This document presents an approach to improve the understanding of traceability business process by using ontologies as a requirements modeling technique.

Keywords- software requirements, computer science related discipline: information management, management related discipline: information systems

I. INTRODUCTION

Traceability on a manufacturing organization, aims the persistence of the relevant information related with the organization core activities. Nowadays a traceability business process (BP) is mandatory and unavoidable on any organization acting as a product provider. Externally, it is explicitly required on customer contracts, particularly when established with original equipment manufacturers (OEM). Governments, also, enforce it through rules and regulations. Internally, to pursue continuous improvement and answer the requirements of increased efficiency, it is necessary to track the manufacturing activities information with high accuracy and detail.

Organizations face several difficulties to implement and sustain a business process satisfying traceability demands. The roots of main difficulties lie on the lack of understanding and agreement by main players on the meaning of traceability concepts, concrete demands, and the process nature itself. Traceability is not a new concern, yet it cannot be considered well understood and defined.

The relevance of this research topic was already recognized on academic and business fields. European Commission's invested €100M on projects TRACE [1] and PETER [2], to increase research on food traceability. GS1, an international not-for-profit association composed by multinationals, retailers and manufacturers, created a Global Traceability Standard on 2006 [15].

IT departments are one of the main players to provide a solution, as this process only becomes manageable when supported by software applications. An organization possessing a degree of operational complexity that require software solutions to handle its manufacturing and logistics activities, cannot cope with traceability on a manual approach supported solely by paper work [45]. Besides, higher complexities on operational activities (e.g. raw material income, lot use, resources parameters) enforce the support of software solutions [46].

However, the development of these solutions is compromised, since requirements elicitation, by the lack of understanding on appropriate support to this process. Current research aims to facilitate the development of software solutions to support traceability BP, and along process to provide artifacts that act as enablers on organizational efforts to implement this business process. This PhD thesis addresses the knowledge improvement of traceability BP, supported by core artifacts, such as an ontology of traceability BP and respective taxonomy, which are expected to provide a common and improved understanding to all players, and become particularly valuable along the requirements elicitation efforts.

Traceability core activities are deeply connected with information handling: acquire, relate, persist and provide [35, 43]. Advances on these areas, through new artifacts, techniques or methods may positively feedback traceability process, triggering and sustaining its improvement [9].

This manuscript sustains that significant traceability problems are addressable through software engineering research, namely, the construction of domain models based on ontologies. Resulting outputs will benefit software engineering and business (e.g. Quality, Logistics, and Operations) fields simultaneously. Also promising is the potential to create new artifacts to software developers.

Next section provides a summary of relevant literature on traceability business process (traceability BP) in manufacturing organizations. Third section addresses the research objectives and the methodological approach. Section 4 briefly describes past work and preliminary results. In Section 5 future work and expected results are presented. Last Section depicts some conclusions.

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II. State-of-the-Art

This section presents traceability BP state-of-the-art, the main problems a manufacturing organization encounters to set it up and how research addresses them so far.

A. *Definition and Goals*

On this document, traceability is understood as "the ability to track forward the movement through specified stage(s) of the extended supply chain and trace backward the history, application or location of that which is under consideration" [15].

The traceability responsibilities are the identification and trace of the history, distribution, location, and application of products. A traceability system must record and follow the trail as products that come from suppliers, are processed and distributed as end products.

Traditionally, its main purpose is linked to product recall: "... a procedure to withdraw all products with a particular deficiency from the supply chain" [24].

But traceability may serve many other organization processes. Töyrylä identified applications that benefit from traceability data (Table I.). These applications, consumers of traceability information present the broad range of its usage.

Traceability can protect a producer from product liability claims, providing the evidences necessary to prove law requirements were completely fulfilled. It may also serve to demonstrate a product origin or flow. Proof-of-origin usually aims to satisfy market demand for information [10, 12].

Traceability data can be the primer input to monitor, control and manage organizational quality and processes, also its information may become a solid support for their improvement [8, 24]. Proof-of-quality implies the ability to provide evidences on quality assessments realized on manufacturing process. An organization may reject the responsibility on failures based on these evidences. Besides, it may also self-promote a Quality image toward its customers, becoming quality certified [10, 24]. Traceability information can provide the basis to identify security breaches, through the products' monitoring along its supply chain, and enable the identification of counterfeit and illegal items. It may also be used to track moments or locations along the supply chain where products are prone to suffer damages or be deviated.

TABLE I. Traceability Consumer Applications

Consumer Applications	Guard	Promote
Recall	x	
Product -liability-prevention	x	
Quality- and process-improvement	x	x
Proof-of-quality and proof-of-origin	x	x
Logistics		x
Security	x	x
After-sales	x	
Accounting		x

On logistics, traceability information may be used to optimize material routes and improve planning and management, mainly due to improved links to the other organizations with whom there is collaboration.

Warranty data may be handled on Traceability, linked to a product, and serving as input to after-sales.

Traceability may work with accounting applications to evaluate inventory or with controlling applications to identify process inefficiencies.

Traceability information, on a manufacturing organization, protects or limits the damage and costs if a problem occur, menacing the organization [14]. Simultaneously it also sustains the organization change management process and respective improvement efforts as presented on table A1 [24, 28, 31].

There is another important traceability BP responsibility that does not specifically fit prior classification. This process must implement and obey government regulations, laws, customer requirements and standards (mandatory for respective certification) that directly address traceability.

B. *Relation with Software Solutions*

According to Töyrylä, "technical enablers include the computerization of data processing and the use of automatic identification in data collection." The need to ensure "Long-term availability of data" and "the frequency, quickness and accuracy of the information collection" address directly data persistence and recording responsibilities of software solutions [45].

Software solutions are also enforced by the need of fast response times, particularly when retrieving data [11]. On manufacturing environments, traceability activities must be synchronized with production infrastructure and respective operations [28]. The automation of manufacturing enforces a similar approach on related traceability activities. Panetto [38] suggested that any manufacturing software solution should have traceability data acquisition embedded.

Neto [35] and Terzi [43] stated that traceability activities are information management activities, rendering IT knowledge applicable on the study and improvement of traceability itself.

Buhr [9] recognizes it is not only the traceability process that pulls software solutions with supporting needs. The information technology revolution exemplified by the Internet and the underlying information-technology hardware (e.g., increased computer processor speeds, increased data-storage capacity, electronic data capture and measurement devices) push and enable traceability process to wide its scope and detail. Terzi [44] identified new technologies which applied on product identification leverage traceability software solutions to more detail and accuracy.

C. *Opportunities*

Despite their best efforts, manufacturing organizations face several vicissitudes when implementing a traceability business process. Some of the difficulties are related with the support of traceability BP by software solutions, and root problems specific of IT field. In parallel they also raise opportunities that are better tackled through software solutions. Main challenges, identified on literature, are presented hereafter.

Ideally "all information regarding products is recorded" [38]. However the size of traceability data has an impact on the respective required management effort. To improve traceability efficiency or even to render it practicable, the quantity and quality of the information that should be collected must be reduced to a manageable and appropriate amount. This evaluation must be sustained on sound knowledge of the traceability BP and the relative interest of subjects to trace [24, 31, 46].

A software supporting traceability must be able to receive, identify and handle data, regards its type [21, 26, 38, 43, 44, 46]. "The heterogeneity of applications managing information (ERP, PDM, MES... [1]), of users transforming, using and producing information (different operators), even of the meaning, the same information may address on different domains of pertinence (business or manufacturing), raises difficulties to the information recovery, leading traceability systems to fail at collecting information" [46]. Interoperability problems are outcomes of the differences between organizational units and between partner organizations.

Traceability is deeply interconnected with other business processes. The product/process data to trace is embedded in the activities included on other organizational processes [38, 41]. Due to the pervasiveness of traceability activities, respective responsibility is spread among several organizational unit, each one with different interests and approaches [44].

Traceability BP is not limited to a single organization boundary with a single set of traceability syntax, semantics, and concepts [16, 26, 27]. Also on the organizations network traceability requirements must be balanced with security, or secrets constrains [41].

As Gampl [14] states the organization' management lack a clear knowledge of the traceability nature. This lack is common also among stakeholders giving birth to vague, fragmented and incomplete requirements [8, 33].

Several efforts were developed to minimize the lack of knowledge problem. Various enterprises join together and defined a Traceability Business process standard [15]. ISO standards refer traceability and certify its implementation [5]. SAP summarized traceability best-practices [42], and European community issued new regulations [13]. All these documents contain valuable knowledge to guide the efforts to implement traceability.

III. Research Objectives and Methodological Approach

A. Research Objectives

The literature review revealed that lack of knowledge, on traceability BP, besides being a constraint on organization efforts towards its implementation, also was the root or acted as an amplifier of other perceived difficulties. Within the development of software solutions, the work of several players, is polluted by misunderstandings and fragments of traceability concepts. These difficulties have high impact on developers of software solutions, and interfere on the early stages of a solution development, on requirements engineering and design [19].

Traceability BP body of knowledge is currently scattered among several initiatives such as ISO standards, European regulations, and best-practices [1, 5, 13, 15, 42]. Regards the richness of contained knowledge, this documentation is hard to apprehend and use on the context of IS application domain. "There is a clear need to make them more abstract and to define methodologies in order to facilitate understanding of their defined concepts" [38].

The improvement of traceability understanding from the software developer's point of view will reduce lack of knowledge about what the system should do the technological options and the future situation [33]. It will also reduce "misunderstanding of concepts, ideas and definitions, making use - whenever possible - of shared standards" [44].

Tursi [46] propose the use of an "Ontology for the representation of domain's knowledge, in order to ensure a non ambiguous understanding of objects and concepts". A traceability BP ontology providing the domain concepts and relationships among them (conceptual relations) provides an adequate solution to address this difficulty [7].

Gasevic recognized that existing ontology development methodologies are fairly general and only suggest steps to be followed [17, pag.65]. Resulting ontologies tend to be very sensitive to their developers skills, and specificities of the environment where the knowledge is acquired. For the purpose of this research the resulting ontology must be general and independent of any particular organization characteristics. Thus the development process must be repeatable and result on similar traceability ontologies despite their developers or the environment where it occurs.

Therefore, the first research question is:

Q.1. How to create a traceability business process ontology?

Contained on this ontology, are general characteristics, recognizable as adequate properties of a software solution, aiming the support of traceability BP. Characteristics that refer the purpose, the needs, the goals, the functionalities, the constraints, the qualities, the behaviors, the services, the conditions, or the capabilities, and may ground a process to identify a software solution requirements [25].

The specific needs on the software to support traceability for a particular organization are only possible to obtain through requirements elicitation. From this effort, however, it is also common to collect overlapping or conflicting requirements, all together with others that are isolated and that do not make sense on domain.

This ontology, providing a more abstract and global overview of the domain, may be used to drive and focus the refinement of requirements, identifying the gaps where additional requirements should procured or even completing them. It may also clarify the conflicts between requirements. Main challenge is how to juxtaposing the detail, specific

[1] Enterprise Resource Planning (ERP),Product Data Management systems (PDM),Manufacturing Execution Systems (MES)

requirements from organization stakeholders with the ontology broad domain mapping.

Second research question is brought by this possibility:

Q.2. How to infer and validate the requirements and models of a Traceability software solution from respective ontology?

The identification of traceability BP requirements was also proposed on Terzi [44], Samarasinghe [41], and Khabbazi [28] studies. On a parallel approach, Ramesh [39, 40] proposed "a framework for a traceability based knowledge management system to support the design, customization and delivery of information product and e-service families".

B. Methodological Approach

The previous literature review identified, that problems addressed on current study, were already described and explained. However they are not yet solved. To reduce their significance, and simultaneously improve the understanding of traceability phenomena, an adequate strategy is to prescribe solutions to these particular problems and create artifacts that embody those prescriptions [34]. This strategy belongs to design science paradigm. It is focused on business needs and in utility. Also the goals aimed by presented research questions are appropriate to be pursued through Design Science, as it "seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts" [18]. Hevner cleared that these "IT artifacts are broadly defined as constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices), and instantiations (implemented and prototype systems)" [18].

An important characteristic of Design Science is its pro-activeness with respect to technology, attempting to lead the evolution of software research and not merely react to it [18, 22].

Therefore, the proposed study will be structured according Design Science Research (DSR) methodology.

DSR uses an iterative approach (see Fig. 1) beginning with the Awareness of a Problem, a solution is created, drawn abductively from existing knowledge. The rigor of DSR is derived from the effective use of prior research (existing knowledge base) [18]. Solution and respective Artifacts are evaluated through metrics that instantiate the research goals [34]. These steps are repeated until a satisfactory solution to problem is found.

On research conclusion the knowledge acquired during process is consolidated, discovered through the detection and analysis of contradictions, only present on the specific act of constructing [30].

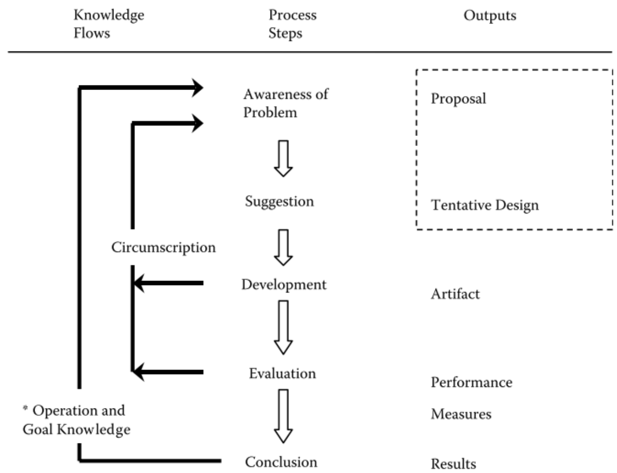

Figure 1. Design Science Research Cycle (Vaishnavi [30]).

IV. PAST WORK AND PRELIMINARY RESULTS

This research aims the development of new knowledge, in parallel with artifacts that uphold the development of IS solutions supporting traceability BP. It pursues Hevner's principle [18], where "The objective of research in information systems is to acquire knowledge and understanding that enable the development and implementation of technology-based solutions to heretofore unsolved and important business problems."

The technological solutions this research pursuit is an ontology of traceability BP, able to support the development of software solutions mainly on requirement elicitation and on solution validation [6].

This PhD work is partially conducted on a manufacturing organization, Bosch Car Multimedia Portugal S.A.. The first cycle of the research plan is currently on the development stage. The awareness of problem was grounded on lessons learned from past projects to implement traceability on the enterprise, which confirmed the negative contribution of lack knowledge to projects success, as literature also identified.

On this first cycle a traceability taxonomy is being developed. It will be used as input on next Traceability related project during requirements elicitation. On the design of current cycle a taxonomy was preferred to an ontology as the main artifact to reduce study complexity. However this option may limit study's scope to the Requirements phase of the project, as we foresee that Architecture and Verification/Validation project's phases may only be addressed on this research through the use of an ontology.

V. FUTURE WORK AND EXPECTED RESULTS

Subsequent research cycles will address the development of a Traceability Ontology and its contribution to Software Engineering on the knowledge area of Software Requirements [6]. At end of each cycle we will obtain constructs (i.e. basic language of concepts to characterize phenomena), models (i.e. constructs combined in higher order constructions), and methods (i.e. ways of performing goal-directed activities) [34]. In the process, this research may contribute on the improvement of theories related with the methodological construction of the artifacts or, related with relationships between artifact elements [23, 30].

Through the development of the Traceability Ontology we will obtain a well-organized body of organizational and strategic knowledge. To ensure that resulting ontology is generic, yet complete, major inputs for its creation will come from existing literature on academic and business field, namely existing traceability standards. This approach discards the single and specific knowledge that may exist on the development environment, in favor of the one with broad acceptance. Simultaneously, by enforcing the use of similar inputs it expectable the outcome of similar traceability ontologies. This knowledge shared across IT department and other stakeholders, will ground the deepening and sharing on the understanding [47]. This research vector with main focus on creating an ontology will use as start-up studies aiming the development of an enterprise ontology [4, 7] and product ontology [46], and on its prosecution adjust and improve the theories, methods and models used. We intend to use the 4SRS (Four Step Rule Set) method on the ontology development, and also to promote the results uniformity and quality [48].

Research cycles linked to the installation of traceability on an organization will also enable to pursue the reuse of domain knowledge [32] and the prevention of misunderstandings [20]. These research cycles focus on the ontology use, as a source of generic requirements to an IS solution supporting traceability BP, which instantiate the systematic framework conceived by Yu [47] to help developers understand what stakeholders want. As Sutcliffe [3] and Lam [32] endorsed they promote re-usability, even at later stages, improving software development productivity and quality.

Another study focus is the use of the ontology to support the verification and validation of requirements expressed by stakeholders and of the models on proposed software solution. The development of techniques that, by overlapping the ontology and stakeholders' requirements, base the evaluation of requirements reasonableness, consistency, completeness, suitability, and lack of defects [19]. We also expect that the ontology may be used (translated) as meta-model enabling the quality inspection of the software solution' models. More than behavioral models, on traceability, the data models [36] are critical due to the large volumes of information it uses and generates. Careful decisions need to be made about what information the system will need to represent, and how the information held by the system corresponds to the real world phenomena being represented.

Also on this research cycle we will study the creation of the domain model through the traceability ontology instantiation.

This research will reduce the task of creating application-specific models and will provide tools for its evaluation [39].

VI. CONCLUSIONS

Literature review enlightened that traceability is important to the scientific community, and also, that serious problems are still demanding proper solutions.

Organizations may obtain immediate benefits, if current difficulties they face when handling this business process are reduced. The root of main difficulties, lie on the lack of understanding and agreement, by main players on the meaning of traceability concepts, concrete demands, and the process nature itself. Several efforts were developed to minimize this problem through the creation of standards, laws, and regulations. Yet, each of them was unable to produce a complete traceability conceptualization or implementation guideline. Each one is focused on a strict range of interests, and scope it addresses.

This document proposes the use of software engineering methods and techniques (namely, ontologies and models) to aggregate, disambiguate, and blend existing knowledge.

This research expects to contribute to the body of knowledge of traceability business process, mainly to the software requirements community. Main relevance of this study will come from artifacts conceived and respective applicability on manufacturing organizations to implement software solutions.

The analysis and synthesis of literature on ontology building is also expected to produce a valuable feedback to respective authors, regarding completeness, coherence, etc.

The development and use of the artifacts, constructs, models, methods, and theories will be tested, and improved or adapted. The observation of this development will bring new knowledge to ontology engineering and requirements engineering.

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