# SUSTAINABLE REFERENCE ONTOLOGY DEVELOPMENT IN METROLOGICAL DOMAIN

**Carlos A. Costa, berto@dem.uminho.pt**
**João Mendonça da Silva, jpmas@dem.uminho.pt**
CT2M, Universidade do Minho, Campus de Azurém, 4800-048 Guimarães, Portugal

**João Sarraipa, jfss@uninova.pt**
UNINOVA, Faculdade de Ciências e Tecnologia, FCT, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal

***Abstract.*** *Manufacturing teams face the challenge of integration and reuse of computational information systems and knowledge. The management of information systems dealing with heterogeneous data and semantics meets the problem of interoperability between software applications, and it has been the basis to research on methodologies for the sustainability of reference ontology development. Ontologies facilitate the computational understanding, communication and seamless interoperability between people and organizations. They allow key concepts and terms relevant to a given domain to be identified and defined in an open and unambiguous way. Therefore, ontologies facilitate the use and exchange of data, information, and knowledge towards intelligent systems interoperability. Tasks on distributed and heterogeneous systems demand support from more than one ontology. Multiple ontologies need to be accessed by the same, but also different systems. The distributed nature of ontology development has led to dissimilar ontologies for the same or overlapping domains. Thus, various parties with different ontologies often do not understand each other. To solve these problems, it is suggested the use of ontology mapping geared for interoperability. This paper proposes a methodology to support the development of a common reference ontology for a group of endeavors sharing intense supply chain and metrological information exchange. This methodology enables each partner to keep its own terminology, glossary and ontological structures, providing seamless communication and interaction with the others, assessed by interoperability checking processes for an overall interoperable level of interacting systems. A use case in mechanical engineering domain is described and the proposed methodology demonstrated.*

***Keywords****: CAD, Product lifecycle management, metrology, knowledge management, ontology harmonization*

## 1. INTRODUCTION

The globalization of markets and manufacturing has forced the management to look in processes that penetrate networks of organizations. The formation of cooperation and collaboration alliances between several small organizations is proving, in multiple cases, to be more efficient and competitive by comparison with big companies. Thus, the research on manufacturing management has turned from an intra-enterprise focus towards an inter-enterprise focus [1].

Manufacturing and its supply chains consist of different structures: business processes and technological, organizational, technical, topological, informational, and financial structures. All of these structures are interrelated and change in their dynamics. To ensure a high responsiveness level, the manufacturing and supply chain plans must be formed extremely quickly, but must also be robust enough to a quick adaptation. The increasing competitive pressures coupled with the rapid advances in information technology have brought manufacturing planning into the forefront of the business practices of most organizations [2]. Consequently, there has been a growing interest in electronic business (e-business) solutions to facilitate information sharing between organizations in the supply chain [3,4]. However, partnerships cause some problems mainly in integrating Product Life Cycle phases, since manufacturers, distributors, designers, retailers, warehouses, often acquire their proprietary solutions which are, typically, not interoperable with another [5].

Due to the large number of worldwide available software components in a specific manufacturing domain, each enterprise has its own software, thus when it is needed to do business with other enterprises in the same domain, application and data interoperability problems emerge [6]. Standardization in data structures appeared to solve the referred communication problems [7]. Several initiatives were taken to address this issue, like ISO10303. ISO 10303, also known as STEP, is the standard for the exchange of product model data. STEP Application Protocols have been widely used in industrial environments, to support systems interoperability through the exchange of product data in manufacturing domains. However, this kind of data representation standards did not solve all the problems [8].

Semantics interoperability problems still remain to be solved [9,10]. More recently, the development of ontologies, as promising techniques with capabilities to solve semantic issues, has been addressed by important companies and SMEs. Thus, each company is struggling to develop competencies at this ontological level, but inevitably different perspectives will lead to different final results, and achieving different ontologies in the same business domain is the reality [11,12]. One possible solution is to have a reference ontology for a specific domain where all the domain enterprises should use in their business. Although, to force manufacturers or suppliers to adopt a specific ontology as reference is not an easy task, since each enterprise does not foresee any outcomes by changing their knowledge. Thus, an advantageous solution would be to let them to keep their terminology and classification in use, and adopt a reference ontology. The adopted ontology will be the organization knowledge front-end, enabling inter-enterprises communications sharing the same terminology and semantics. Since this reference ontology will become their front-end, each organizational enterprise should feel motivated to participate in its building process, contributing with their own terminologies, definitions and classification structure.

System methodologies for enterprise interoperability facilitate organizations to keep its technical and operational environment, improving its methods of work and the usability of the installed technology through quality assurance of the system software components, ontological harmonization of the enterprises product models in use, assessed by a fitting validation framework for conformance testing and interoperability checking.

To get an enterprise organizational system interoperable, a domain reference ontology has to be adopted which enhances inter-enterprise's semantics interoperability concerning to the contents of a standardized data representation model. These both components (reference ontology; data representation model) should be complemented with software quality assessment and interoperability checking methodology able to make the model conformance testing (Fig. 1).

The paper proposes the integration of the VALTE (section 2) and MENTOR (section 3) methodologies, complemented by interoperability checking methods (section 4), to contribute for seamless manufacturing supply chain planning (section 5) in mechanical engineering domain. The paper finishes discussing a case study in the mechanical engineering industrial context.

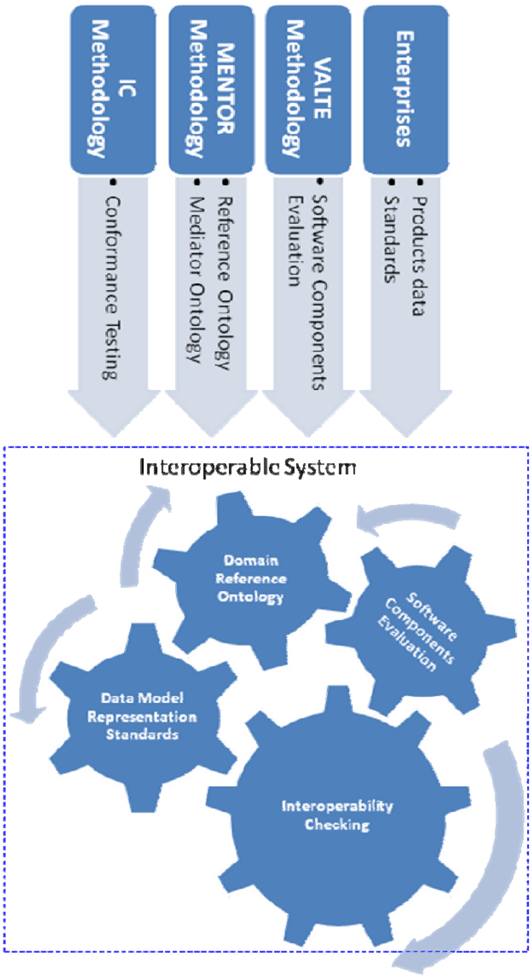


Figure 1. System interoperability methodologies

## 2. VALIDATION AND TESTING OF SOFTWARE COMPONENTS

The essential parts of software quality evaluation are the quality model, the method of evaluation, software measurement, and the supporting tools [13]. To develop good software, quality requirements should be specified, the software quality assurance process should be planned, implemented and controlled, and both intermediate products and end products evaluated [14].

VALTE is an evaluation methodology for supply chain software components, using as reference the Software Product Quality Evaluation Reference Model that describes the process, activities and tasks performed during the quality evaluation of a software product. This reference models is defined by the standard that contains general requirements for specification and evaluation of software quality and clarifies the general concepts providing a process description for evaluating quality of software product, stating the requirements for the application of the evaluation process [15]. This specification is part of the SQuaRE series of standards created by ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) [16][17].

The VALTE methodology reference details the activities and tasks providing their purposes, outcomes and complementary information that can be used to guide quality evaluation of a supply chain software component. To evaluate the software quality it is needed, first to prepare the evaluation, then establish the evaluation requirements, specify, design, execute and, finally, report the evaluation (Fig. 2).

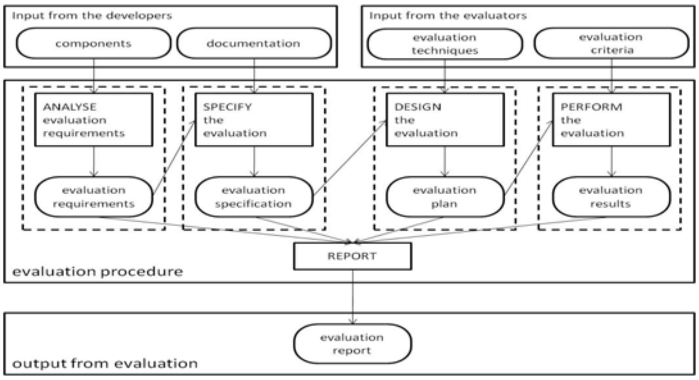

Figure 2. Information flow and activities of the VALTE evaluation methodology

The developers must provide as input the components and their documentation, in the other hand the evaluators should define the evaluation techniques and the evaluation criteria, in this paper the evaluation is defined by the VALTE methodology for a supply chain software component [18].

The principal motivation for using a standardized methodology when performing evaluation activities is to promote the following desirable evaluation process characteristics:

- Objectivity: the evaluation results should be factual, i.e. not coloured by the feelings or the opinions of the evaluator.
- Impartiality: the evaluation should not be biased towards any particular result;
- Reproducibility: evaluation of the same component to the same evaluation specification by a different evaluator should produce results that can be accepted as being identical;
- Repeatability: repeated evaluation of the same component to the same evaluation specification by the same evaluator should produce results that can be accepted as being identical.

The evaluation procedure comprises a number of steps (Analyse; Specify; Design; Perform) which divide the evaluation into discrete activities. The evaluation requirements are formal records of the agreement between the producer of the software and the evaluator of what is covered by the evaluation process. It provides a list of software characteristics which is to be evaluated, their evaluation level and it identifies the source of data and evidence which can be used in the evaluation process. The evaluation specification, besides the more formal description of the evaluation requirements it consists on the identification of the received documents and classification of the available items into product, process and supportive information, in order to identify which evaluation techniques can be applied. The evaluation plan includes the list of evaluation modules to be applied and that will guide the evaluation activities. The evaluation results will be stated based on the metrics and measures defined and the positive or negative response of the software components to all the tests performed.

The intended of this evaluation strategy is to be a guide when actually running architecture evaluation activities. For that, it contains a level approach to quality characteristics and a flexible view on classifying components and process information. The evaluation methodology is designed to support the evaluation of all architecture components without need for modification of its basic principles. This will provide a more balanced and equal evaluation result of all the components of the architecture.

VALTE identifies relevant evaluation techniques in order to have a set of applicable Evaluation Modules (EM) defined and applied to evaluate supply chain planning architectural components proposing seven evaluation modules according with the evaluation techniques defined for each quality characteristic. These modules describe and guide the evaluators when performing the evaluation of architecture components: EM1 - Functionality: Functional Test Cases; EM2 - Functionality: Unit Tests; EM3 - Reliability: Fault tolerance analysis; EM4 - Usability: User interface; EM5 - Efficiency: Execution time measurement; EM6 - Maintainability: Inspection of documentation; and EM7 - Portability: Analysis of software installation procedures.

The intended of this evaluation strategy is to be a guide when actually running architecture evaluation activities. The level approach to quality characteristics and a panoramic view on components and process information classification helpfully provide required support. The evaluation methodology is designed to support the evaluation of all architecture components without need for modification of its basic principles. This will provide a more balanced and equal evaluation result of all the components of the architecture.

## 3 MENTOR: METHODOLOGY FOR REFERENCE ONTOLOGY DEVELOPMENT

A reference ontology development follows the MENTOR methodology. Its main objective is to help an organization to adopt or reuse and to build, a domain reference ontology, after through several main steps as semantic comparisons, basic lexicon establishment, mappings among ontologies and others operations on knowledge base representations [19].

The method to support the development of a common reference ontology for a group of enterprises sharing a business domain, provides several steps as semantic comparisons, basic lexicon establishment, mappings among ontologies and other operations on ontologies. This methodology considered the state-of-the-art in terms of ontologies merge and concatenation (and applications and tools as well [20-23]) but trends in the research field [24][25].

This method is composed by two phases with three steps each (Fig. 3): the Lexicon Settlement - Phase 1 (steps: 1; 2 and 3), and the Reference Ontology Building - Phase 2 (steps: 4; 5 and 6). All of these steps are deeply described in the following two pictures where each step has a set of actions which has a number related to the step which belongs to (e.g. 1.1 is an action of the step 1).

The Lexicon Settlement phase (steps: 1; 2 and 3) represents a domain knowledge acquisition which comparatively to the human language apprentice phase could be represented in computer science as a semantic organized structure with definitions.

The thesaurus can represent such words structure of associated meanings and thus should be built in order to establish the lexicon of a specific domain. This phase has three steps: Terminology Gathering (step 1); Glossary Building (step 2) and Thesaurus Building (step 3). These steps define a set of workflows that establishes a thesaurus of the domain before starting the ontology building.

Figure 3 (left part) depicts the state diagram of the lexicon settlement phase. The terminology gathering step concerns to the process of collecting all relevant terms (action 1.2) in a specific domain previously defined (action 1.1). All the participants in the process should give their inputs. There is no rule from where the terms should come. Since they are related with the domain established. Tools for automatic extraction of domain related terms can be found, nevertheless there is always need of a human checking before close the terms list to not miss any domain terms. All the terms provided from the contributors are acceptable in this step (action 1.2). Nobody has authority to erase other's participant term. The term should be collected with reference to the contributor in order each contributor provide term's annotation in the next step (action 2.1).

Glossary is a specialized vocabulary with corresponding annotations. This vocabulary includes terms that are unique to the subject, have special meaning in the field of interest. The annotations include descriptive comments and explanatory notes for the terms, such as definitions, synonyms, and references. A Glossary can be used when communicating information in order to unify knowledge sharing. The Glossary Building step (step 2) intends to build a glossary in the domain defined. It starts with annotations attribution (action 2.1) to the terms collected. Each contributor should provide the annotations for his own terms. After having all the terms provided with annotations, it proceeds to the terms revision cycle (actions: 2.2; 2.3 and 2.4). In this cycle it could be useful to use a multi-language dictionary (action 2.0) in case of the organization members don't use the same natural language. The dictionary will help translations to the agreed language for the reference ontology. The terms revision process can have semantic and syntactic cases of mismatches (action 2.3), where they are recorded as a semantic mismatch for future mappings using the proposed Mediator Ontology (MO).

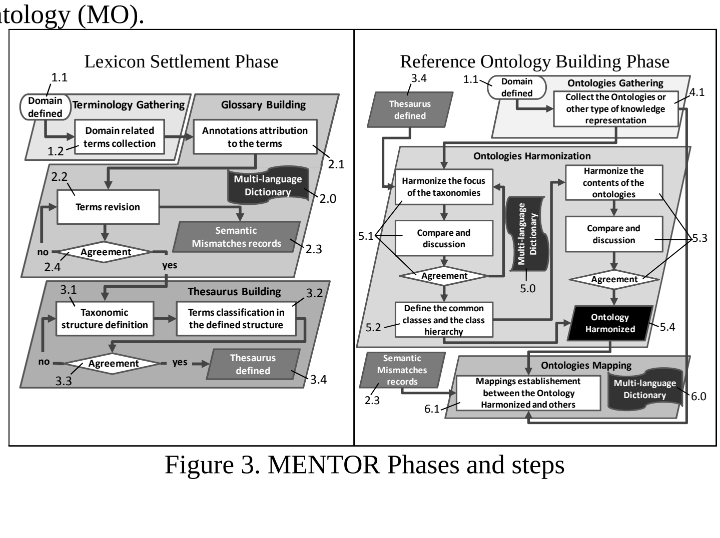


Figure 3. MENTOR Phases and steps

After a careful revision in all the terms (action 2.2) with a successful agreement (action 2.4) in their meaning consolidation, the glossary is defined from the terminology list in the domain specified. Another output from this process is the semantic mismatch records (action 2.3): this is made using the Mediator Ontology.

The Thesaurus Building step (step 3) is composed by a cycle where firstly, the knowledge engineers define a taxonomic structure (action 3.1) from the glossary terms, establishing some as thesaurus node terms. Secondly, the other terms are classified to the right paths in the existent taxonomic structure, being the thesaurus leafs (action 3.2). If there is an agreement (action 3.3) in the structure and in the terms classified, the thesaurus is defined (action 3.4). If not, the cycle starts again from the taxonomic structure definition (action 3.1). The thesaurus defined will enhance the ontology harmonization process in the next phase.

The Reference Ontology Building phase - Phase 2 (steps: 4; 5 and 6) is the phase where the reference ontology is built and the semantic mappings between the organizational ontologies and the reference one is established. Figure 3 (right part) describes this.

The first step comprehends ontologies gathering (action 4.1) in the previously domain defined (action 1.1). Other type of knowledge representation could be used as input for the harmonization ontologies process together with the thesaurus defined (action 3.4) in the previous phase. The harmonization method for building ontologies, proposes the development of a single harmonized Ontology's by two cycles (actions: 5.1 and 5.3) where first the structure is discussed until having agreement on it (action 5.1), which result on the definition of the common classes and the class hierarchy (action 5.2), and then the same process for the ontology contents definition (action 5.3). From this process new semantic conflicts could be found. After agreement, the resolution could be recorded in the Mediator Ontology for further mapping establishments. With all the agreements accomplished, the harmonized ontology is finalized (action 5.4) together with the mapping tables (action 6.1), describing the ontological relationships between the harmonized ontology and each one of the individual ontologies through the use of the semantic mismatches records (action 2.3).
Semantic difficulties related to the natural language of the potential users of the harmonized ontology are likely to happen. To assist on it, the ontology is complemented with a multi-language dictionary where a set of normalized tokens gives the reference to the corresponding concepts and definitions in different native languages (actions 5.0 and 6.0).

## 4 VERIFICATION OF INTEROPERABILITY

During latest years, the architecture of the STEP Application Protocols has been revised to promote the reuse of software components, where the testing and quality assurance plays a critical role in the implementation of the STEP software components when applied to different types of manufacturing and e-Business systems.

Interoperability Checking (IC) plays an important role to the company's systems, providing an appropriate mechanism to check if they are able to seamless exchange information between them. The methodology proposed for the presented case is based in the development of an Abstract Test Suite (ATS) that is used to define the set of tests to be used to verify the interoperability between the systems [26]. Figure 4 shows the diagram with the methodology for validation, in this case considering to systems in validation, i.e., "Computer System" and "IC System".

To guarantee the systems interoperability, these steps would be executed to all the cases defined by the ATS [27]. As depicted, the first step consists in reading a XML file provided by the "IC System". Also, the file must be validated with the Conformance Testing (CT), depicted in the system validation section. After the "Computer System" read and "understand" the information in the file, the "Computer System" modifies it with new information and send it back to the "IC System". Then, the "IC System" analyses the modified file, also improving the CT, and confirms (or not) it is able to understand the modified information that received from the "Computer System".

If the information is correctly in the modified file, the IC can notify company that their systems pass the current test. Then company must pass to the second test, executing the same steps. Doing all the defined test files, IC can ensure the Interoperability of the company's system. This service will be available online, allowing the users to download the test files and check its system. The upload of the modified files will be done by email to the community IC system. After complete the verification of the received file, the community IC system, will notify the user of its interoperability with other complaint systems.

## 5 CASE STUDY

To guarantee the survival in today's competitive and demanding digital world of manufacturing business, the European companies, especially SMEs, should be more agile, self-sustainable and responsive to the changes in the supply chain. Obtaining and maintaining a competitive edge in supply chain is not only the concern of individual SMEs, but should be also addressed by the entire chain jointly. The manufacturing and supply chain partners should collaborate effectively so as to better align supply and demand forecasts to have a joint strategy for handling exceptions that will occur in the way of realizing the "the network is the business" vision.

Nowadays SMEs consider the search for products in electronic catalogues as an important method for parts selection and supply. Along supply chain several typical situations require such part's search (for example in the replacement of a component during manufacturing or for subsequent maintenance purposes). Also, when designers intend to provide alternative solutions, preventing single supplier dependency and reducing the manufacturing costs, the inclusion of alternative parts in the design of a product is a wise approach of management requiring the handling of a range of electronic catalogues.

The necessary incorporation of different brought-in parts requires detailed data check and update by different teams, to keep valid the initial design conditions and maintain the product assembly consistency. This task is often facilitated with computational tools, and the components' data representation should be of common understanding, to reduce re ¬work and time consuming during catalogue examination.

Considering the specific example of searching for a classic mechanical bolt, many catalogues in paper or in digital format can be found. Amazingly, although all these catalogues reference to the same type of physical component, each one usually represents their specifications in different formats and with heterogeneous contents and classification. In fact, different catalogues tend to adopt different variables, unlike coding fields (though equivalent) or widespread designations, most of them diverging from available advisory ISO standard designations.

Hence, the simple choice of mechanical components suppliers by a mechanical manufacturer brings interoperability problems. Suppliers have defined various nomenclatures for their products and its associated meanings (and consequently knowledge). Thus, the need to align applications and semantics, to exchange products data emerged as a priority to solve the dilemma.

Figure 4 describes the validating scenario, where a set of enterprises agreed to work together to supply a big common client with various mechanical parts which are built collaboratively.

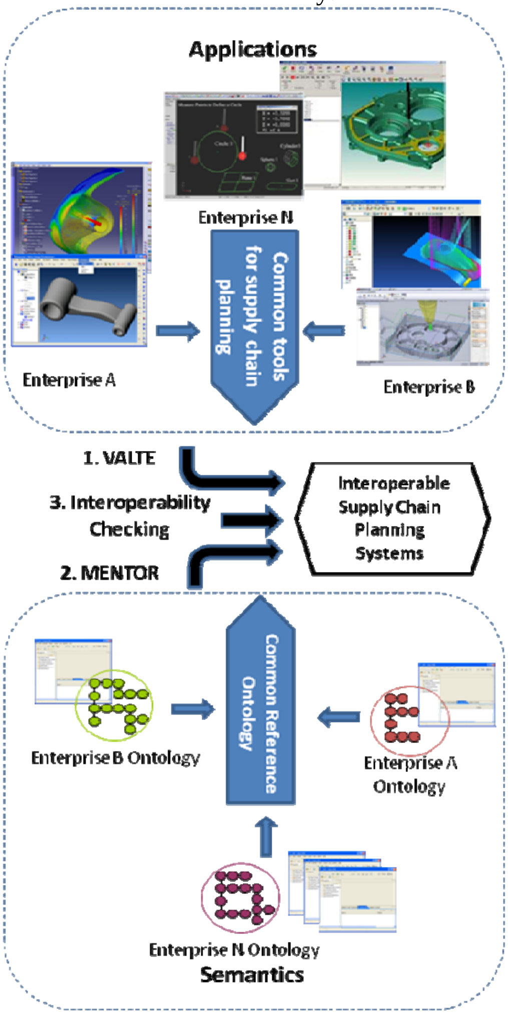

Figure 1. Case study and validating scenario

The first step is to follow the VALTE methodology (upper part of the Fig. 4), which will guide the applications evaluation activities. The evaluation follows a plan that includes the list of evaluation modules to be applied against the defined requirements related to the desired level of the software components characteristics. The evaluation results are then stated based on the metrics and measures defined, and the positive or negative response of the software components evaluation, to all the tests performed, defines if the applications belong to the set of common tools for a specific supply chain planning. The myriad of applications which gave strong support to different supply chain stages, spanning from CAD to CAPP or CMM, require a interoperable level of data exchange to profit from computational resources, in which each SME is engaged. The data from CAD applications, like CATIA or ProEngineer, in addition to data matching and semantic agreement level, require matching in technical requirements level for a successful interoperable communication with CAPP applications, like JobBoss or PLM management solutions.

In the second step, to establish a common semantic level it is developed a reference ontology to the endeavours that are working together (lower part of Fig. 4). Thus, the MENTOR methodology is used to develop such reference ontology. During the reference ontology building phase, it is produced a mediator ontology which records all the semantic operations performed in this process. One of the applications of these semantic operation logs is to use that recorded information for semantic translation. An example of such process is when a message with a product request is sent from an Enterprise A to an Enterprise B, and the mediator ontology is used to get the “semantic translation” of the information present in the message, which uses syntax accordingly to the reference ontology, to the equivalent syntax used in the Enterprise B.

Figure 5 shows a subset of the terms used by a Reference Ontology concerning the bolt domain. In this example, when enterprise B receives a request of a “Hexagonal Bolt” with a “M16 diameter”, the message is translated to a “hexagonal head Bolt” with a “Thread=Metric” with a “nominal diameter=16” assisted by terms included in the reference ontology. Although these mappings are relatively smooth to operate at Classes level, the complexity increases when going deeper in the established hierarchic semantics.

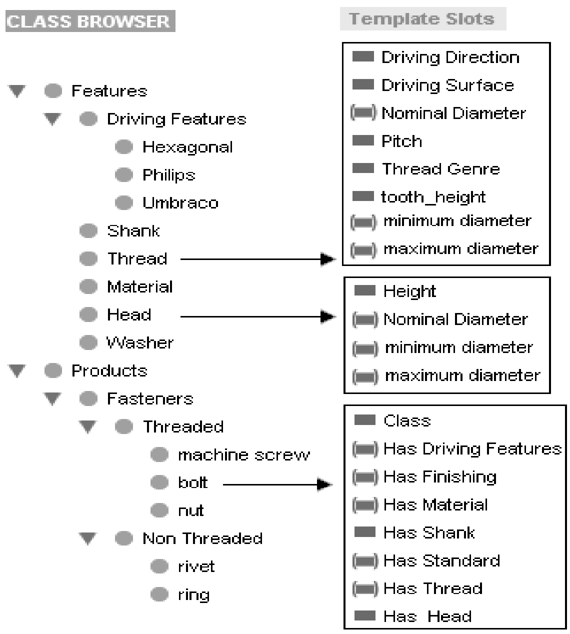


Figure 5. Reference Ontology overview

Now, it was found that Enterprise B has two terms that Reference Ontology doesn’t consider, which are Maximum Distance and Minimum Distance. It was found too that an Enterprise C, acting in the same domain of interest, has also the term Tolerance not considered in the reference ontology.

During the harmonization phase, domain engineers from both enterprises decided to use them as reference. Thus, the concepts Maximum Distance and Minimum Distance, used as a property, by enterprises B, it may result in a no-interoperability relatively to enterprise C. The same may occur due the term Tolerance used by the last.

Hence, it was created three new other concepts in reference ontology: Maximum Diameter, Minimum Diameter and circularity. The first two defined as the maximum and minimum allowable variability in the process or characteristic in analysis; and the last concept defined by the difference between the radius of two concentric circles, whose value must be less or equal than to tolerance [ISO 1101, Annex B]. MO logs all this operations, keeping the consistency between the ontologies.

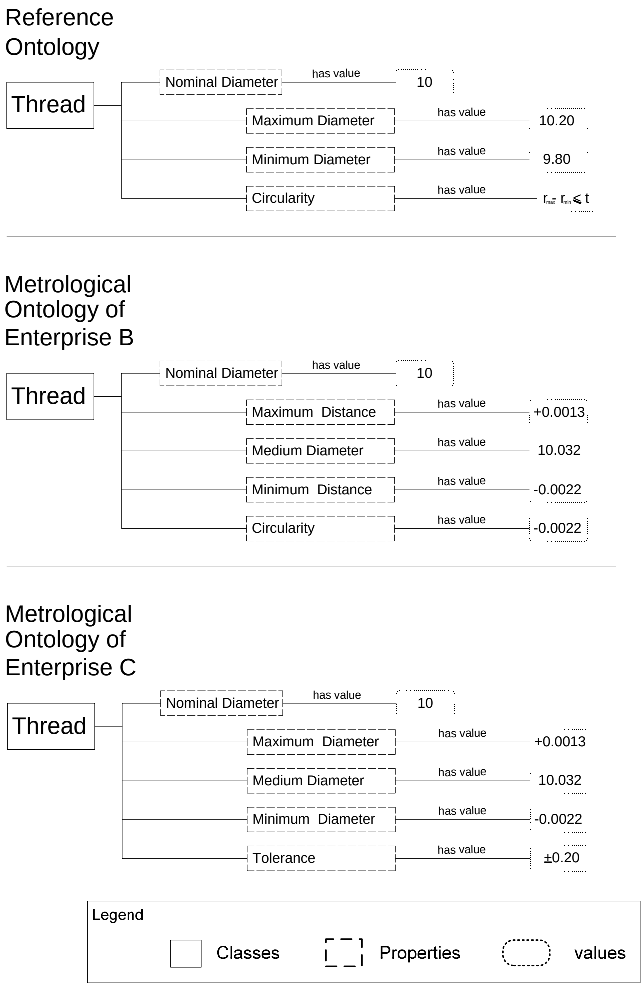


Figure 6. Mediator’s Translation Example

Semantic messages translation can be one of the MO use. Since all the ontology related operations are saved in the MO, appropriate queries could be used for semantic translations between the organizations members, including an hypothetical organizational front-end which uses the established reference knowledge. The example of Fig. 6 explains what happens to Enterprise B side when using the MO to translate messages according to reference ontology. The *maximum diameter* and *minimum diameter* reference concepts, which appear in the communication content, is replaced by MO to *maximum distance* and *minimum distance*. This way, Enterprise B gets and understands the messages with its own terminology and semantics, while the communication with external partners is under a common interoperable framework to all the endeavours.

One immediate advantage of the use of MO, is that method enables the computational systems of any enterprise to smoothly communicate with external parties as it was using the Reference Ontology. This is also the main motivation that enterprises may consider to adopt the Reference Ontology building process, independently of its domain expertise.

To ensure the interoperability between the systems (i.e., the third step on this use case) it is applied the Conformance Testing (CT) to the exchanged files. Based on the defined methodology for CT, the architecture shown in the Figure 7, is used to validate such files. The architecture was designed based in web-services, able to receive the files in XML format and checking them against the reference testing model using an Application Engine developed in JAVA, SAX, Schematron and XALAN.

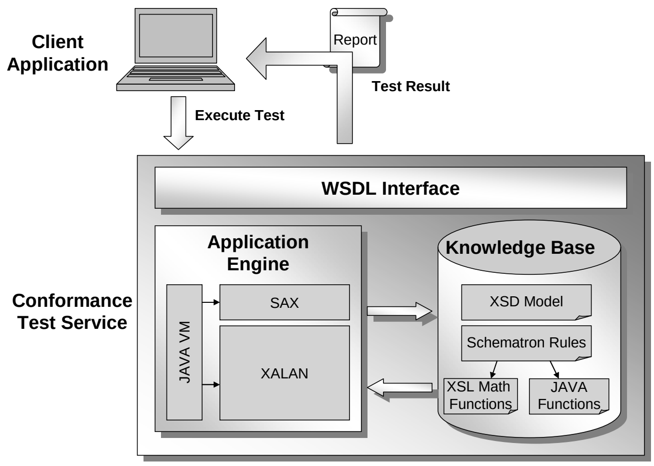


Figure 7. Architecture for CT system validation [23]

Using the CT the user can check the files against the defined models, ensuring its correct implementation. The CT checks the XML against syntactic and semantic rules and sends back the detected errors enabling its correction. Following the same example as described before, if is defined that an attribute, in the "Thread" entity, named "nominal diameter" with a value 10 must be related to 10.20 and 9,80 (maximum and minimum diameters), and the system detects a relation which have "nominal diameter=10" with 10.25 as a *maximum diameter*, the CT with the semantic rules will detect the error reporting it to the user.

With CT executed to its XML files, the next step is the application of the IC. To apply IC, the user will analyze and modify the test files, sent by the IC system, and send it back to evaluation. After check all the files, defined in the ATS for IC, the user receives the confirmation that its system is interoperable. With all the ATS executed (CT ATS and IC ATS), the system validation can ensure that the systems are in conformance with the model defined and is interoperable with others system of this type.

## 6 CONCLUSIONS

The paper proposes a methodology to enable computational systems, of any set of manufacturing enterprises which work together, to seamless communicate between each other. With it, they are enabled to understand each other using its own metrological syntax and semantics present in its own data representation when supported by a reference ontology. This achievement is assessed by software components evaluation and post conformance testing procedures. Together, this methodology and conformance testing services have been applied with good results in a real scenario, encouraging further research

The development of new framework functionalities in the future are expected, i.e., A) Automatic management of the Reference Ontology along its life cycle, by monitoring, supervising and intelligent tuning in the advent of the systems changes and updates; B) improvement in the automatic generation of the reports according to a normative schema (e.g., defined in EXPRESS and XML), to enable automatic inference and reasoning on the errors found, and provide automatic correction of the identified errors by an expert system; C) development of a cloud of web services able to set up and manage the knowledge sharing of organizations through the web, with the conformance testing services.

## 3. ACKNOWLEDGEMENTS

This work has been partly funded by the European Commission through the IST Projects i-Surf, UNITE and ENSEMBLE, and the European Commission FInES initiative: Future Internet Enterprise Systems Cluster. The authors wish to acknowledge the European Commission for their support, and to acknowledge our gratitude and appreciation to all partners for their contribution during the development of various ideas and concepts presented in this paper.

## 4. REFERENCES

[1] Rudberg, M.; Klingenberg, N.; Kronhamn, K. (2002). Collaborative supply chain planning using electronic marketplaces. In: Integrated Manufacturing Systems Journal; vol. 13; N. 8; pp: 596-610; MCB UP Ltd; ISSN: 0957-6061; 2002.

[2] Gupta, A.; Maranas, C. D. (2003). Managing demand uncertainty in supply chain planning. In: Computers and Chemical Engineering 27 (2003) 1219/1227.

[3] E-Manufacturing and Web-Based Technology for Intelligent Manufacturing and Networked Enterprise Interoperabillity, Panetto, Hervé ; Gonçalves, Ricardo ; Pereira, C. E. . Journal of Intelligent Manufacturing, v. 17, p. 639-640, 2006

[4] Value proposition of interoperability on BIM and collaborative working environments, António Grilo; Ricardo Jardim-Goncalves, Journal Automation in Construction AUTOCON, Special issue, 2009
[5] Jardim-Goncalves, R.; Grilo, A; Steiger-Garcao, A; (2007). Developing interoperability in mass customization information systems, in book Mass Customization Information Systems in Business, ISBN-10: 1599040395, Idea, 2007.1.
[6] Anderl, R., Mendgen, R., Analyzing and optimizing constraint structures in complex parametric CAD models. In: Brüderlin, B, Roller, D. (eds.), Geometric Constraint Solving and Applications, Berlin Heidelberg, Springer-Verlag, 1998
[7] ISO10303, 2003, www.tc184-sc4.org
[8] Enabling interoperability of STEP Application Protocols at meta-data and knowledge level, Ricardo Jardim-Gonçalves, Nicolas Figay and Adolfo Steiger-Garção, in International Journal of Technology Management (IJTM), 2006
[9] Drejer, A.; Gudmundsson, Agnar Exploring the concept of multiple product development via an action research project, Integrated Manufacturing Systems, 2003, Vol. 14, Number 3, pp. 208-220,
[10] Silva, João P.M.A., Jardim-Goncalves, Ricardo, Monteiro, AC, Steiger-Garcao, Adolfo, " Make the most of interoperability along PLC stages: A framework based on multilevel integration", DETC2004-57733, Salt Lake City, Utah, USA, Sept 2004
[11] Fox, M.S., Gruninger, M., (1997), "On Ontologies and Enterprise Modelling", International Conference on Enterprise Integration Modelling Technology 97.
[12] Knowledge Framework for Intelligent Manufacturing Systems, Ricardo Jardim-Goncalves, Joao Sarraipa, Carlos Agostinho, Hervé Panetto, International Journal of Intelligent Manufacturing, 2009
[13] Suryn W., Abran A., "ISO/IEC SQuaRE. The 2nd generation of standard for quality of software product". Proceedings of 7th IASTED International Conference on Software Engineering and Applications, SEA 2003, November 3-5, 2003, Marina del Rey, CA, USA.
[14] Trudel S., Lavoie J-M., Paré M-C., Suryn W., "The design of the software quality evaluation method combining CMMI and ISO/IEC 14598: the context of a small company". Proceedings of 12th International Software Quality Management & INSPIRE Conference (BSI) 2004, Canterbury, Kent, UK 5-7 April 2004. Article a obtenu le prix du meilleur article scientifique 2004.
[15] ISO/IEC CD 25040: Software engineering - Software product Quality Requirements and Evaluation (SQuaRE) - Evaluation reference model and guide, Switzerland: International Organization for Standardization.
[16] ISO/IEC 9126-1: Software Engineering-Software product quality-Part 1: Quality model. Geneva, Switzerland: International Organization for Standardization.
[17] ISO/IEC 14598-1: Software product evaluation-Part 1: General overview. Geneva, Switzerland: International Organization for Standardization.
[18] Vieira, H.; Jardim-Goncalves, R. (2009). VALTE – Methodology for VALidation and TEsting of Supply Chain Software Components. In: 15th International Conference on Concurrent Enterprising (2009).
[19] Sarraipa, J., Silva, J., Jardim-Goncalves, R. and Monteiro, A. (2008). MENTOR – A Methodology for Enterprise Reference Ontology Development. In: 2008 4th International IEEE Conference on Intelligent Systems.
[20] Fernandez, M.; Gomez-Perez, A.; Juristo, N. (1997). METHONTOLOGY: From Ontological Art Towards Ontological Engineering. Symposium on Ontological Engineering of AAAI, Stanford, California, 1997, pp. 33-40.
[21] Stumme, G.; Madche, A. (2001). FCA-Merge: Bottom-up merging of ontologies. In 7th Intl. Conf. on Artificial Intelligence (IJCAI '01), pages 225--230, Seattle, WA, 2001.
[22] Noy, N. F.; Musen, M. A. (2003). The PROMPT Suite: Interactive Tools for Ontology Merging and Mapping. International Journal of Human-Computer Studies, Volume 59, Issue 6, December 2003, Pages 983-1024.
[23] Gangemi, A.; Pisanelli, D. M.; Steve, G. (1999). An Overview of the ONIONS Project: Applying Ontologies to the Integration of Medical Terminologies. Data & Knowledge Engineering 31, pp. 183-220.
[24] Uschold, M.; King, M. (1995). Towards a methodology for building ontologies. Proceedings IJCAI-95 Workshop on Basic Ontological Issues in Knowledge Sharing, Montreal, Canada.
[25] Antonio De Nicola and al. (2005). Proc. of 16th International Conference on Database and Expert Systems Applications (DEXA), Denmark, LNCS no. 3588, Springer Berlin, pp. 655-664.
[26] Jardim-Goncalves, R., Grilo, A, Steiger-Garcao, A., (2006) Challenging the interoperability between computers in industry with MDA and SOA, Computers in Industry, Elsevier
[27] Wiles, A.; Relevance of Conformance Testing for Interoperability Testing (2003), ACATS ATS-CONF, 2003.

## 5. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.