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Methodology for Enterprise Interoperability Assessment

Dissertação para obtenção do Grau de Mestre em
Engenharia Electrotécnica e de Computadores

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Framework and Methodology for Enterprise Interoperability Assessment

To my parents, brother, sister and girlfriend

Acknowledgments

The accomplishment of this work meant a lot to me, since it represents the ending of a very important phase of my life. However, this personal achievement was not possible without the unconditional support and love of my parents, Adelina and Paulo, that all those years believed in me, and in several ways made it possible, so this work is dedicated to them firstly. I also want to thank and dedicate this document to my brother and sister, Miguel and Marta, for believing in my capabilities and the support they gave me along these 25 years. I want to say a very special thank to my girlfriend Raquel Melo especially for all the unconditional love and support, but also for being my partner along this graduation (we finally did it!). Mariana Melo, Miguel Carrinho and Francisca Carrinho, all of you deserve my special dedication for everything you did to me, you really mean a lot in my life.

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Abstract

With the evolution of modern enterprises and the increasing market competitiveness, the creation of ecosystems with large amounts of data and knowledge generally needing to be exchanged electronically, is arising. However, this enterprise inter and intra-connectivity is suffering from interoperability issues. Not visible when it is effective, the lack of interoperability poses a series of challenging problems to the industrial community, which can reduce the envisaged efficiency and increase costs. Those problems are mostly caused by misinterpretations of data at the systems level, but problems at the organizational and human levels may pose equivalent difficulties. Existing research and technology provides several frameworks to assist the development of collaborative environments and enterprise networks with well-defined methods to facilitate interoperability. Nonetheless, the interoperability process is not guaranteed and is not easily sustainable, changing upon frequent market and requirement variations. For these reasons, there is a need for a testing methodology to assess the capability of enterprises to cooperate at a certain point in time. This dissertation proposes a methodology to assess that capability, with a corresponding framework to evaluate the interoperability process, applying eliminatory tests to assess the structure of the organizations, the conceptual models and their implementation. This work contributes to increase the chances enterprises have of interoperating effectively, and enables the adoption of extraordinary measures to improve their current interoperability situation.

Keywords: Enterprise Interoperability; Interoperability assessment; Conformance checking.

Resumo

A evolução das empresas modernas e da competitividade dos mercados levou ao aumento da criação de ecossistemas, onde vastas quantidades de dados e conhecimento são partilhadas de forma electrónica. Apesar de poder tomar uma forma invisível quando os problemas não são detectados, a inter e intra-conectividade de dados pode levar a problemas de interoperabilidade e arruinar a comunidade industrial, através da redução da sua eficácia e a um aumento de gastos. Os problemas de interoperabilidade podem surgir tanto ao nível dos sistemas, devido a interpretações equivocadas de dados, como a nível organizacional e das relações humanas. Visando o objectivo de facilitar a interoperabilidade, diversas ferramentas foram criadas fazendo uso da aplicação de métodos bem definidos que ajudam ao desenvolvimento de ambientes colaborativos e redes empresariais. Ainda assim, o processo de interoperabilidade não é garantido e facilmente sustentável, podendo variar com as oscilações frequentes do Mercado. É por isso necessário criar-se uma metodologia que verifique a capacidade de duas ou mais empresas cooperarem em determinado ponto. Esta dissertação propõe uma metodologia para avaliar essa capacidade, através de uma ferramenta que avalia o processo de interoperabilidade, através de testes eliminatórios que equacionam a estrutura das organizações, o seu modelo conceptual e a sua implementação. Deste trabalho resulta a hipótese que as empresas têm de interoperar com eficácia e a facilitação do uso de medidas extraordinárias para melhorar o actual estado de interoperabilidade.

Palavras Chave: Interoperabilidade empresarial; Avaliação de interoperabilidade;

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Acronyms

AIF	Athena Interoperability Framework
AP236	Application Protocol 236
API	Application Programming Interface
ATC	Abstract Test Case
ATS	Abstract Test Suit
C4IF	Connection Community Consolidation Collaboration Interoperability Framework
DoCEIS	Doctoral Conference on Computing, Electrical and Industrial Systems
EA	Enterprise Architecture
EBXML	Electronic Business using eXtensible Markup Language
EI	Enterprise Interoperability
eID	electronic Identification
EIF	European Interoperability Framework
EISB	Enterprise Interoperability Science Base
ENSEMBLE	Envisioning, Supporting and Promoting Future Internet Enterprise Systems Research through Scientific Collaboration
ETSI	European Telecommunications Standards Institute
EU	European Union
EUT	Equipment Under Test

FInES	Future Internet Enterprise Systems
GRIS	Group for Research in Interoperability of Systems
HTTP	Hypertext Transfer Protocol
IAAS	Infrastructure as a Service
IB	Interoperability Barrier
ICT	Information and Communication Technology
IDEAS	Interoperability Development for Enterprise Application and Software
IEEE	Institute of Electrical and Electronics Engineers
IS	Information System
ISO	International Organisation for Standardization
IUT	Implementation Under Test
LCIM	Levels of Conceptual Interoperability Model
LISI	Levels of Information System Interoperability
MEI	Minimum Effective Interoperability
MPI	Maximum Potential Interoperability
MTS	Methods for Testing and Specification
NC3TA RMI	NATO C3 Technical Architecture Reference Model for Interoperability
NIST	National Institute of Standards & Technology
OIM	Organisational Interoperability Maturity
OS	Operating System
OSI	Open System Interconnection
P2P	Peer-to-Peer
PAAS	Platform as a Service

PICS	Protocol Implementation Conformance Statement
PIXIT	Protocol Implementation Extra Information for Testing
RFID	Radio-Frequency Identification
SA	Scientific Areas
SC	Supply Chain
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
STEP	Standard for the Exchange of Product model data
SUT	System Under Test
TC	Test Case
TP	Test Purpose
TSS	Test Suit Structure
TTCN	Tree and Tabular Combined Notation
UML	Unified Modelling Language
XML	Extensible Markup Language
XSD	XML Schema Definitions

Chapter 1 - Introduction

Nowadays the concept of cooperation between enterprises and enterprise systems demands a big concern about data and knowledge sharing, especially in heterogeneous environments such as international supply chains or product development networks. Competitive markets are becoming increasingly complex and dynamic and the traditional way of doing business does not provide the expected efficiency (Jardim-Goncalves, Agostinho, Malo, & Steiger-garcao, 2007). Indeed, in most cases, a single company cannot satisfy all customers' requirements. It needs to streamline its supply chain (SC), and collaborate actively with partners to create valued networks between buyers, vendors, and suppliers (Agostinho & Jardim-Goncalves, 2009). Therefore, enterprise systems need to be interoperable.

As defined by the IEEE (IEEE, 1990), interoperability refers to the capability of two or more systems to exchange information, and subsequently use that information in other activities. The main enabling concern for interoperability in enterprise environments is the ability of people and systems to communicate with efficiency. In fact, enterprise interoperability (EI) suggests that organizations can seamlessly interoperate with others at all stages of development in focal areas, removing barriers to communication, fostering a new networked business culture, and transferring and applying the research results in industrial sectors. However, achieving that is not trivial and usually the problems associated with systems interoperability derive from enterprise organizational issues, conceptual information models that are not compatible, or technological handicaps (ISO, 2011).

In cases where multiple systems are used for managing different areas of an enterprise network, several problems may arise in the event that the systems have not been designed from the outset to interoperate (Jardim-Goncalves, Agostinho, & Steiger-Garcao, 2012), also similar issues may occur if when multiple systems are used inside the same enterprise by different departments. If they are only partially interoperable, translation or data re-entry is required in order to assure the efficiency of information flows (White, O'Connor, & Rowe, 2004).

1.1 Context and Motivations

With the evolution of modern enterprises, information exchange is becoming even more important but also more complicated. Cooperation is seen as a competitive advantage to respond to client needs, maximizing the profits and reducing the response times. However, in order to achieve these goals there is a rising need to interoperate with heterogeneous enterprises, i.e. small and large companies that may have different organizational cultures, structures, motivations and technologies. However this integration process need to be thoroughly executed, or else it may cause a lot of issues to all involved entities. A well known example of this kind of problems was played by Airbus when the project of the mega jet A380 reached 2 years of production delay and a $6 billion slippage, the company assumed that one of the causes was due to interoperability problems in different design software used in the multiple factories involved (Matlack, 2006).

To ensure in advance that enterprises and their internal systems are interoperable and capable of working cooperatively in an efficient manner, there is a need of some kind of simulation for testing and validation purposes that allow detecting loss of information or misinterpretations cause by a set of variables that are already defined on enterprise interoperability frameworks by organizations like ISO or ETSI.

The goal of this thesis is to contribute to interoperability efficiency, defining an evaluation framework and methodology capable of quantifying and qualifying end-to-end enterprise systems interoperability. With it, companies are able to categorize their readiness to participate in collaboration networks, identifying potential problems beforehand, as well as potential gaps that when covered could enhance their collaborative performance.

1.2 Research Method

The methodology used to develop this thesis was based on the Scientific Method. It consists in seven steps as described in (Schafersman, 1997), and as illustrated in Figure 1-1.

Each step is defined and explained as following:

- **Problem Characterization -** In this step, is identified a significant problem and its characteristics ending with a research question that will be the base of the work. The problems identified in this thesis are: How to assess the interoperability status of an existing collaboration? And how to evaluate if it is worth to start a collaboration relationship?
- **Background Research -** This step is based on the study of similar work that handles information about the characterized problem.

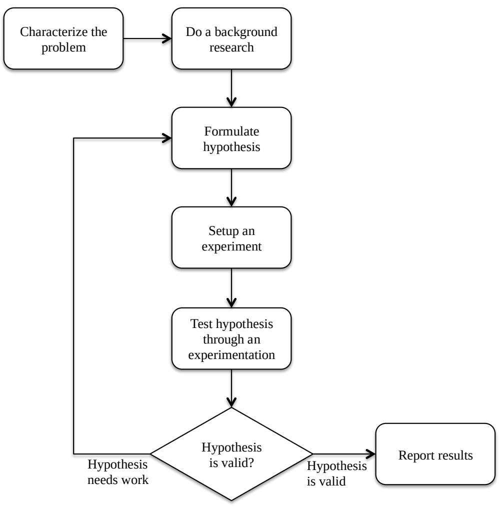

Figure 1-1 - Research method illustration

This leads to the need of gathering scientific information about the existing work in interoperability evaluation and categorization.

- **Formulate Hypothesis -** Based on the background research the hypothesis must bring clarity, specificity and explain the characterization of the problem, in a way that it can be solved. In this thesis, it is required that the hypothesis focuses on the problem of classify and categorise the interoperability status of a network.
- **Setup an Experiment -** Setting up an experiment is the creation of a methodology for evaluate the interoperability status and suggest a solution to rectify the issues. Since the hypothesis must be validated, it is necessary to set up an experiment, allowing replication by others in a feasible way, by implementing a proof of concept.
- **Test Hypothesis -** At first a test set must be defined according to the characteristics of the problem and the formulated hypothesis. It is necessary to evaluate the outcomes of the methodology designed in order to evaluate the hypothesis proposed, so it have to be tested using the designed experimentation. For each test data should be collected for further analysis and hypothesis validation. After the application of all tests and data outputs collected, the results are interpreted and if applicable, qualitative and quantitative data analysis should be applied to the result.
- **Validate Hypothesis -** After validating the results of the experimentation, verification of the validity of the hypothesis proposed is necessary. Validation needs to take into account the characteristics of the problem. The results can empower the hypothesis or demolish all the work done so far, leading to the making of a new hypothesis and therefore the remake of work since step 3.
- **Report Results -** After the positive results, is possible to consider work valid and define the recommendations for further research. The outcome should result in a contribution to the scientific community, scientific papers should be written to present the consolidate results and should be finalised with a dissertation about the hypothesis, such as this document.

1.3 Research Problem and Question

- Is it possible to assess whether an enterprise is fit for interoperation?
    - If yes, is it possible to forecast potential interoperability issues before technical developments lead to unrequired costs?
    - Can existing collaborations benefit from that assessment identifying the source of existing problems and indicating potential solutions?

1.4 Hypothesis

If the maturity and compatibility of the different knowledge levels within two enterprises can be evaluated and categorized, then one can determine if those enterprises are fit for interoperation, as well as identify existing problems and define eventual solution paths.

1.5 Dissertation Outline

This dissertation is divided in seven chapters, with each chapter having the following characteristics:

- - Introduction**:** The first chapter begins with the context and personal motivation to develop this work, leading to the research questions. The scientific method that is the approach used to do this work is also presented, and the hypothesis formulated. The chapter is concluded with this outline of the document.
- - Enterprise Interoperability**:** The second chapter presents the related work elements studied in the area of enterprise interoperability. It is presented the state-of-the-art of the EI frameworks, and the EISB initiative that have the goal to develop a scientific base for enterprise interoperability.
- - Interoperability Evaluation**:** This section is the continuation of the background of the thesis, this part is dedicated to methods to assess and test interoperability process, including conformance testing, interoperability checking and formal analysis of the mappings between conceptual models.
- - EI Evaluation Framework**:** The fourth chapter presents the framework created to support the EI evaluation. At first, the structure that supports the evaluation process is described and later are presented the test methodology.
- - Proof-of-Concept Implementation**:** The fifth chapter begins with the description an application scenario with the test cases associated with it. To finish is presented the proof-of-concept implementation overview, where all test phases are described.
- - Proof-of-Concept and Hypothesis **:** This chapter presents the tests used to validate the formulated hypothesis. It begins with the description of the methodology adopted to test the hypothesis. Furthermore is listed the acceptance of this work by the scientific community. The results of the tests are presented and through its analysis is verified if the initial objectives were achieved.
- - Conclusions and Future Work**:** The seventh and final chapter presents a summary of this dissertation, highlighting the most important aspects of the research. It also presents taking into account the obtained results, a potential direction for future research.

Chapter 2 - Enterprise Interoperability

With the growing need to exchange information by electronic means, increased the concerns with data misinterpretations. By this starting point, IEEE (IEEE, 1990) defines the ability of two or more systems or components to exchange information, and subsequently use the information that has been exchanged as interoperability. At an enterprise environment, a similar relationship can be identified between enterprises or even services inside a company, allowing them to cooperate in order to achieve better results with the final system.

Enterprise systems are large-scale, application-software packages that use the computational, data storage, and data transmission power of modern information and communication technology to support processes, information flows, reporting, and data analytics within and between complex organizations. The integrated content managed by these systems may be used to provide a configuration management solution throughout the life cycle of products and processes.

It is recognized that the advantage of one company over another stems from the way it manages its process of innovation. However, if the enterprise systems used are not efficient and experience communication and automation issues, innovation might not be realized. Hence, EI has become an important area of research to ensure the competitiveness and growth of enterprises(Cluster, 2008), (FInES, 2010).

Enterprise interoperability qualifies the faculty of enterprise to establish a partnership activity in an efficient and competitive way in an environment of unstable market, but it requires even more efforts to accomplish than the common interoperability process between simple systems because a whole new set of issues arises while trying to cooperate between enterprises with different company’s goals, market views or incompatible company structures.

If a group of enterprises with a set of different views, conceptual models and implementations, want to cooperate there is a need to define data mappings, identifying relationships and smoothing issues caused by data misinterpretations, acting as a data mediator that allow the execution of data transformations.

In order to smooth the difficulties to interoperate, several frameworks was developed, trying to provide solutions to fill the gaps between systems, working as guide book to assist along the process.

2.1 Enterprise Interoperability Architectures and Frameworks

Enterprise Architecture is both a challenging and confusing concept that also needs to be understood when talking about the enterprise.

When compared to other fields where the architect has a solid role and needs to use recognised standards to specify and architect (e.g. a building), in enterprise it tends to use many heterogeneous and often overlapping approaches, which create obstacles for correct understanding of systems and their capabilities in industry (D. Chen et al. 2008). EA should be organised in a way that supports reasoning about the structure, properties and behaviour of the system, thus defining its components and providing a blueprint from which it can be developed. Therefore, integration is a property that necessarily needs to be part of an EA, and has become an established research domain since the 1990s, as the extension of computer integrated manufacturing(Agostinho, 2012).

Enterprise integration is an essential component of enterprise engineering, concerning the usage of specific methods, models and tools, to design and to continually maintain an enterprise in an integrated state so that it can fulfil domain objectives (Panetto & Molina 2008)

The growing need for cooperation between enterprises and systems aroused the need for reference frameworks to assist interrelating information from many perspectives. According to the IDEAS road-mapping scope and objectives (IDEAS, 2003), such a framework should be able to represent interoperability of all types and kinds of enterprise architectures and platforms. Thus, the requirements from organizational, business and many other aspects of the enterprise must be better understood.

Some of the most popular frameworks in this area are presented bellow, following the definition where ***'an interoperability framework is an agreed approach to interoperability for organisations that wish to work together towards the joint delivery of public services. Within its scope of applicability, it specifies a set of common elements such as vocabulary, concepts, principles, policies, guidelines, recommendations, standards, specifications and practices.'*** (ISA, 2010)

2.1.1 IDEAS Interoperability Framework: The Vision for 2010

According to the IDEAS network (IDEAS, 2003), the state-of-the-art in research, industry, standardization bodies and providers was not, in the early 2000's, in the form of a coherent set of views that fit in common frameworks. Thus, the process to collecting industrial challenges, defining visions, goals and missions, and the development of scenarios of future interoperable enterprises was becoming increasingly more difficult and also important. The goal of the network was to develop common visions that needed to be realized in order to assist the enterprise interoperability process. Hence, three main requirements were identified as:

- The interoperability vision statement definition;
- Harmonized e-Business, e-Government and solution provider visions;
- Technology and research vision for interoperable enterprises.

All should have a set of common approaches and technologies that will be decisive in achieving future interoperable solutions, such as:

- Enterprise architecture – separable layers, perspectives and views;
- Intelligent infrastructures – supporting integration, adaptation and extension;
- Work process services – providing knowledge development and management;
- Web services – providing capabilities to "plug and execute" software components;
- Visual enterprise modelling will make the services adaptable and reusable across industry sectors;
- User environments and workplaces can be generated and supported by active knowledge models that can also provide development and management of services;

2.1.1.1 IDEAS vision statements

Interoperability vision statement

"By 2010 enterprises will be able to seamlessly interoperate with others"

This vision was a contribution to the "plug-and-do business" vision where organizations can easily cooperate with other ones. The main goal was to make computing simpler, cheaper, more secure and reliable, and more effective and user-friendly.

e-Business vision

"Managers will govern and manage values, strategies investments, tasks resources and risks in on-demand business opportunities"

Customizable computing solutions were intended to be based on dynamic architecture models and intelligent infrastructure services. This way the computing should be simpler, more effective and user-friendly.

e-Government vision

"Case handlers will continuously generate solution workplaces and execute work, enabled by evolving intelligent infrastructures"

Layered architectures de-coupling law and rules from case-handling knowledge and ICT issues, and using intelligent infrastructures services was expected to be possible. New approaches should be more effective and efficient. In addition to being able to manage changes in case-handling models, solutions and architectures, users were supposed to have services to tailor their workplaces.

Solution provider vision

"By 2010 solution partners will use repeatable services to deliver, deploy, adapt and manage customised solutions (adapt, authorise and do-business)."

Providers were supposed to be able to deliver, deploy and support solutions through services in portal-based user environments and workplaces. There should be architectures and intelligent infrastructures with services developed and offered at all layers and for most tasks.

Technologist vision

"Enable customisable solutions, built from active knowledge models, adaptive architectures and standardised services!"

Technology and standards were intended to provide new approaches to supply computing services, using web as a multi-sensory arena for collaborative working, to realize dynamic work environments. Industrial should not have to be concerned about data quality, applications integration, security and many other engineering concerns.

Research visions

The major technologies for achieving interoperability were enterprise modelling, ontology and enterprise architectures integrated by intelligent infrastructures and services as process tasks managed by the infrastructure. For each of this technology was proposed a vision as follows:

- Architecture and intelligent infrastructures vision – *"Enterprise architectures and intelligent infrastructures with services for architecture adaptation and extension, services for workplace generation, and for application and database integration will be developed and offered!"*
- Enterprise modelling vision – *"Enterprise modelling enables cross-enterprise teams to perform dependency and performance analysis, to develop enterprise specific enterprise*

knowledge architectures, and to support generation of simple workplaces as well as elaborate design environments. The powers of enterprise visual scenes will augment human capacities for design, problem solving and learning!"

- Ontology vision – *"Reference enterprise ontology for POPS and other aspects will be developed and services to dynamically embed and integrate ontology definitions in the different enterprise knowledge architectures will be developed. Ontology must be flexibly implemented. Consistency and compliance are important for enterprise nomenclature"*

2.1.1.2 Interoperability Framework

IDEAS defined a framework for capturing and inter-relating the multiple visions from many perspectives, called the IDEAS Interoperability Framework. It has been designed intending to be intuitive, allowing for contributions from a wide range of stakeholders in enterprise systems interoperability, such as end-users, analysts, solution providers. The framework (as illustrated in Figure 2-1) introduces two-dimensional views comprising *Interoperability Aspects* including enterprise, architectures & platforms, as well as ontological areas, and *Quality Attributes* that cover security, performance, portability and other non-functional concerns.

	Framework 1st Level	Framework 2nd Level	ONTOLOGY	QUALITY ATTRIBUTES			QUALITY ATTRIBUTES		
			Semantics	Security	Scalability	Evolution	Performanc e	Availabilit y	Portability
ENTERPR. MODEL	Business	Decisional Model							
		Business Model							
		Business Processes							
	Knowledge	Organisation Roles							
		Skills Competencies							
		Knowledge Assets							
ARCHITECT PLATFORM	Application	Solution Management							
		Workplace Interaction							
		Application Logic							
		Process Logic							
	Data	Product Data							
		Process Data							
		Knowledge Data							
		Commerce Data							
	Communica tion								

Figure 2-1 – IDEAS Interoperability Framework (IDEAS, 2003)

2.1.2 Athena Interoperability Framework (AIF): Holistic Approach

The Athena interoperability framework defines an interoperability reference architecture that relates the modelling solutions coming from the three different research areas of Athena integrated project 22/04/2013 23:19:00, namely enterprise modelling, architectures and platforms, and ontology. Figure 2-2 depicts the reference architecture that focuses on the provided and required artefacts of two collaborating enterprises. According to this architecture, interoperations can take place at four distinct levels:

- Interoperability at the **enterprise/business** level should be seen as the organisational and operational ability of an enterprise to co-operate with other, external organizations with others.
- Interoperability of **processes** aims to make various process work together, by defining the sequence of the services according to specific need of a company

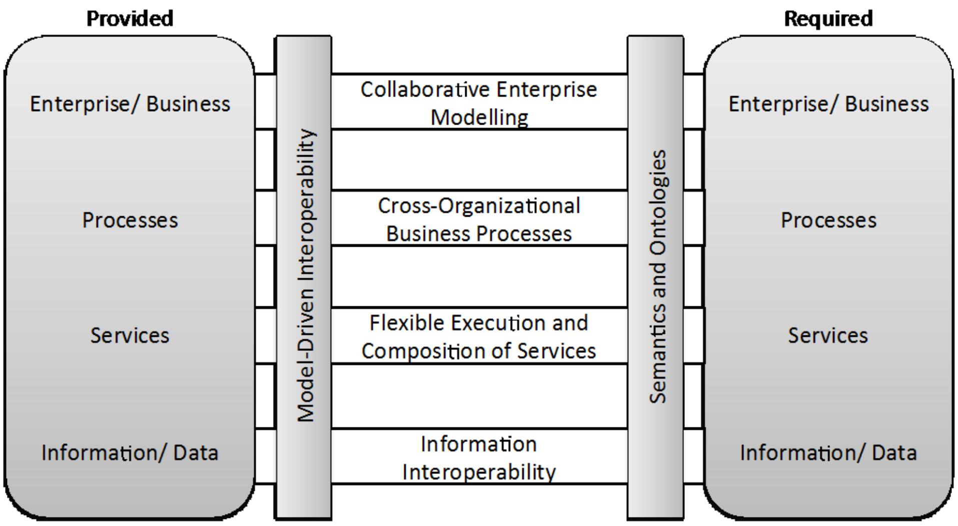

Figure 2-2 - ATHENA interoperability reference architecture (ATHENA, 2007)

- Interoperability of **services** is concerned with identifying, composing and executing various applications.
- Interoperability of **information/data** is related to the management to the management, exchange and processing of different documents, messages and/or structures by different entities.

For each of these levels, a model-driven interoperability approach was prescribed, where models are used to formalise and exchange the relevant provided and required artefacts that must be aligned and made compatible through negotiations and agreements at conceptual, technical and applicative dimensions Figure 2-3

- **Conceptual integration**, which focuses on concepts, metamodels, languages and model relationships. The framework defines an interoperability reference architecture that provides us with a foundation for systemizing various aspects of interoperability.
- **Applicative integration**, which focuses on methodologies, standards and domain models. The framework defines a methodology framework that provides us with guidelines, principles and patterns that can be used to solve interoperability issues.
- **Technical integration**, which focuses on the software development and execution environments. The framework defines a technical architecture that provides development tools and execution platforms for integrating processes, services and information.

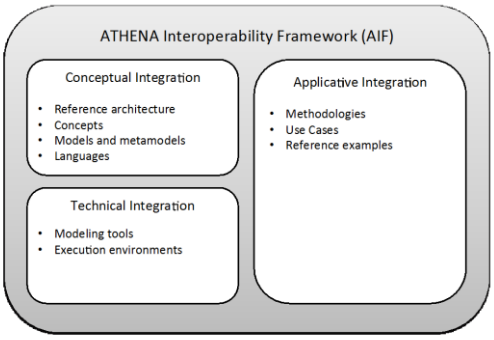

Figure 2-3 - Structure of the AIF

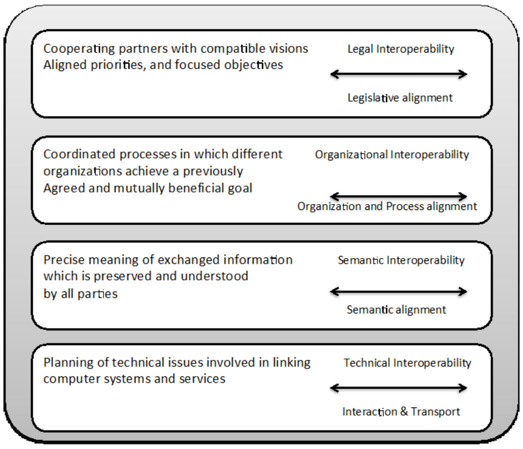

Figure 2-4 - EIF: Interoperability levels

2.1.3 European Interoperability Framework (EIF): eGovernment Dimension

Complementary to the Enterprise, interoperability is both a prerequisite for, and a facilitator of, efficient delivery of European public services. It addresses the need for: cooperation among public administrations with the aim to establish public services; exchanging information among public administrations to fulfil legal requirements or political commitments and; sharing and reusing information among public administrations to increase administrative efficiency and cut red tape for citizens and businesses.

The result is improved public service delivery to citizens and businesses by facilitating the one-stop-shop delivery of public services, and lower costs for public administrations, businesses and citizens due to the efficient delivery of public services. Therefore, to achieve the proposed results, EIF (ISA, 2010), defines a conceptual model subdivided in three layers: basic public services, secure data exchange and aggregate public services:

- Basic public services - The most important components are base registries that provide reliable sources of basic information on items such as persons, companies, vehicles, licences, buildings, locations and roads. Such registries are under the legal control of public administrations and are maintained by them, but the information should be made available for wider reuse with the appropriate security and privacy measures.
- Secure data exchange - From a business point of view, administrations and other entities exchange official information that may involve access to base registries. This should go through a secure, harmonised, managed and controlled layer allowing information exchanges between administrations, businesses and citizens;
- Aggregate services - Aggregate public services are constructed by grouping a number of basic public services that can be accessed in a secure and controlled way. They can be provided by several administrations at any level, i.e. local, regional, national or even EU level.

This framework also describes four levels of interoperability . Each deserves special attention when a new European public service is established. The practical implementation of the conceptual model requires each of these levels to be taken into account Figure 2-4.

2.2 Categorizing Interoperability using Maturity Models and Levels

Several authors have been proposing different solutions to assist in achieving interoperability between systems, which requires resolution of issues at various distinct interoperability layers. Normally, the proposed types of interoperability follow a scale of advancement, in which the higher a type is placed in the scale, the more advanced and complete the interoperability is accomplished. An early classification for interoperability maturity was defined in the Levels of Information System Interoperability (LISI), focusing on the assessment of systems against increasing levels of sophistication regarding the exchanging and sharing of information and services during the system's life cycle (C4ISR Architecture Working Group 1997). As evidenced in Figure 2.5 a), this occurs through five levels, i.e.:

- Level 0 - Isolated interoperability in a manual environment, where direct electronic connection is not allowed or available and systems are typically stand-alone;
- Level 1 - Connected interoperability in a Peer-to-Peer (P2P) environment, where systems are providing some form of simple electronic exchanges for homogeneous data files, e.g. media;
- Level 2 - Functional interoperability in a distributed environment that enables data sets to be passed from system to system with the use of the formal data models;

- Level 3 - Domain-based interoperability in an integrated environment of shared data, which is understood by multiple users thanks to a domain-based data model; and finally
- Level 4 - Enterprise-based interoperability in a universal environment, where systems are capable of operating using a distributed global information space across multiple domains. This level of interoperability means that multiple users can access and interact with complex data simultaneously that is shared and distributed throughout the environment.

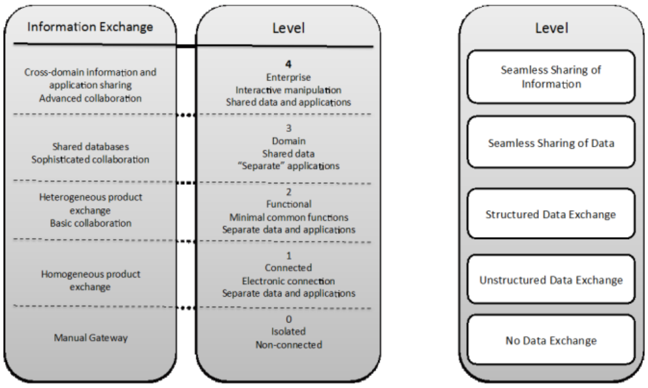

Figure 2-5 - a) LISI Maturity Levels (adapted from C4ISR Architecture Working Group); NC3TA Reference Model Interoperability

Later, other examples of classification from relevant interoperability frameworks and models followed and have been widely referenced, e.g., Peristeras & Tarabanis (2006) proposed the Connection, Communication, Consolidation, Collaboration Interoperability Framework (C4IF), which uses basic linguistic concepts to categorize information systems communication in four layers. Tolk & Muguira (2003) proposed the Levels of Conceptual Interoperability Model (LCIM) to bridge the gap between implementation focused methods and conceptual models, while Panetto (2007) summarized several others proposing different classifications based on maturity levels for interoperability.

The NC3TA Reference Model for Interoperability is another example of interoperability levels classification (NATO 2003). Developed with the idea to establish measures of merit to evaluate the degree of interoperability between two existing systems by applying standard means, the NC3TA RMI focus on the exchange of information in form of data between the systems and the ability to invoke procedures and use the other systems functionality. It recognizes interoperability in five complementary levels classified in terms of amount and quality of data sharing(see Figure 2.5 b)):

- No Data Exchange - No physical connection exists
- Unstructured Data Exchange - Exchange of human-interpretable, unstructured data (free text)

- Structured Data Exchange - Exchange of human-interpretable structured data intended for manual and/or automated handling, but requires manual compilation, receipt, and/or message dispatch
- Seamless Sharing of Data - Automated data sharing within systems based on a common exchange model
- Seamless Sharing of Information - Universal interpretation of information through cooperative data processing

With the risk of not presenting all, Table 2-1 summarizes an extensive list of interoperability maturity models and levels that have been analysed in this review.

Table 2-1 - Interoperability Maturity Levels (ENSEMBLE, 2012a)

Approach	Classification Layers	Type
LISI	Five interoperability maturity levels focused on technical interoperability and the complexity of interoperations: • Isolated Systems, Connected Systems, Distributed Systems, Domain Systems and Enterprise Systems, Affecting four layers of information: • Procedures, Applications, Infrastructure and Data.	Maturity Levels & Interoperability Layers
OIM	Five maturity levels extending LISI into the more abstract layers of organizational command and control support: • Independent, Ad hoc, Collaborative, Integrated, and Unified.	Maturity Levels
NC3TA Reference Model for Interoperability (RMI)	Five degrees and sub-degrees of technical interoperability: • No Data Exchange, Unstructured Data Exchange, Structured Data Exchange, Seamless Sharing of Data, and Seamless Sharing of Information.	Maturity Levels
C4IF	Four interoperability layers for systems interchange: • Connection, Communication, Consolidation, and Collaboration, Containing three objects of integration: • Channel, Information, Process.	Maturity Levels & Interoperability Layers
AIF	Five level maturity scale: • Performed, Modelled, Integrated, Interoperable, and Optimizing, Where the organizational context is provided for more specific and technical improvements across the three views on interoperability: • Conceptual, Applicative, and Technical. All of which, can be addressed across four interoperability layers with different concerns: • Enterprise/Business, Processes Services, and Information/Data.	Maturity Levels, Interoperability Views & Layers
Interoperability classification framework	Six kinds interoperability solutions: • Synchronic Interoperability, Model-driven Interoperability, Semantic-driven Interoperability, Vertical Interoperability, Horizontal Interoperability, Diachronic Interoperability.	Maturity Levels & Interoperability Layers
Interoperability Efficiency Pyramid	5 level pyramid relating network efficiency with industrial adoption and technological development: • Slack, Unregulated, Standard-based, Semantic, and Sustainable	Maturity Levels

Approach	Classification Layers	Type
Maturity levels for interoperability in digital government	Five-level model: • Computer Interoperability, Process Interoperability, Knowledge Interoperability, Value Interoperability, and Goal interoperability. Might be applied by public organizations to identify current maturity and future direction for improved interoperability.	Maturity Levels

As it can be easily deduced from the Interoperability Layers in Table 2-1, there is no consensus reached and often the various layers are interconnected among themselves. The different layers, as currently proposed in the bibliography, define in high level the necessary stack for interoperable systems, however, their abstraction level hinders researchers and practitioners to really identify problems and provide solutions.

There are some common features among the presented approaches, especially the classification layers that for the majority of the methodologies are divided in a scale of advancement composed by five levels. However all of them have at least smooth differences in terms of areas of applicability, goals and classification criteria.

2.3 Standards in Enterprise Interoperability

Standards are of key importance to enable enterprise interoperability. They are great enablers to the agreement of terminology, thus allowing communication and cooperation between software components, processes, organisation units and humans (D. Chen & Vernadat 2002). Standardisation initiatives, supported by standardisation bodies (such as ISO17, IEC18), developed by industrial communities (e.g. IEEE19) or by European projects, have been trying to contribute towards data exchange and systems communications. However, each focuses on one particular aspect of interoperability without aligning their enterprise knowledge and skills for taking advantage of seamless cooperation (Panetto 2007).

A large number of standardization groups exist, supported by local governments and international communities. Nonetheless, even among them they have replication of efforts, while the full potential benefits could only be achieved if interoperability is underpinned by a coherent set of open, and internationally accepted ICT standards (Mason 2007; Ray & Jones 2006). As a result for many projects as ATHENA and INTEROP, ISO defined a standard framework for enterprise interoperability summarized in the next section.

2.3.1 Standard Framework for EI

In this line, ISO standard 11354 (ISO, 2011) defines an holistic framework to structure the interoperability requirements to enable communication rather than defining the communication itself, and is thus independent of specific technologies. It defines concerns, barriers and approaches relatively to EI.

2.3.1.1 Interoperability Concerns Viewpoint

To achieve enterprise interoperability, there are four concerns that must be identified, as show in Figure 2-6: data, service, process and business.

- Data interoperability concern - Interoperability of data refers to the ability of all kinds of entities exchange data and to relate different data models on to the other (ISO, 2011). This is the most important concern for the majority of enterprises since it is the substance of exchange.
- Service Interoperability concern - Interoperability of service refers to the ability of partners to request, provide and utilize each other's services (ISO, 2011). In order to achieve this goal there is a need to describe previously the incompatibilities concerns that include the detailing of all partner services.
- Process Interoperability concern - Interoperability of process refers to the ability of partners exchange information and other entities needed for process operation (ISO, 2011). This includes finding solutions to map, connect, merge and translate heterogeneous process models and applications from enterprise to enterprise.
- Business Interoperability concerns - Interoperability of business refers to the ability of enterprises to cooperate with partners for the conduct of business through interaction at various levels of their respective organizations (ISO, 2011). The incompatibilities in this area arise from different business models, methods, decisions, goals, culture and commercial approaches.

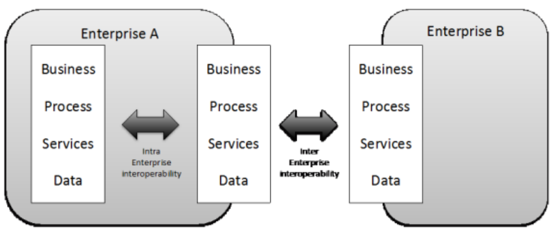

Figure 2-6 - Kinds of intra/inter EI concerns (ISO, 2011)

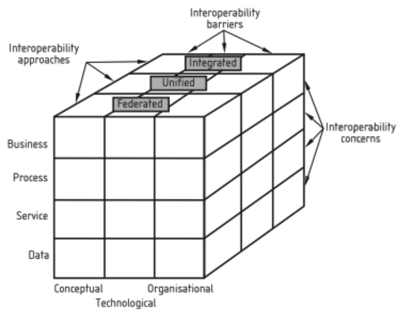

Figure 2-7 - EI framework graphical representation (ISO, 2011)

2.3.1.2 Interoperability Barriers Viewpoint

Many interoperability issues are specific to particular application domains while barriers are generic incompatibilities and mismatches that obstruct the sharing and exchange of information. Following the framework for enterprise interoperability proposed in the ISO standard 11354, EI can be a difficult process due to incompatibilities and mismatches caused by three barriers:

- Conceptual barriers - Conceptual barriers need to be detailed in terms of the syntactic, semantic and semiotic incompatibilities of exchanged items(ISO, 2011): The fist (syntactic) applies when different people or systems use different ways to represent information; the second (semantic) applies when the meaning of exchanged information is not sufficiently similar, and; the last (semiotic) applies when participating entities interpret the information differently in different contexts.

  This barrier is the most important because of the need for both the exchange if entity content and the usability if that content.

- Technological barriers - Technological barriers represent the incompatibilities that affect the ability to exchange information. In information systems this barrier is caused by interfaces that don’t allow the exchange of information to occur correctly or at all
- Organizational barriers - The organizational barrier is caused by human-related issues that directly affect the interoperation between enterprises. Organizations with different structures, methods and policies need an increased effort to interoperate because there is a need to find mappings between partners to soften the heterogeneity.

2.3.1.3 Interoperability Approaches Viewpoint

So far the deployment of EI has been based strongly on the support of a “big bang” transition to a more efficient, enterprise-wide “best way” of working. However, this new best way of working is defined by a relatively small group of dedicated expert analysts (industrial engineers, business engineers, information analysts etc.) and implemented and maintained top-down, leaving bottom-level knowledge in enterprises largely unexploited and solutions are sometimes not getting the expected adherence (Interoperability, 2008).

Due to this, and also to the limited budget available for the “big-bang” transitions, ISO standard 11354 (ISO, 2011) states which approaches can be used to address and implement interoperability. There are three well-defined approaches:

- Integrated approach - In this approach there is a need of some kind of agreement about a common way to represent the information, ensuring a common syntax and semantic so the exchanged entities can be interpreted in the same manner by all enterprises involved in the process.

- Unified approach - In this approach there is a need to define a meta-level structure that will allow to do the mappings from one system to another. With those mappings defined, it will be possible to do a translation between participant entities, but with the cost of possible loose of information.

- Federated approach - In this approach there isn't a need for common meta-models to interoperate. All the actors on the interoperability process shall adjust dynamically their operation, using a priori information about the capabilities of the entities to be involved in the exchange.

This standard also defines a cube where each of the three axes represent concerns, barriers and approaches Figure 2-7. This graphical representation classifies the system, and provides the right approach to solve specific problem.

2.3.2 Using Data Standards to Enhance Interoperable Information Sharing

Standardization rapidly became an evident priority for many industrial sectors where large collaboration networks exist (e.g. automotive, aeronautics, etc). Several dedicated reference models covering many industrial areas and related application activities, from design phase to production and commercialization, have been developed that enable industrial sectors to exchange information based on common models (PDES Inc 2006).

When using standards as the reference format for information exchange, organizations need to be concerned with describing only one mapping between its internal system model and the standardized model being used in the communication. Therefore, for each message exchanged between two different organizations, only a single mapping is required(Agostinho, 2012).

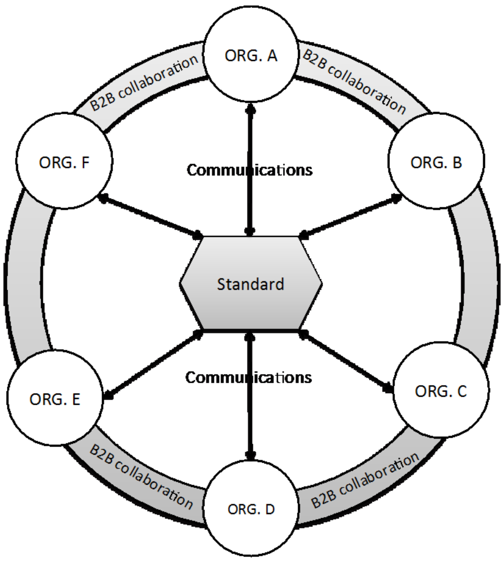

Figure 2-8 - Standard-Based Interoperability (adapted from (Agostinho & Jardim-Goncalves, 2009))

The choice of the adequate standard to adopt in the collaboration network is of major importance to the success of this type of interoperability. In the event that the standard is less expressive than a local system, possible data loss will need to be accounted for, and the network might lose efficiency. However, if the standard is comprehensive enough, standard-based interoperability is more efficient than the unregulated one, where every message exchanged between two different enterprises requires an initial effort to establish a mapping among the models used by both, in order to be understandable i.e. the total amount of mappings required within the network is reduced. The total mappings correspond to the number of organizations, so in this case, the collaboration effect is maximized and when a new enterprise enters the network, it only needs to perform a one-time effort of integration with the standard model, Figure 2-8. The remaining ones entail no additional effort (Jardim-Goncalves et al., 2012), also the time spent with this operation only needs to tally the time for the definition of a single mapping, and this mapping has the benefit of not requiring the involvement of the other network members, leaving them undisturbed.

The total time spent on the communications between two organizations is significantly reduced using standards because it minimizes the human interventions and requests for clarifications, which reduce the number of messages exchanged in the communication (Jardim-Goncalves et al., 2012).

2.4 Enterprise Interoperability Science Base (EISB)

Recently is occurring the Enterprise Interoperability Science Base initiative with goal to define a scientific base to define and structure enterprise interoperability. A review of the definitions and structures of science bases in neighbouring sciences (ENSEMBLE, 2009) reveals that there is no common structure or content to such science bases. However a methodology, which might be applied in defining a science base, emerged based on application of generally accepted scientific principles. This was discussed and elaborated to provide the basis of a methodology for definition of the EISB.

The definition and objectives of a science base for Enterprise Interoperability were also analysed, leading to an outline structure for an EISB to include formalized problem and solution spaces as well as structured EI domain knowledge divided into twelve main Scientific Areas of EI.

2.4.1 EI Scientific Areas

In order to identify a proper structure for Enterprise Interoperability, which can at a second stage be mapped to the four fundamental layers/concerns defined in 2.3.1.1 "Interoperability Concerns Viewpoint", one has to focus on the real object of observation, which is the ―Enterprise‖, and by analysing it in its core components to identify the interoperability needs within them.

An Enterprise, as defined in (Sullivan, A., Sheffrin, 2003) is ―…an organization designed to provide goods, services, or both to consumers." Following ENSEMBLE (ENSEMBLE, 2011), the main ingredients of such a system are the following:

- *Infrastructures* referring to all the facilities and non-human assets possessed by an enterprise, which are used for their operation. Under infrastructures, software platforms, hardware systems, building facilities, automobiles, etc. can be classified.

- *Data* used for the business transactions within and outside the boundaries of the enterprise. This includes the documents, application forms, transactional data exchanged by the enterprise.
- *Processes* including all the related, structured activities or tasks that produce a specific service or product.
- *Policies* embracing the different rules that are applied either due to external (e.g. legislation, business association rules, etc.) or internal factors (e.g. working hours, dress code, etc.).
- *People* with all the human resources that are part of an enterprise system.

With the evolution of business environments, in (Lampathaki et al., 2012) , these ingredients have been extended to a list of twelve scientific areas (S.A.) to keep in mind while managing systems that need to cooperate., those are defined along four levels of complexity , where the higher levels are a composition of the lower ones, as shown in Figure 2-9.

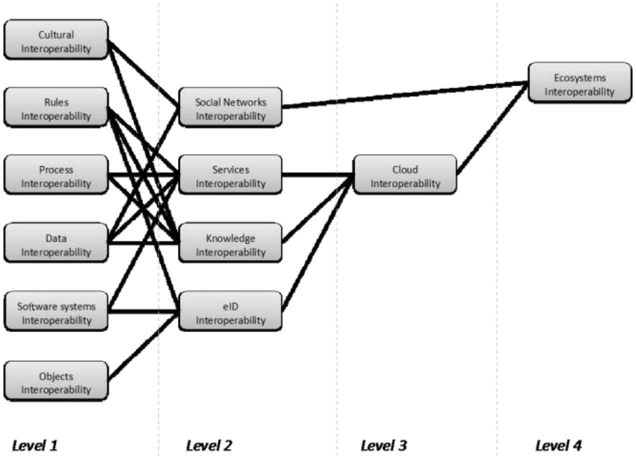

Figure 2-9 - EI Scientific Areas

- ***[S.A.1] Data Interoperability***: The ability of data to be universally accessible and reusable. (http://www.fines-cluster.eu/fines/mw/index.php/Data_Interoperability)
- ***[S.A.2] Process Interoperability***: The ability to connect processes of different enterprises in order to exchange data. (http://www.fines-cluster.eu/fines/mw/index.php/Process_Interoperability)
- ***[S.A.3] Rules Interoperability***: The ability of entities to match their business and legal rules for conducting transactions. (http://www.fines-cluster.eu/fines/mw/index.php/Rules_Interoperability)
- ***[S.A.4] Objects Interoperability***: Refers to the networked interconnection of everyday objects. (http://www.fines-cluster.eu/fines/mw/index.php/Objects_Interoperability)
- ***[S.A.5] Software Interoperability***: The ability of enterprise software to work with other enterprises software. (http://www.fines-cluster.eu/fines/mw/index.php/Software_Systems_Interoperability)

- ***[S.A.6] Cultural Interoperability***: The degree to which knowledge and information is anchored to a unified model of meaning across cultures. (http://www.fines-cluster.eu/fines/mw/index.php/Cultural_Interoperability)
- ***[S.A.7] Knowledge Interoperability***: The ability of share and use intellectual assets, take advantage of it to extend it through cooperation (http://www.fines-cluster.eu/fines/mw/index.php/Knowledge_Interoperability)
- ***[S.A.8] Services Interoperability***: The ability of discover, aggregate and use a service that belongs to other entity. (http://www.fines-cluster.eu/fines/mw/index.php/Services_Interoperability)
- ***[S.A.9] Social Networks Interoperability***: The ability of enterprises to utilize social networks for collaborations and interconnection purposes. (http://www.fines-cluster.eu/fines/mw/index.php/Social_Networks_Interoperability)
- ***[S.A.10] Electronic Identity Interoperability***: The ability of different eID systems to collaborate in order to automatically authenticate entities and to pass on security roles and permissions to eID holders. (http://www.fines-cluster.eu/fines/mw/index.php/Identity_Interoperability)
- ***[S.A.11] Cloud Interoperability***: The ability of cloud services to be able to work together. (http://www.fines-cluster.eu/fines/mw/index.php/Cloud_Interoperability)
- ***[S.A.12] Ecosystems Interoperability***: The ability of instant and seamless collaboration between different ecosystems. (http://www.fines-cluster.eu/fines/mw/index.php/Ecosystems_Interoperability)

2.4.2 EI Hypothesis and Laws

In every scientific discipline, laws are defined as analytic statements, usually with an empirically determined constant. Such scientific laws must always apply under the same conditions, and imply a causal relationship between the elements that they contain. Laws are generally applicable observations or guidelines, which are grounded in observation and rationalisation from cases. Since a law is a distillation of the results of repeated observation, its applicability is generally to circumstances either resembling or extrapolating those already observed. Scientific laws must be confirmed and broadly agreed upon through the process of inductive reasoning.

In the domain of Enterprise Interoperability, the ENSEMBLE Experts Scientific Committee and experts from neighbouring scientific disciplines concluded that(ENSEMBLE, 2012):

- The interoperability domain has not yet reached the required maturity level to establish laws. Interoperability like Software Engineering has not actually been overly concerned with its core theory up to date.

- Laws in mathematical format are not applicable, yet we may observe regularities and patterns. Strict regularities, such as laws, can only be found in a very high and abstract level.
- However, it is a good approach to try to introduce some initial observations based on empirical data.

Nevertheless, the observation of the EI domain and of the various problems and solutions available can lead to the definition of a series of hypotheses which seem logical and true, but require to be verified through further experimentation in order to prove their actual applicability. It has to be noted, that the hypotheses presented in this section are only a small part of the complete set of hypotheses that could be drawn, as the further one investigates EI and its neighbouring sciences, the more hypotheses he can identify22/04/2013 23:19:00:

- Scientific Areas (S.A.s) belonging to the same granularity level are independent of each other.
- Interoperability Barriers (Conceptual Technical, Organisations) are highly related with each other and thus the degree of Interoperability in each IB is highly affecting the other IBs.
- There are many Solution Paths to resolve an Interoperability problem.
- The use of multiple, connected Solution Paths can provide a solution for an Interoperability Problem as well as an individual Solution path can.

Apart from the EISB generic hypotheses listed above, there are hypotheses present in the different Scientific Areas, which also need to be checked for their validity. Some of these hypotheses are the following:

- S.A. 1: The degree of interoperable data structures in an enterprise is highly related to the intention of an enterprise to share its data and its data models.
- S.A. 2: Business Process Standardisation lowers the effort for interconnecting the processes of enterprises.
- S.A. 3: The more business and legal rules exist, the highest the effort to ensure interoperation is.
- S.A. 4: Objects Interoperability can be solved by the use of unique but registered object identifiers (IDs).
- S.A. 5: Web Services offer high degree of Interoperability and enable developers to interconnect any kind of software systems.
- S.A. 6: Language Semantics will enable the instant transformation of textual meanings.
- S.A. 7: Enterprises that pose high amounts of business knowledge are more difficult to interoperate due to organisation issues, as compared to enterprises with less business knowledge.
- S.A. 8: Services that allow auto discovery and addressability are by nature interoperable with other ones.

- S.A. 9: The degree of Interoperability is not affected by the size of the social graph of an enterprise.
- S.A. 10: The utilisation of certificates from trusted and interconnected authentication providers is a step towards higher degrees of Interoperability.
- S.A. 11: Enterprise Interoperability over the Cloud is a matter of PaaS solutions and not IaaS.
- S.A. 12: The more enterprises are willing to expose and share their complete operational assets, the easier they can team up and build virtual ecosystems and digital alliances.

2.4.3 Problem and Solution Space

The problem space of the EISB refers to a space where known cases and issues regarding interoperability are stored, enabling the presentation of a "before-after" situation for any of those issues, alongside with the solution paths (mainly referring to the utilization of methods and tools) that have been employed in such cases in order to reach the optimized situation.

2.4.3.1 Moving from Problem to the Solution Space

The way to move from the problem to the solution space is a progressive and repetitive method where various steps are taken once the status of an enterprise is identified through the EI Assessment Framework. The main steps to be taken, as shown in Figure 2-10 and in Figure 2-11 are the following:

1. Identification of the industry sector the enterprise under investigation belongs to
2. Assessment of EI Interoperability Status
3. Definition of the desired "to-be" status
4. Fitting to existing problem patterns which resemble the current problem
5. Fitting to existing "to-be" patterns based on the solution path chosen
6. Identification of existing solution paths that bring the current "as-is" status closer to the desired "to-be".
7. Repetition of steps 1 to 6 until one reaches the anticipated status.

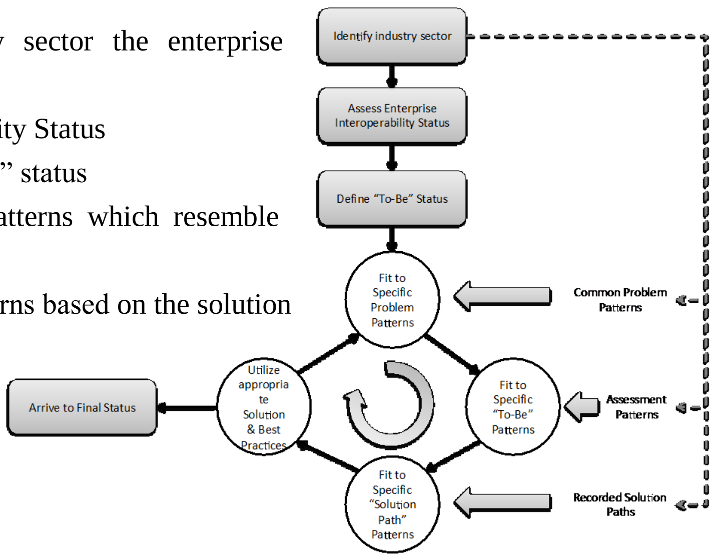

Figure 2-10 - Moving from the Problem to the Solution Space (ENSEMBLE, 2012b)

The iterative process illustrated above is a necessity (at least until there is a vast population of the various problem solution registries), as it will be quite impossible to find exact matching problem and solution patterns. For this case, the arrival to the anticipated "to-be" status will be gradually achieved, through following solution paths that gradually improve the EI status of an organisation, with the aim to arrive closer to the desired destination.

As problem patterns and solution patterns will be developed in the future, the analysis of their comparison will lead to the creation of new selection paths which will populate the solution paths repository and will be applicable in similar problems that will emerge.

The vast identification of patterns and paths will eventually lead to a huge number of combination which would however tend to stabilise and as a result emerging problem will be tackled in less time with less effort, as the already identified paths will indicate the most compelling and convenient ways to get closer to the solution.

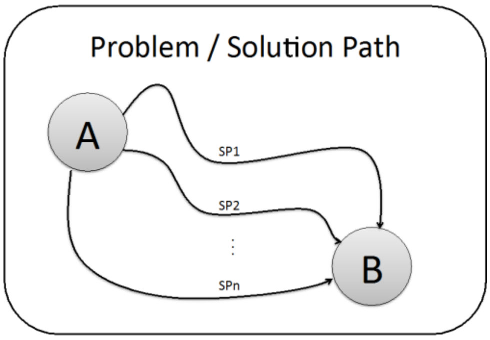

Figure 2-11 - Problem/Solution Model (ENSEMBLE, 2012)

2.4.3.2 Problem and Solution Space

Based on the above-mentioned process, the Table 2-2 presents an example of how the indicative problem space can be connected with the solution elements.

Table 2-2: Identification of Potential Solution Elements for Indicative Problems (ENSEMBLE, 2012)

Problems / Issues	Possible Solution Elements
SA.1 – Data Interoperability	
Semantic Data Issues - The data exchanged between two entities is “labelled” completely different although containing the needed information, and therefore it is unable to be understood by the responsible systems	• Semantic Data Representation • Unified data schemas
Data Standards Incompliance - Documents used for communication in various transactions do not have the same data fields in order to be processed automatically	• Unified data schemas • Data Standardisation
Schema Matching Inability - Inability to fully or partially match the Data Schema coming from a partner’s system	• Automatic matching • Graph matching • Schema Matching
Data Formats Differentiation - Although the required data for a transaction is send over, there is a problem to process the data due to incompatible data formation, and further transformations are needed	• Data Mediation • Automatic matching • Unified data schemas • Graph matching
SA.2 – Process Interoperability	
Process Models Absence - The processes used by an enterprise are not documented and there is an inability to conduct transactions with other entities as they are not aware of the various touch points and decision flows	• Process Modelling
Complex/Different Process Flows - Processes used by an enterprise are way to different from the majority of same processes used by other partners/organisations, resulting in an inability to automate	• Process Reengineering • Process Alignment • Process commonalities • Model transformation

Problems / Issues	Possible Solution Elements
Non Standardised Processes - Although the processes used by an enterprise are clearly documented and in many cases matching with those of other partners, full Interoperability is hindered by the fact that they do not comply with globally accepted process flows	• Process commonalities • Model transformation • Process Standardisation
Manual Process Execution - An enterprise possesses the needed IT systems to communicate with partners and processes are aligned, however there is a need to manually trigger the workflows for conducting a transaction	• Automated Process Execution • Integration of structured and unstructured operations
SA.3 – Rules Interoperability	
Rules Models Absence - The business and legal rules that apply to an enterprise are not documented making it impossible for the enterprise and its business partners to automatically conduct transactions	• Rules Modelling • Rules-languages • Decision Support Systems
Legislation Incompatibilities - The differentiation in legislation between different regions/territories/countries hinders the generic description and execution of business transactions, as those rules are mapped on a one-to-one basis, making generic models incapable of operating	• Legislation Homogenisation/Alignment
Manual Rules Monitoring and Decision Making - Although an enterprise and its partners are aware of the business and legal rules surrounding a transaction, the lack of an automatic mechanism to monitor them and decide accordingly hinders the full automatic execution of the transaction	• Decision Support Systems • Rules Execution
SA.4 – Objects Interoperability	
RFID inconsistencies - Objects moving across different environments, although recognised in their host environment through RFID tags, are not recognisable and usable in the other environments	• RFID interoperability
Hard-coded and restrained operations Objects - Things that operate in a networked environment have hard-coded functions which limit their capabilities and their operation scope, although they could be generically programmed to work in any internet based environment	• Internet-connected objects/Internet of Thing • Networked Smart Objects / Devices • Interfaces • Mechatronic engineering
SA.5 – Software Interoperability	
Technology dependant Software Components - Software Components used in IT systems have specific requirements regarding the underlying architecture and technology, which eventually limits their ability to be used for interoperation with other systems	• Component-based software engineering
Closed System Architecture Constraints – Software systems that are constrained in operating based on specific architectures do not offer the possibility to be contact or to contact other external systems over the Internet	• Service- oriented Architecture (SOA) • Web Services
Absence of Software Development Io Evaluators – Software developers do not possess mechanisms which will evaluate and monitor on the fly the Io capabilities of the systems under development, making it hard to reconfigure systems at a later stage in order to increase their Io degree	• Software Interoperability Monitoring and Evaluation • Requirements engineering for interoperable enterprises
SA.6 – Cultural Interoperability	
Language differences – Execution of transactions between organisations with different native languages is always hindered (sometimes little, but other quite much) due to the inability to quickly and precisely communicate because of language difficulties	• Language interpretation
Other Cultural Issues – Dealing with enterprises in other regions can be problematic because of various cultural issues such as different availability due to religion/national festivities, different policies in working conditions, etc.	• Regional aspects compatibility • Policy Interoperability • Alignment in traditions, religions and ethics
SA.7 – Knowledge Interoperability	
No Access to Knowledge – Existing knowledge in enterprises is often hard to access and to transport, as there are no mechanism and procedures defined for successfully sharing, transporting, storing and retrieving this knowledge, leading to unnecessary delays and effort consumptions	• Knowledge mining • Knowledge discovery • Knowledge Sharing • Knowledge Repositories

Problems / Issues	Possible Solution Elements
Difficulties in forming joint group alliances - Organisations or units with different knowledge assets but complementary towards a common goal are not able to rapidly and effectively match their capabilities in order to operate quicker towards achieving their common objective	• Semantic Knowledge mapping • Knowledge sharing • Business Units Alignment • Ontology Matching
Systems without background knowledge – In many cases, systems operated by enterprises do not possess any background knowledge mechanisms which could ease out various operations and increase the degree of interoperation with other systems by realising the information that they carry and the information which is fed to/ requested by them either from their host organisation or from the external entities.	• Smart Infrastructures, • Context-aware systems • Knowledge embedded systems
SA.8 – Services Interoperability	
Service Unawareness – An enterprise fails to utilise existing services as there are not clear and precise mechanisms to identify and retrieve them, or to find out how they can be used.	• Inference engines • Automatic service discovery, description, composition, negotiation
Unproperly Designed and Developed Services – Services offered by organisations are designed and developed without taking into account existing standards and practices, resulting to one-to-one implementations that cannot be reused for collaborating with other organisations	• APIs • Service Deployment • Service Engineering • Service Mediation
Isolated and Non-Reusable Services – Enterprises are able to find and utilise services, however their added value is kept to a minimum as they cannot be combined to provided real value	• APIs • Enterprise Mashups • Service-oriented Architectures (SOA) • Web Services
SA.9 – Social Networks Interoperability	
Absence of Social Network Integration – Enterprises which make use of Social networks are unable to automatically import the feedback they get through this network, or utilise these networks to connect with other organisations	• Social Network Integration • Social Business Models • Social Analytics & Social • Cross-Networks Analysis
SA.10 – Electronic Identity Interoperability	
Inability to verify Digital Credentials – An Enterprise is unable to verify and grant access to external users (although it should) due to disconnected and not interoperable authorisation and ID storing infrastructures	• Single Sign On Architectures • Global identity management • Digital Signatures Interoperability • Federated Identity Management Systems Interoperability • Electronics ID Cards Infrastructures & Services • Electronic Identity Security
SA.11 – Cloud Interoperability	
Incompatible Cloud Applications – An enterprise in unable to deploy its applications to different cloud providers, or utilise jointly applications from different clouds due to the underlying cloud technology	• Advanced virtualization • Standardized API's • OS interoperability • Cloud Application Interoperability • Cloud Orchestration • Unified Cloud Interfaces • Cloud Federation
SA.12 – Ecosystems Interoperability	
Inability to integrate to Virtual Enterprises – An enterprise is unable to work under a broader "Virtual Enterprise" due to problems to align its whole operation to such a theme	• Virtual Enterprise Integration • Business Ecosystems Interoperation • Distributed Systems and Agents

2.4.4 EISB Tools

This section provides an overview of an initial set of EISB tools, which should be developed and deployed in order to facilitate the verification, the applicability and the expansion of the EISB developments. These tools, which can be also regarded as modules of a bigger infrastructure as depicted in Figure 2-12, will be based on the developments of the EISB and will be used in order to showcase how the EISB establishments can influence any enterprise in its quest to achieve higher degrees of interoperability.

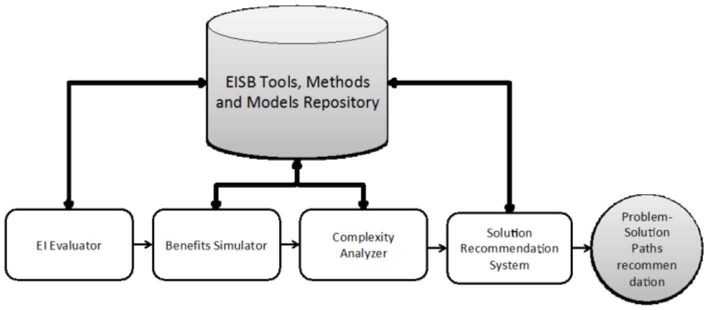

Figure 2-12 - The initial set of EISB Tools (adapted from (ENSEMBLE, 2011))

- EI Evaluator - The EI Evaluator is mostly based on some automation mechanisms such as conformance testing. The main purpose of this specific tool is the evaluation whether a specific system is interoperable with another, or following a pre-defined data exchange standard.

  The evaluation process envisages the maturity assessment of any of the 12 EISB Scientific Areas (SA) across same 3 EI levels/barriers defined for the EISB assessment framework(ENSEMBLE, 2012):

  1. The fist EI level to be addressed is the organizational one. Since it is a human-intensive level, this step can be performed using manual mechanisms such as questionnaires, interviews, etc., to calculate the assessment matrix. It allows to determine the interoperability maturity at the management levels of the enterprise, and when not sufficiently mature impedes interoperability at any of the other levels;
  2. Then the evaluation of conceptual interoperability follows, and besides the manual mechanisms, depending on the SA, in is possible to apply some automation and determine the effective interoperability as well as the maximum potential in term of the syntactic and semantic interoperation. As in the organizational level, if interoperability at the conceptual level is not sufficient it impedes technical interoperation;

3. The final evaluation is at the technological level to assess ICT mismatches and implementation mistakes. Here a number of frameworks are already defined and can be reused in the EISB scope, e.g. conformance testing and interoperability checking as explained in Chapter 3 .

- Benefits Simulator - The Benefits Simulator will be based heavily on the Interoperability Assessment Framework proposed by ENSEMBLE. The main purpose of this specific tool will be the simulation of the various offerings/benefits of an enterprise if the latter decides to invest in the improvement of its status in any of the 12 Scientific Areas.

- Complexity Analyzer - The Complexity Analyzer is a support system that based on the different problem/solution models provides the enterprise an estimation of the complexity involved in the implementation of the different solutions proposed.

- Solution Recommendation System - The Solution Recommendation System is the last part of the initial EISB tools chain, and it is intended to provide recommendations regarding the possible solutions that may be employed by the different organizations in their effort to improve their EI capacity.

2.4.5 EISB Knowledge Base

The EISB Knowledge Base is a component that intends to capture the EISB framework with precise and semantically meaningful definitions, gathering the knowledge held by domain stakeholders in interpretable knowledge bases, thus transforming it to explicit knowledge.

The EISB framework includes a mechanism provided for assessing the interoperability of enterprise systems and applications, enabling to position themselves within the EISB problem space, as in section 2.4.3 - “Problem and Solution Space” and benefit from the one or more solution paths available by being able to identify the status quo of an organization, and classify it based on its performance on the different EI Scientific Areas.

A front-end interface for the Knowledge Base that supports this project is available online through the FInES wiki: http://www.fines-cluster.eu/fines/mw/index.php?title=Main_Page

2.4.5.1 EISB Reference Ontology

Following the MENTOR methodology (Sarraipa, Jardim-Goncalves, & Steiger-Garcao, 2010), the 12 scientific areas taxonomy can be extended to build the envisaged ontology backbone and enable knowledge management functionalities for the EI body of knowledge (EISB knowledge base), gathering content such as concepts, publications, formal and other descriptive methods, tools, researchers, industrial and scientific committees, and even scientific neighbours.

The ontology has been complemented due to further harmonization with the FInES wiki and other sources of EI knowledge, to a structure with more than 100 classes. As Figure 2-13, the structure is organized in a way that enables it to represent conceptually the EISB Framework and the instances of the EISB Wiki, relating them both while keeping them physically separated. In the example it is possible to see that the EISB scientific areas and sub-areas (part of the EISB glossary of the Wiki) are instances of the 12 EI Scientific Areas of the EISB Framework.

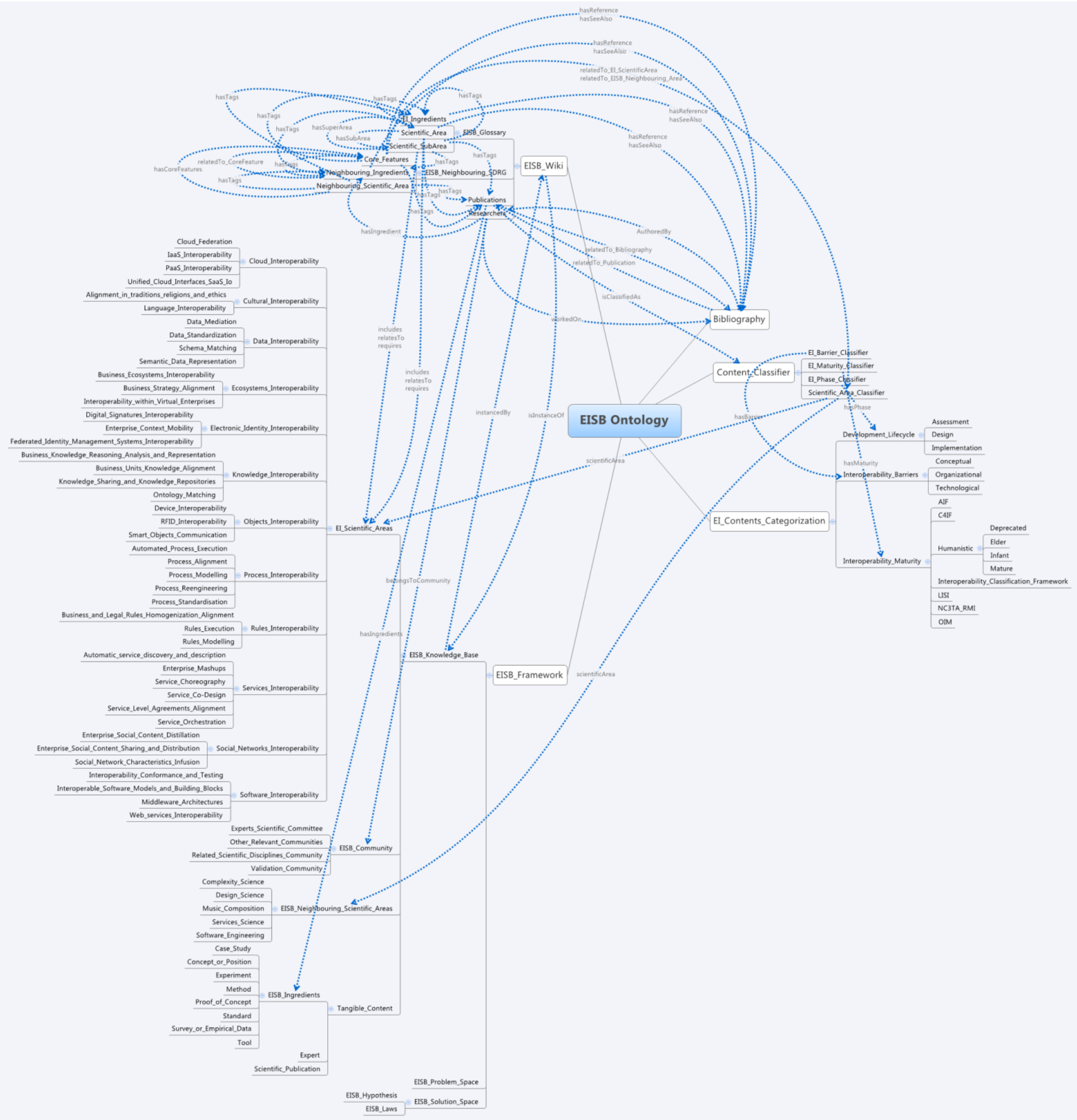

Figure 2-13 - EISB Ontology Structure and Semantic Relationships

Chapter 3 - Interoperability Evaluation

With the aid of several frameworks to guide the enterprise interoperability process, a lot of issues can be avoided but there is still a need for methods to assess and classify the state and quality of the cooperation's in progress. The testing process is a complex phase and should be done in each knowledge sharing interaction in order to detect and avoid all kind of issues that may occur.

The following chapter presents methods to test and measure the interoperability between two or more information systems, starting with the adherence to standards and finishing with specific tests to the implementation itself.

3.1 Conformance Testing

A good start for a stable system with high chances of being interoperable passes for the implementation adherence to a well-specified standard or reference model, however this simple approach turns into a huge issue when some details are neglected, and can compromise the whole interoperability process. In an enterprise environment, if two or more enterprises adopt the same reference model to exchange data with one another, it is not guaranteed that they can achieve an effective data mapping without syntactic or semantic errors.

The capability to evaluate the adherence or non adherence of a candidate implementation to a standard is called "conformance testing"(ISO, 1993). To execute this kind of tests there is a need of a special dedicated test system with full control, access and observability connected to every single SUT as shown in Figure 3-1.

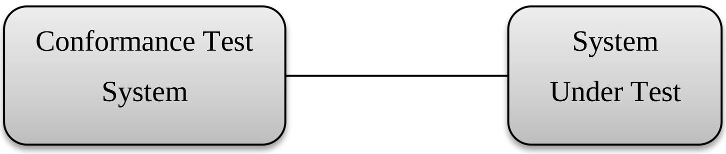

Figure 3-1 - Illustration of conformance testing (ISO, 1993)

Some methodologies have been proposed and standardized to assist the development of a conformance test platform as described in the following sub-sections.

3.1.1 ISO 9646 – OSI Conformance Testing Methodology and Framework

ISO 9646 is a standard developed based on ISO/IEC 7498-1 – OSI Reference Model for Open Systems(ISO, 1994a), which defines a common base to allow the intercommunication of open systems.

This standard defines a methodology divided in 3 stages, Figure 3-2. On the first one, are defined the purposes of the tests, that will allow the creation of the Abstract Test Cases to be applied. The second stage consists in selecting among all the tests, which of them will be applied, and generate a valid and executable test. The last stage is the test execution phase on the Implementation Under Tests, generating reports about the conformance status of the implementation.

This methodology was developed to make available a platform and define a common testing terminology for OSI systems, and can be divided into three main phases (ISO & JTC, 1994):

- Definition of tests purposes – specification of the ATCs to be applied, that will form the ATS, which are implementation independent and described using TTCN.
- Test selection and generation – choosing among all ATCs which of them can be applied to the implementation and transform them into tests capable of being executed.
- Test execution – run the tests on the IUT and observe the response after the stimulus at the PCTR.

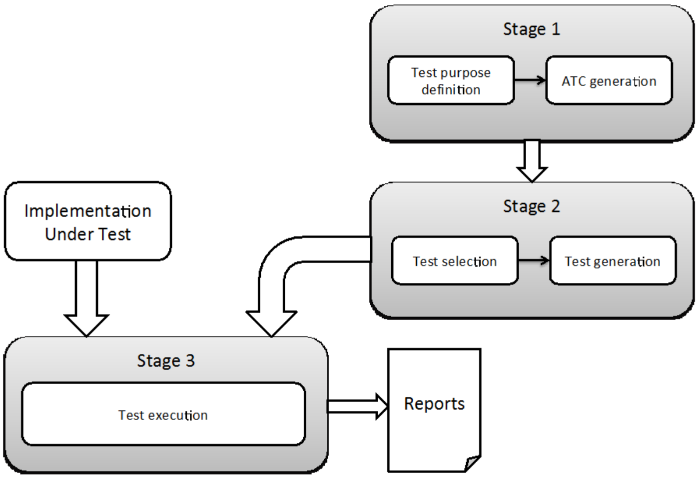

Figure 3-2 - ISO 9646 OSI Conformance Testing Methodology and Framework

3.1.2 ISO 10303-30 – STEP Conformance Testing Methodology and Framework

The 30th part of STEP (ISO, 1994b) defines a methodology and a framework to apply conformance tests, based on ISO 9646. The main stages are equal to the ones described on 3.1.1, except the execution that divides the tests in two types:

- Pre-processed – in these the reference model is inserted in the application in order to produce corresponding data and the output is compared with the expected results.
- Post-processed – a data example if used as the input of IUT, and inferences are made about how this example is handled, in order to inquire it's being interpreted correctly.

3.1.3 ETS 300 406 – Methods for Testing and Specification (MTS)

The goal of this standard developed by ETSI is to describe a methodology for application of conformity tests (ETSI, 1995).

The first part of this methodology is dedicated to identify the test purpose and their structure (Test suit structure). Subsequently, based on the test purpose and TSS, the Abstract Test Cases are defined and described in TTCN.

The tests applied by this methodology are similar to the ones implemented by ISO 9646. First of all are defined the TP and TSS, so later can be developed the ATCs descried in TTCN-3, a redesign of TTCN made by ETSI, that will result in ATS.

Nevertheless, even having the above methodologies, how can we know if a system will be interoperable with another implementation of the same reference model, even when meeting all the requirements specified in the standard or reference model? Conformance testing can evaluate if the implementation is in conformity with all the requirements, but that can't guarantee the same semantic interpretation or the same modules implementation (if the standard envisages multiple conformance options). Thus there is an identified need to complement conformance testing with interoperability checking systems.

3.2 Interoperability Checking

Conformance testing can evaluate if the implementation is in conformity with all the requirements of the protocol, but that can't guarantee a good communication between at least two systems ruled by the same standard, in other words, interoperability is not guarantee.

The purpose of interoperability testing is to prove that end-to-end functionality between two or more systems is as required by the standard that rule them(ETSI, 2003). To execute this kind of testing there is a need of a qualified equipment, shown in Figure 3-3, that come from different supplier of Equipment Under Test, and those tests are based on functionality as experienced by a user(ETSI, 2003).

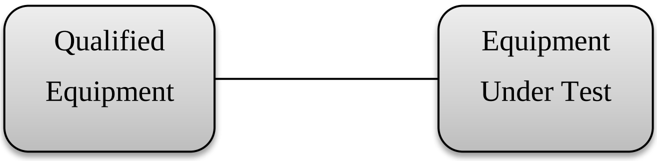

Figure 3-3 - Illustration of interoperability checking (ETSI, 2003)

3.2.1 ETSI TS 102 237-1 – Interoperability Test Methods and Approaches

Although there are a set of standardized methodologies for conformance testing listed on the previous section, for interoperability checking it is not so common. An exception is the ETSI standard TS 1102 237-1, with a lot of common principles to the standard ISO/IEC 9646 adapted to interoperability(Onofre, 2007).

The main difference between this methodology and the ISO/IEC 9646 resides at System Under Test, that is now composed by a Equipment Under Test and one or more Qualified Equipment that works as a reference of a ideal implementation.

Thus, the TP and TSS are also derived from standards, but are now focused on testing specific functionalities of the EUT.

"Conformance and interoperability are both important and useful approaches to the testing of standardized protocol Implementations although it is unlikely that one will ever fully replace the other"(ETSI, 2003)

3.2.2 funStep Interoperability Checking Methodology

This methodology provides two types of conformance tests, the basic preliminary tests applied to check the conformance of the implementation under test, and the tests that assess the capability of the implementation in comparison with the PICS (Protocol Implementation Conformance Statement)

These two types of tests fulfil the needs of two kinds of users, the ones that only need to check if the data is in conformance with the syntax and semantics of any STEP conceptual model, and the users that also need to evaluate the characteristics described in PICS.

The proposed methodology, Figure 3-4, is composed by 7 distinct phases:

1. Abstract Test Suit definition on plan language, based on test purposes, PICS and PIXIT.
2. Abstract Test Cases converted from plan language to TTCN-3
3. Generation of executable tests from the ones defined in TTCN-3

4. STEP model transformation described in express to XSD and Schematron, this phase is very important because the models that result from this transformation are the knowledge base that will be used to apply the conformance tests to XML data
5. Transformed model imported to the tests execution platform.
6. Tests execution over the implementation
7. Report generation

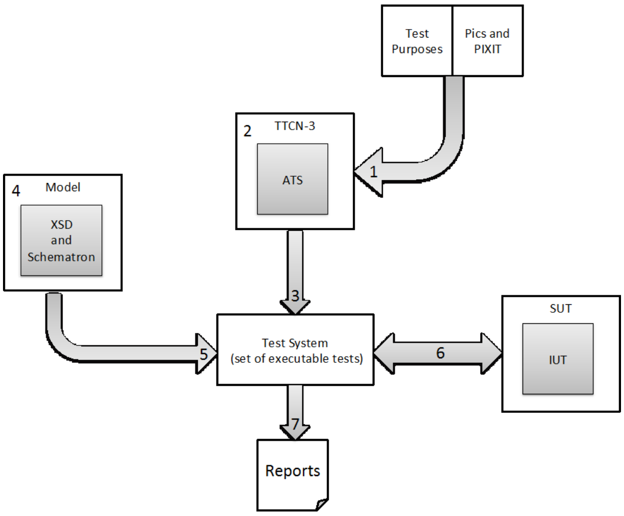

Figure 3-4 - STEP conformance test methodology

Those reports that result from the execution of the defined tests, have the information about the errors that were found.

3.2.3 NIST: Interoperability Testbed

The National Institute of Standards and Technology (NITS) propose a web-based testbed methodology/framework, where the participating nodes in the interoperability testing would be of two logical types: test/monitor type and middleware/application type. The testbed test/monitor node is a single logical node that, however, may consist of multiple distributed functions running on multiple nodes. The middleware/application nodes are distributed among participating organizations.

To enable interoperable behaviour of these nodes, standards at different levels of the interoperability architecture are agreed upon.

The testbed has focused on the three layers of the architecture: messaging, business processes, and business content. Several standards are being used at present time, these are ebXML business process specification and messaging standards and OAG content standards. However, the testbed architecture only requires that the HTTP protocol is used in order to support basic functions of reflecting and monitoring.

The instrument icons on the architecture diagram indicate the areas where the testbed has worked to identify testing needs or developed infrastructure testing and monitoring tools.

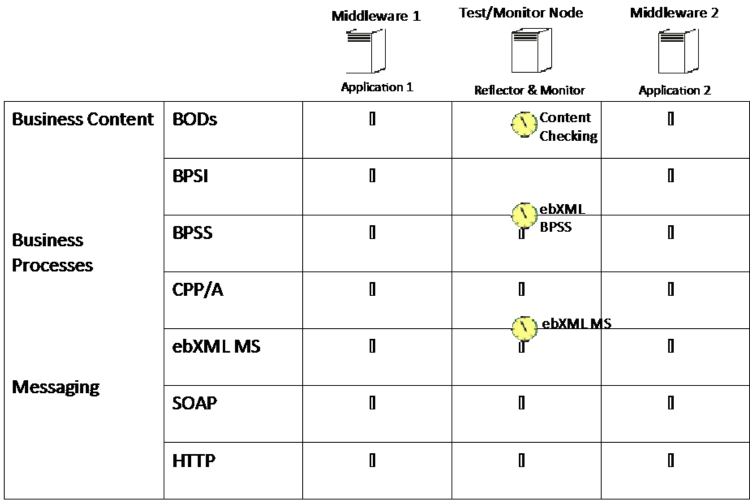

Figure 3-5 - Illustration of NIST architecture

3.3 Measuring Interoperability

The majority of the researches to explore quantitative measures for describing interoperability relationships fails because it considers the system as black boxes and has no concerns about the details and semantics. In order to fill this gap, in (Yahia, Aubry, & Panetto, 2012) proposed an approach based on formalization of the semantic relationships between systems by analyzing the detailed semantics of their conceptual model and relationships.

This work extends the well-known interoperability definition stating that two information systems (IS1 and IS2), in the context of cooperative enterprises, have to satisfy the following properties:

- IS1 needs to be able to communicate some information with IS2
- IS2 needs to be able to understand at least partially the semantics of the information exchanged
- IS2 needs to operate on that exchanged information.

A new evaluation method is also added by selecting a core of mandatory concepts, Figure 3-6, due to the fact that non-mandatory concepts are not necessary for the implementation to operate correctly.

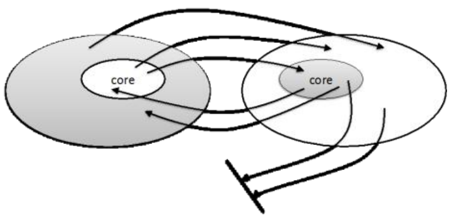

Figure 3-6 - Interoperability properties

The mappings between these two elements allows to identifying the different existing relationships between the conceptual model entities, these relationships defines the correspondence between both elements.

Going deep in the study of the relations arises three properties that characterize them:

- *Property 1*: Non-symmetry - Interoperability is not a symmetric relationship, that means that one element of a system can be interoperable with another but the reverse doesn't occur. Especially in systems that only one interoperability direction is needed.
- *Property 2*: Maximal potential interoperability - When not only the core semantics, but also the non-mandatory are considered to define the interoperability relationships, and all the concepts are instantiated.
- *Property 3*: Minimal effective interoperability - Restricting the relationships to the core semantics provide a guarantee that they are effective, but the interoperability is classified as effective and minimal.

To accomplish the quantitative evaluation of the conceptual models there is a need of formalized measures and specific information about the mappings defined in a real state and an expected state:

- R_c^2- Represent the mappings defined from one model to another
- R_c^{2e} – Represent the mappings containing only mandatory concepts and entities
- $R^2_{c\ expected}$ – Represent the mappings expected

Taking into consideration the Property 2 and 3 and the formalized measures defined arises the Table 3-1.

Table 3-1 - Measures for interoperability assessment

Type of evaluation	Interoperability	Measure	Value conclusion
Maximal Potential Interoperability (MPI)	$V_{1\text{-}2} = \frac{\lvert R_c^2 \rvert}{\lvert R^2_{c\ expected} \rvert}$	=0	S1 is not interoperable with S2
		<100%	S1 is partially interoperable with S2 but only a percentage of the relationships with S2 (R_c^2) are effective. $V_{1\text{-}2}$ can be reached if all concepts taking part into (R_c^2) are mandatory
	$\varepsilon_{1\text{-}2} = \frac{\lvert R_c^{2e} \rvert}{\lvert R_c^2 \rvert}$	=100%	S1 is potentially fully interoperable with S2 but only a percentage of the relationships with S2 (R_c^2) are effective. $V_{1\text{-}2}$ can be reached if all concepts taking part into (R_c^2) are mandatory

Type of evaluation	Interoperability	Measure	Value conclusion
Minimal Effective Interoperability (MEI)	$V_{1\text{-}2} = \frac{\lvert R_c^{2e} \rvert}{\lvert R_{c\,expected}^{2} \rvert}$	=0	S1 is not interoperable with S2
		<100%	S1 is partially interoperable with S2 and this partial interoperability is effective
	$\varepsilon_{1\text{-}2}$ = 100%	=100%	S1 is fully interoperable with S2 and this interoperability is effective

As an illustration, in (Yahia et al., 2012), are presented two conceptual models from two information systems, FIGURE X, and the respective semantic relationships.

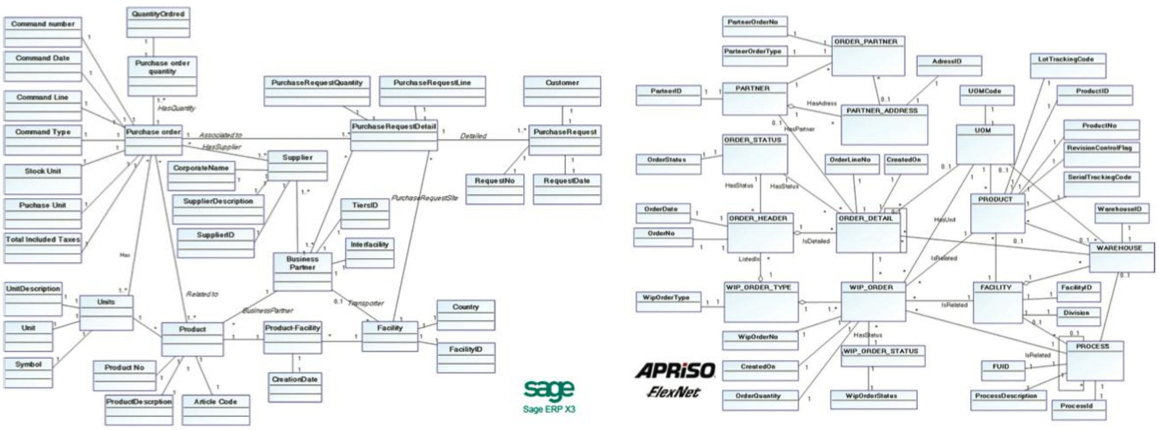

Figure 3-7 - Conceptual model of purchase order in Flexnet application and SAGE X3 application

After execution of the mappings from FlexNet to SAGE information systems, the following information is obtained:

- R_c^2 = 30
- R_c^{2e} = *25*
- $R_{c\,expected}^{2}$ = 37

Applying the equations of the Table 3-1 arises the result of the analysis summarized in Table 3-2

Table 3-2 - Illustration example for measuring interoperability between two information systems' conceptual model

	Result	Effectiveness
Potential Interoperability	$V_{1\text{-}2} = \frac{30}{37} = 81\%$	$\varepsilon_{1\text{-}2} = \frac{25}{30} = 83\%$
Effective Interoperability	$V^{e}_{1\text{-}2} = \frac{25}{37} = 68\%$	$\varepsilon^{e}_{1\text{-}2} = 100\%$

Chapter 4 - EI Evaluation Framework

Interoperability is not visible when it is effective, but the lack of interoperability poses a series of challenging problems to the industrial community(ENSEMBLE, 2012a). Indeed, it leads to significant costs, largely attributable to the time and resources spent when exchanging information. For this reason, it is important to provide a mechanism for assessing the interoperability of enterprise systems and applications, enabling to position themselves within a known problem space (e.g. the EISB problem space) and benefit from the one or more solution available.

In this context, an EI evaluation enables to identify the status quo of an organization in terms of readiness for cooperation and also in terms helping understand what to improve. However, seeking to evaluate any interoperability issue should be considered as a part of a thorough and methodological process rather than an ad-hoc activity. Therefore, to improve the interoperability testing and validation, an approach that views the interoperability process as flow of information from one enterprise to another was adopted, as shown in Figure 4-1. That flow is path dependent, so one enterprise can be interoperable with another but the reverse isn't guaranteed at the same level or at all. Moreover, each step of the path refers to specific testing methods according to the barriers defined in 2.3.1.2 – "Interoperability Barriers Viewpoint", defining a three assessment layers.

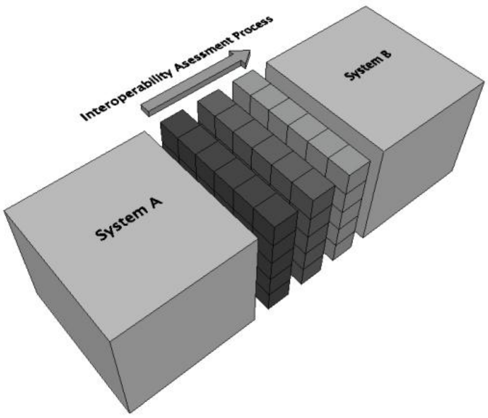

Figure 4-1 - Interoperability assessment process

The detailed evaluation framework realizing the envisaged interoperability assessment process is illustrated in Figure 4-2, which targets the evaluation of systems according to any of the scientific areas (concerns), to their maturity and barriers addressed in a sequential flow. Each barrier has an eliminatory role, thus if the systems do not match the minimum requirements to interoperate while testing each barrier, the whole integration effort is useless. The proposed framework follows the same axes as detailed in the EI framework (ISO, 2011) , i.e. three different axes of evaluation measurement:

- the EI scientific areas that will enable to categorize the type of scientific problems, each evaluated system is experiencing;
- the maturity level to categorize the severity of the problem by beans of a qualitative measurement (the lower the level, the worst is the problem); and
- the EI barriers that relate directly to the assessment layers envisaged in Figure 4-2

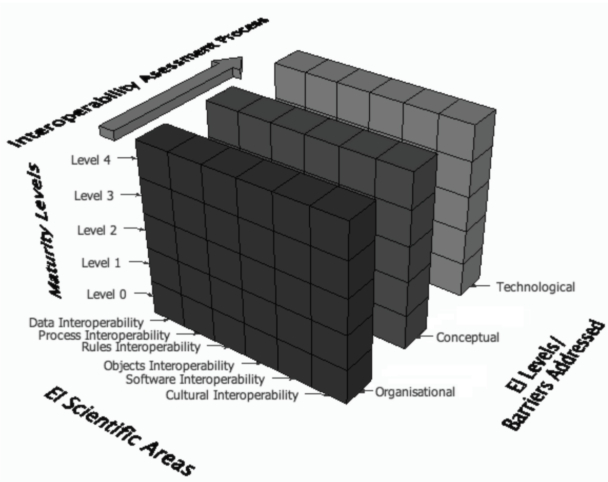

Figure 4-2 - Evaluation Framework

4.1 Axis 1: EI Scientific Areas

The EI scientific areas adopted for the evaluation framework was a simplified version of the S.A. listed in 2.4.1 – “EI Scientific Areas”. Restricting the scientific areas to the lower level of the Figure 2-9, allows decreasing the complexity of the evaluation process. As long as the levels are increasing, the complexity also gets larger making the test definition too extensive. This approach focuses the tests at low-level areas reducing the complexity and the number of tests to be defined.

Since those areas are defined in a tree diagram, it will be possible to test higher-level areas by running a set of tests from a group of lower-level ones, e.g. a knowledge test results from a composition of cultural, rules, process and data testing.

4.2 Axis 2: EI Maturity Levels

This axis arises as a measurement of the interoperability assessment process. For each Assessment layer must be defined specific tests because human related issues cannot be evaluated the same way as the technological ones. Thus, for each scientific area must be applied different maturity levels that are more appropriate to classify that area.

In section 2.2 – "Categorizing Interoperability using Maturity Models and Levels" are presented several categorizations of interoperability using maturity models and levels, however none of them fits perfectly to all three assessment layers or scientific areas. In order to categorize the results of the tests executed at each layer, those methodologies must be adapted according for each case. Therefore it was decided to generalize the maturity classification to a five level scale of values (0-4). The meaning of each level associated with each barrier will be explained in detail in the following section 4.4 – "Evaluation Methodology", where the methodology for implementing the framework is explained.

4.3 Axis 3: EI Barriers and Assessment Layers

The EI Barriers for the evaluation framework have been defined in conformance with the framework for enterprise interoperability proposed in (ISO, 2011) as follows:

- Organizational – is caused by human interaction, their capability and interest too cooperate, especially in hierarchized enterprises where the goals are heterogeneous.
- Conceptual – is caused by different methods to represent information and knowledge, especially in complex systems with a lot of entities containing crucial information.
- Technological – is caused by different interfaces to exchange data or a huge technological gap between the parts interested in cooperate.

This axis represents the interoperability assessment flow, envisaging the advancement along the three assessment layers. This flow is instantiated by the evaluation methodology described hereafter.

4.4 Evaluation Methodology

To evaluate interoperability between at least two systems, there is a need of specific methodologies to test each kind of problem that derive from each EI Barrier, because human-related issues can't be tested the same way as technological issues.

To achieve better results, and avoid costs that result from failed attempts at interoperating systems that are doomed from the start due to own business structure, each test case shall answer the two following questions:

- It's worth trying to cooperate?

- It's technologically possible to cooperate? And that cooperation is maximized?

To find the answer for the first question there is a need to do a set of organizational tests that will check if the structure of the involved enterprises is compatible with each other, if so, the models from each enterprise will be tested to dismiss conceptual issues that inhibit maximization of the cooperation, or simply don't let it happen.

Having a positive result from the initial phase of tests, it is now theoretically possible to interoperate and arises the need to know if the available technology is enough to cooperate. The result of this technological test tells if the available technology is enough to cooperate, and if that cooperation is maximized.

4.4.1 Assessment Layer 1: Organizational Testing

The human decisions and objectives are a strong inhibitor to the interoperability process because humans run enterprises and decide their goals. This way is impossible for two enterprises with distinct market views, objectives or hierarchical structure to interoperate and cooperate for a reasonable period.

To evaluate the organizational influence in the interoperability process there is need to know and compare the motivation and goals of a sample of workers from every hierarchical group from both enterprises. To do this shall be applied questionnaires designed specifically to each kind of worker to get viewpoints from all of them, and some questions directly to the organization. For example, in (Chen, David, Bruno Vallespir, n.d.) are proposed the following questions:

- Persons: are authorities/responsibilities clearly defined at both sides?
- Organization: are the organization structures compatible?

A reasonable number of questions are needed to enhance the credibility of the survey, but a number of right answers is not enough to determine the origin of the issue. To clarify the cause of the problem, specific sets of questions must be defined for the scientific areas that can affect this Assessment Layer. Analysing Table 4-1 in terms applicable scientific areas, all can be assessed because in certain point, all of them are related to organisations and humans.

Table 4-1 - Assessment Layer 1 - applicable scientific areas

	Data Interoperability	Process Interoperability	Rules Interoperability	Objects Interoperability	Software Interoperability	Cultural Interoperability
Organizational Testing	X	X	X	X	X	X

The Maturity levels are defined depending on the percentage of equivalent responses as follows:

- Level 0 – $\geq$ 0%
- Level 1 – $\geq$ 25%
- Level 2 – $\geq$ 50%
- Level 3 – $\geq$ 75%
- Level 4 – = 100%

If the system doesn't have at least level 2 in both ways, it isn't advisable to continue the interoperability process because more than a half of the questions designed to this test have distinct results.

4.4.2 Assessment Layer 2: Conceptual Testing

Due to different enterprise market opportunities and own interests, there is a need to specify the area that both want to cooperate and later share information. In this process both parts need to define a set of data and process, to be tested, that belongs to the previous agreement of cooperation.

Having the specific information selected, an interoperability expert shall define the mappings from one conceptual model to the other, and the reverse, taking into consideration the semantics of each model.

With all the mappings defined on both directions, shall be applied the equations defined by (Yahia et al., 2012), explained in section 3.2.2 and summarized in Table 3-1.

The scientific area that is being assessed, see Table 4-2, depends on the type of model in test. In fact, it is impossible to evaluate all kinds of interoperability recurring to model analysis. If cultura behaviours and objects was represented in an information model to be assessed, that evaluation was at data level, and the other scientific areas was going to remain unassessed. In fact only four kinds of interoperability can be evaluated at this layer:

- The assessment of models that represent databases or information repository will test data interoperability.
- The assessment of models that represent business processes and methodologies will test the process interoperability
- Rules from enterprises represented in information models will be assessed by rules interoperability
- The assessment of models that represent the concept of the software implementation will test the software interoperability.

After the calculation of MPI and MEI, there is a need to get the maturity level that characterizes the system. Since MEI only considers Mandatory concepts to the calculation of the interoperability ratio, it is more important to the goal of the system, and so it has more importance to define the maturity level on this barrier. Those maturity levels are defined as follows:

- Level 0 –MPI < 100%, MEI < 25%
- Level 1 – MPI < 100%, 25% < MEI < 50%
- Level 2 – MPI < 100%, 50% < MEI < 75%
- Level 3 – MPI <100%, 75% < MEI < 100%
- Level 4 – Both MEI and MPI = 100%

If the system doesn't have at least level 2 in both ways, it isn't advisable to continue the interoperability process because more than a half of the mandatory concepts are being lost with this process.

Table 4-2 - Assessment Layer 2 - applicable scientific areas

	Data Interoperability	Process Interoperability	Rules Interoperability	Objects Interoperability	Software Interoperability	Cultural Interoperability
Conceptual Testing	X	X	X		X	

4.4.3 Assessment Layer 3: Technological Testing

This part of the testing methodology will be a validation of the conceptual testing because now there is a well defined model that both parts agreed to follow and each implementation have to be in conformance with that agreement.

Before any kind of interoperability testing, there is a need to check the conformance of both implementations to the standard or agreed conceptual model. If any of the implementations don't pass this conformance test it will be totally not recommended to continue this process before review the first and second step because probably those applications won't be minimally interoperable or at all. To implement a conformance test platform shall be used one of the methodologies listed in 3.1.

If the system pass the conformance testing, will begin the interoperability checking itself that need at least one qualified equipment to run the tests as shown in Figure 4-3. To test the system an interoperability expert shall define a set of abstract test cases that form an abstract test suit (ATS), which will be executed by the test driver that can be a human or an automatic application like

TTCN-3 to test communication protocols (ETSI, 2003). Those tests shall include data sharing and service invocation from and to EUT.

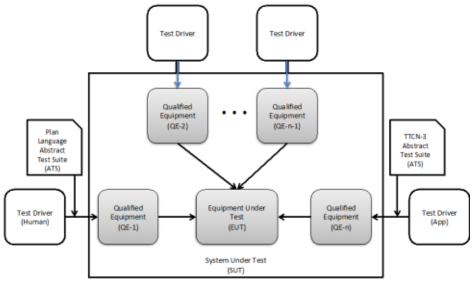

Figure 4-3 - Interoperability checking architecture

Since this Assessment layer only concerns about technological tests, it will only be able to apply to a restrict set of scientific areas, see Table 4-3. It is impossible to evaluate all kinds of interoperability recurring to technological tests, only because there are lot of inhibitors to interoperability that are not present on the implementations such as human and organizational related issues. In fact only it is only possible to assess data and software areas, because both of them are the only directly related to the implementation of enterprise systems.

Table 4-3 - Assessment Layer 3 - applicable scientific areas

	Data Interoperability	Process Interoperability	Rules Interoperability	Objects Interoperability	Software Interoperability	Cultural Interoperability
Technological Testing	X				X	

The maturity levels to technological testing are defined as follows:

- Level 0 – 0% successful tests
- Level 1 – 25% successful tests
- Level 2 – 50% successful tests
- Level 3 – 75% successful tests
- Level 4 – 100% successful tests

The result of this testing phase can’t be interpreted in isolation because it is a validation from the conceptual testing, and so the maturity level shall not be lower than the one achieved on that test. If the level is higher, shall be defined another ATS that identifies the missing concepts that are detected on conceptual testing. If the maturity level is lower than expected, the whole process shall stop and be reviewed.

4.4.4 Usability of the Results

At section 2.4.3 – "Problem and Solution Space" is presented a set of possible issues with an associated solution to guide the recovery process, depending on the cause of the issue.

When the origin of the problem is focused on the assessment layer 1, the resolution may be very troubled because of local laws that may counter the efforts to interoperate. However for the second and third assessment layers, those issues can be softened using specific tools.

The expected state is achieved when both technological and conceptual testing have the same maturity level, and when this level isn't the optimal, there is a technological gap between those states as show in Figure 4-4.

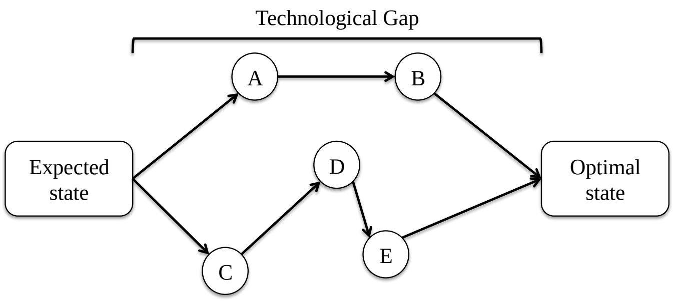

Figure 4-4 - Technological gap

To reduce or eliminate the technological gap there are several tools and frameworks available on the EISB knowledge base that will be a bridge between the expected state and the optimal, or at least closer to it. These kinds of tools are fully dependent of the system under test, so each case must be specifically observed to find the best solution path.

Chapter 5 - Proof-of-Concept Implementation

5.1 Application Scenarios and Test Cases

The objective of a scenario is to describe, step by step, how a user (or users) intend to exploit a system, essentially capturing the system behavior from the user's point of view (CRESCENDO 2009). It was decided to scope this thesis' application scenarios approaching two different views on interoperability assessment:

1. Assess the interoperability potential from a new collaboration network. In this case, a well-known business collaboration network from the furniture industry has been chosen, i.e. a Supply Chain (SC).
2. Evaluate the interoperability status of an existing network relationship. Here, a simpler academic scenario has also been defined and used to test the methodology while information from the industrial case was not made available.

5.1.1 Supply Chains in the Furniture Industry

Supply chains are critical infrastructures for the production, distribution and consumption of goods and services (Nagurney 2006). According to Ganeshan & Harrison (1995), based on the customer's order, they enable raw materials, supplies and components to be modified into finished products and then distributed to the consumers. This involves two major types of communication, supported by physical and information flows (W. J. White et al. 2004). The first usually involves moving goods "forward" from suppliers to consumers in each link of the chain, while the information flow involves exchanging product and financial data, namely electronic catalogues, orders and payments for materials, services, supplies and final products (Agostinho, 2012).

Since these networks are characterized by non-centralized decision-making, changes in the availability of supplies, prices, as well as disruptions to transportation or communication may cause effects that propagate throughout the entire network and decrease SC efficiency.

In this scenario, a manufacturer desires to upgrade its existing supply chain by publishing its product catalogue in a larger number of retailers, using the standard AP236 (ISO, 2006), as represented in a simplified version in Figure 5-1. This way, manufacturer would increase the sales potential and minimize the risks of data misinterpretations by adopting an international standard for the representation of product data. Nevertheless, the manufacturer does not want to take this step without being sure that he will indeed maximize its interoperability potential with the retailers. As illustrated on Figure 5-2, the goal of the scenario is to analyze whether a manufacturer catalogue, represented in Figure 5-3, is interoperable with two retailers using the Standard AP236 - “Application protocol: Furniture catalog and interior design” as an information mediator, i.e. the manufacturer system should be able to transform furniture catalogue data to the standard format, and the different retailers should be able to read it.

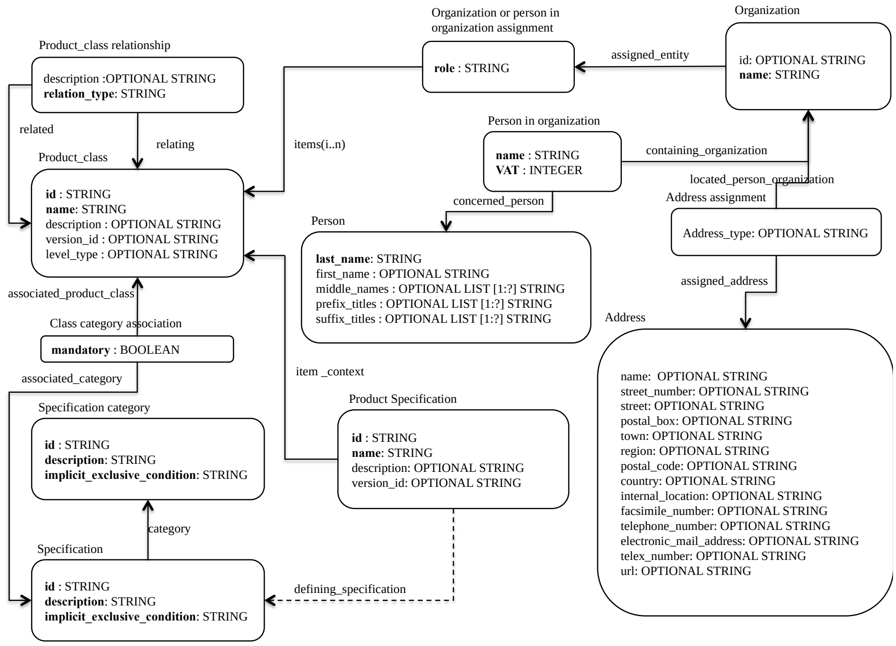

Figure 5-1 - Illustration of a simplified version of ap236 catalogue model (ISO 10303-236:2006)

Therefore, the whole effort from the manufacturer to turn his catalogue interoperable with the retailers in order to communicate with them transparently and automatically is explained in the next steps:

1. The first step comprises the application of a questionnaire at both sides of the process, manufacturer and retailers. In order to determine whether the manufacturer's effort is advantageous. Thus, the questionnaire is generated to this specific case and results are interpreted aiming the continuity of the evaluation process.
2. The second step goal is to verify if the conceptual models of both parts of the process are mappable to a common the specified common standard AP236. Those data mappings are defined by interoperability experts, linking all mappable nodes and identifying the relations between both models and the standard. Those associations are registered in a local knowledge base that will support the interoperability assessment process.

3. After the knowledge gathering step, the evaluation phase initiates with the applying of the testing methodology defined in 4.4 – “Evaluation Methodology”.

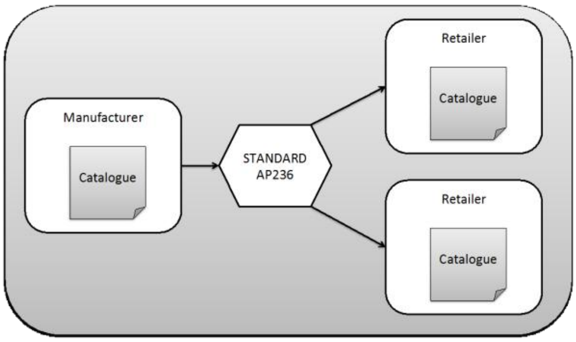

Figure 5-2 - Application scenario: Furniture Industry

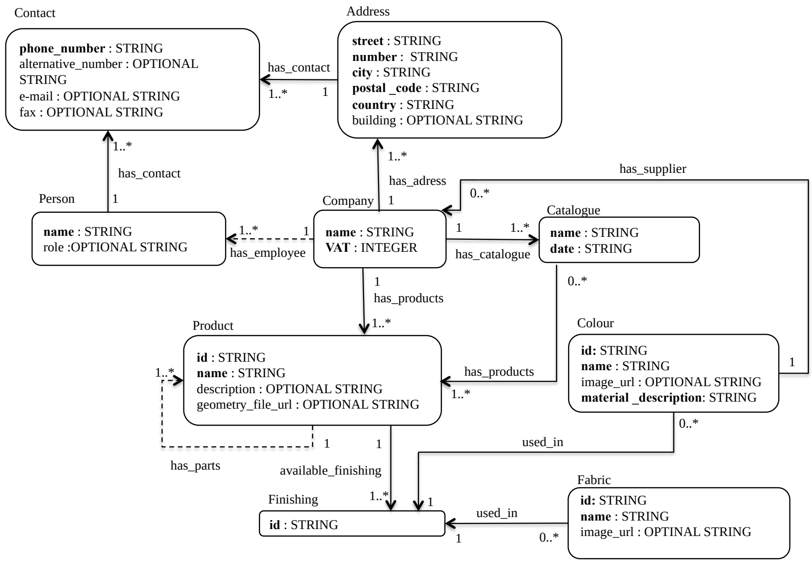

Figure 5-3 - Illustration of a manufacturer catalogue model

5.1.1.1 Test Cases

TC1.1: Organizational assessment - applying questionnaires to the manufacturer and retailers side and evaluate the number of equivalent answers

TC1.2: Conceptual assessment – identify the mappings from the manufacturer catalogue to the standard AP236 and determine the amount of data loss

TC1.3: Conceptual assessment – identify the mappings from the standard AP236 to the retailers catalogue and determine the amount of data loss

TC1.4: Technical assessment – Executing conformance checking on the manufacturer implementation

TC1.5: Technical assessment - Executing front end actions from the manufacturer to the retailers side

5.1.2 Geometric Shapes: Triangle

There are several ways to represent geometric shapes by electronic means, such as 3D models and figures, but in order to allow a deep cognition of the specific data inherent to those geometric shapes, a information model must be defined, including the most information available.

This more academic scenario is composed by network of four enterprises that are joining efforts to develop a geometric model in a collaborative way. Each one of them uses a different UML tool (UniStep, ArgoUML, MagicDraw UML, Altova UModel), and its imperative to exchange the information models in the network, in order to correlate the models and evolve. Although UML is a standardized modelling language with a solid XMI base, many existing tools that implement this standard export extra information that is not comprised in the standard, and can make the files not importable by other applications. Furthermore, there are several versions of XMI that can also cause interoperability problems.

The implemented network follows the flow depicted at the Figure 5-4, in order to asses the interoperability status of the network the following steps are applied:

1. The first step comprises the application of a questionnaire at all four enterprises involved in the process. In order to determine all the enterprises have the same goals and flexibility to work together. Thus, the questionnaire is generated to this specific case and results are interpreted aiming the continuity of the evaluation process.
2. The second step goal is to verify if the conceptual models of all involved parts of the process can be mapped among each other. Those data mappings are defined by interoperability experts, linking all mappable nodes and identifying the relations between all models. Those associations are registered in a local knowledge base that will support the interoperability assessment process.
3. After the knowledge gathering step, the evaluation phase initiates with the applying of the testing methodology defined in 4.4 – “Evaluation Methodology”.

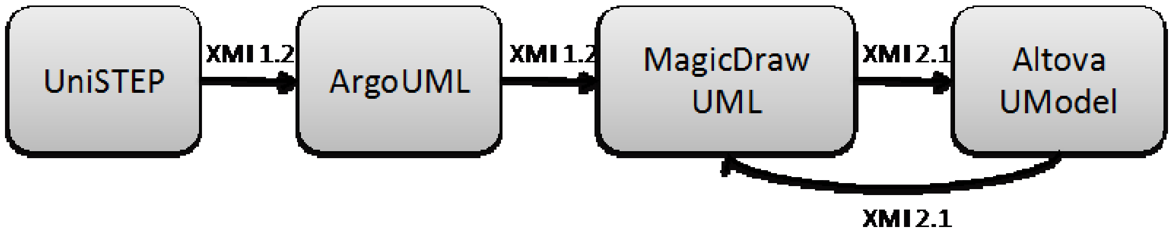

Figure 5-4 - Academic scenario: network of enterprises to develop geometric models

5.1.2.1 Test Cases

Since this scenario is only academic, the organizational test case cannot be applied because the results are meaningless. The UML tools available in the market do not have the conceptual model available, thus is impossible to execute conceptual testing.

TC2.1: Technical assessment – Model data exchanging from first to the second member of the network

TC2.2: Technical assessment – Model data exchanging from second to the third member of the network

TC2.3: Technical assessment – Model data exchanging from third to the forth member of the network

TC2.4: Technical assessment – Model data exchanging from forth to the third member of the network

5.2 Implementation Overview and Technology Used

The Implementation was planned in three phases according to the proposed assessment methodology, as follows:

1. Organizational testing – Application of a set of questions to all involved parts of the process and comparison of answers.
2. Conceptual testing – Model analysis software that calculates the data loss and give the maximum potential interoperability and minimum effective interoperability as results of the analysis.
3. Technological testing – funStep conformance checking tool, and front-end actions on all enterprise software involved

However, there are some important details on both specified scenarios that are described bellow.

Supply Chains in the Furniture Industry

- At the conceptual test stage, the model mappings and results from the standard AP236 to the retailers models will not be demonstrated because it is similar to the one did to from the manufacturer to the standard.
- For the technological test, will only be applied the conformance checking tool from funStep because the implementation of the mappings at the manufacturer side is still in progress, since the objective of this test is to determine if the integration effort is worth.

Geometric Shapes: Triangle

- As was decided to the first scenario, the model mappings and results will only be shown between two of the four enterprises that compose the network.
- The technological testing will only be composed by an interoperability checking demonstration. To apply conformance checking, it was needed the conceptual models of the software used by all enterprises to develop the model, and unfortunately it is not available because the tools are commercial and do not offer the needed information.

5.2.1 Organisational Testing

The structure of the questionnaires developed to assess the organisational layer is composed by a set of questions that covers the scientific areas of the Table 4-1. The answer must be chosen among five options.

The Table 5-1, Table 5-2, Table 5-3, Table 5-4, Table 5-5 and Table 5-6 represent a set of questions applied to each scientific area.

Table 5-1 - Data Interoperability

	Not at all	Low	Fair	Quite Good	High
I am able to match/map data from other organisations so that my systems understand it better.					
I am able to automatically send/receive information to/from all of my partners in the right format.					
My documents follow a standard like UBL (Universal Business Language), OAGIS , CII (Cross-Industry Invoice), EDI etc?					

Table 5-2 - Process Interoperability

	Not at all	Low	Fair	Quite Good	High
My transaction related processes are modelled and shared with partners					
I do not need to care about the transaction flow with a partner. My system does it for me.					
All my business processes comply to global standards like BPMN (Business Process Modelling Notation) or UML (Unified Modelling Language).					

Table 5-3 - Rules Interoperability

	Not at all	Low	Fair	Quite Good	High
I can easily retrieve all the rules related to my business processes and to that of other collaborating partners (local or abroad)					
I am using automatic rule engines to carry out decision making tasks in transactions					
My systems are flexible enough to comply to various legislation and business rules regarding transactions					

Table 5-4 - Objects Interoperability

	Not at all	Low	Fair	Quite Good	High
My company operates sensors and other related objects which are connected to my systems					
My systems are able to receive information from external sensors or send information to objects of partners					
The sensors/objects used in my organisation operate based on standards so they can be reused by others if needed (like standard RFID, eTags, etc)					

Table 5-5 - Software Interoperability

	Not at all	Low	Fair	Quite Good	High
Software Systems in my organisation are connected with each other					
My systems are based on SOA (Service-Oriented Architectures) and can be accessed/make use of Web Services					
Software Systems used in my organisation use open standards/interfaces					

Table 5-6 - Cultural Interoperability

	Not at all	Low	Fair	Quite Good	High
My organisation is aware of various cultural differences (like holidays) of all my clients/partners					
My systems automatically translate documents received/sent to organisations speaking another language					
My systems are flexible to carry on by themselves/postpone transactions that could not be carried our right away due to cultural difference (e.g when a working day for me, is bank holiday for my partners)					

After the application of the questionnaires recurring to Google Forms, resulted an average percentage of 64% of equivalent answers. Following the proposed methodology it is worthy to continue with effort to interoperate and proceed to the conceptual testing.

5.2.2 Conceptual Testing

The conceptual testing system was developed based on MMEditor tool developed by GRIS. It was added an Interoperability assessment feature represented in Figure 5-5. That feature implements the conceptual testing stage of the framework explained in 4.4.2 – "Assessment Layer 2: Conceptual Testing", recurring to two classes. The interface class implements the I/O functions, and is responsible to the results window popup, and integration with the base MMeditor implementation. The maths class is responsible by all the calculations involved in the process, by implementing functions that are invoked by the interface class.

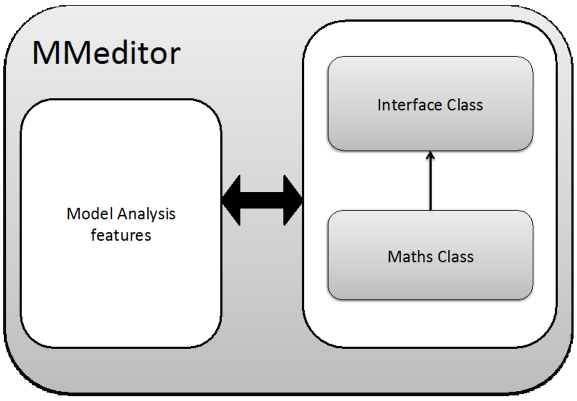

Figure 5-5 - Interoperability assessment feature integrate with MMeditor

This stage of the framework was only applied to the first case scenario, because to be applied to the second scenario, it was needed the conceptual models of the commercial tools used by the enterprise network, and it is not available.

As specified by TC1.2, the model was imported to the MMeditor. As show in Figure 5-5 the model from the manufacturer is represented at the left side of the figure and the standard is at the right side, in order to identify the mappings from the manufacturer conceptual model to the standard AP236.

Those mappings were identified, see Figure 5-7, and are defined following the structure <origin_entity,(destination_entity)>. Thus, the set of identified mappings containing mandatory and optional entities are described by the following equation, where the bold represent the mandatory entities:

R_c^2= {
<**phone_number**,(telephone_number)>; <alternative_number,(telephone_number)>;
<e-mail,(electronic_mail_adress)>; <fax,(facsimile_number)>; <**contact**,(Adress)>;
<**Adress**,(Adress_Assignment)>; <**Street**,(Street)>; <**number**,(postal_box)>;
<**city**,(town)>; <**postal_code**,(postal_code)>; <building,(Adress_type)>;
<**has_adress**,(assigned_adress)>; <**country**,(country)>; <**person**,(person in organization)>;<**name**,(last_name)>;<**name**,(first_name)>;<**name**,(middle _name)>
<**VAT**,(VAT)>; <**company**,(organisation)>; <**name**,(name)>;
<**catalogue**,(product_class)>; <**name**,(name)>; <**date**,(id)>; <**product**, (product_class)>; <**id**,(id)>; <**name**,(name)>; <description,(description)>;
<**finishing**,(Product Specification)>; <**id**,(id)>; <has_parts,(product_class)>;
<Fabric,(specification)>; <**name**,(id)>; <colour,(specification)>;
<**name**,(id)>;<**material_description**,(description)>; <**has_employee**, (concerned_person)>
}

R_c^2= 37

Excluding the optional concepts and identifying only the mandatory results the R_c^{2e}, with the result presented bellow. This set of mappings represents only the ones that are essential to guarantee the minimal effective interoperability.

R_c^{2e} =*28*

However, the best case scenario was to have all the entities mapped from the manufacturer model to the standard. Thus, the expected number of mappings in that case is represented by the equation $R_{c\ expected}^2$, with the result presented bellow.

$R_{c\ expected}^2$=50

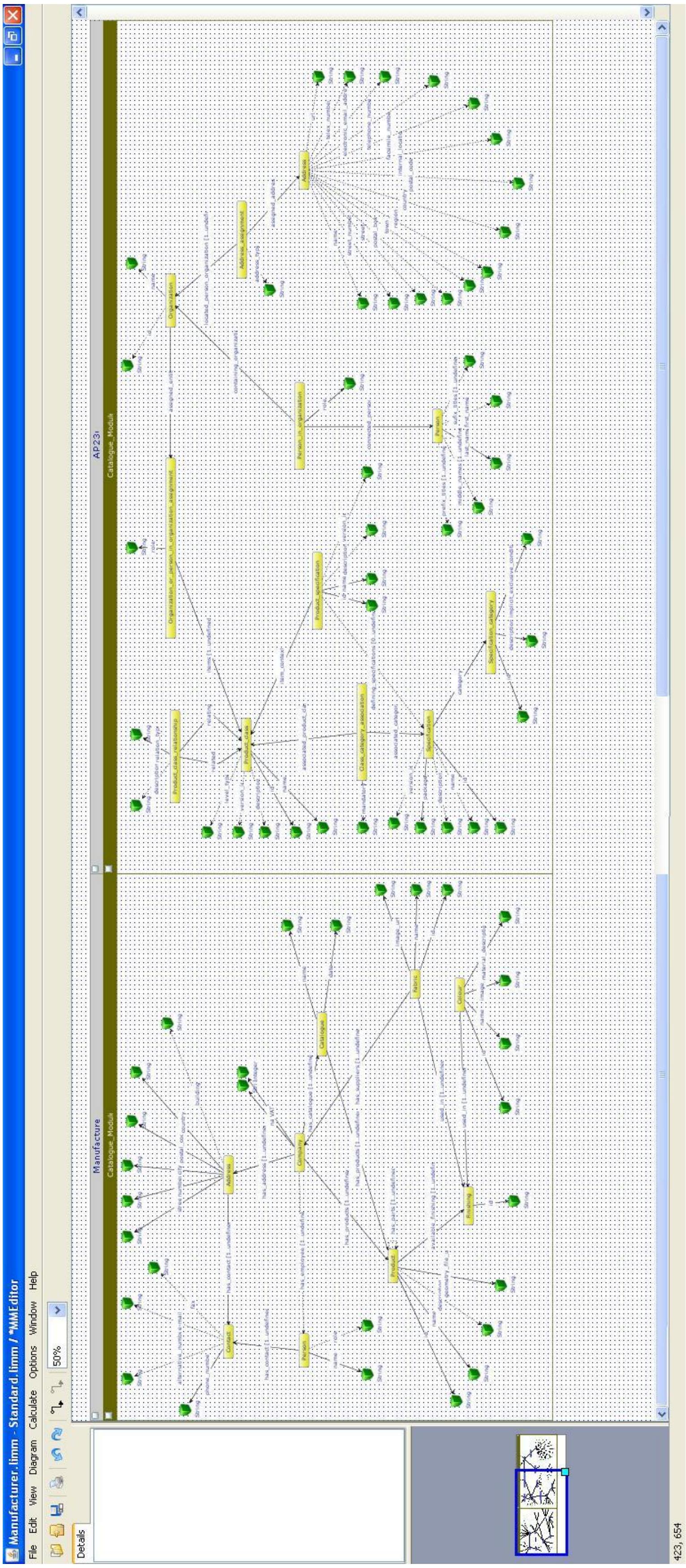

Figure 5-6 - Manufacturer and AP236 Models imported to MMeditor

Thus, applying the equations presented in Table 3-1 results the maximal potential interoperability and minimal effective interoperability, which are presented in the Figure 5-8 and explained in the Table 5-7.

Table 5-7 - Results of Conceptual Testing for Scenario 1

Type of evaluation	Interoperability
Maximal Potential Interoperability (MPI)	$V_{1\text{-}2} = \frac{\lvert R_c^2 \rvert}{\lvert R_{c\,expected}^2 \rvert} = \frac{37}{50} = 74\%$ $\varepsilon_{1\text{-}2} = \frac{\lvert R_c^{2e} \rvert}{\lvert R_c^2 \rvert} = \frac{28}{37} = 76\%$
Minimal Effective Interoperability (MEI)	$V_{1\text{-}2} = \frac{\lvert R_c^{2e} \rvert}{\lvert R_{c\,expected}^2 \rvert} = \frac{28}{50} = 56\%$ $\varepsilon_{1\text{-}2} = 100\%$

The analysis of the results, according to the proposed methodology, determines that is worthy to continue with the efforts to interoperate, and proceed to the technological testing.

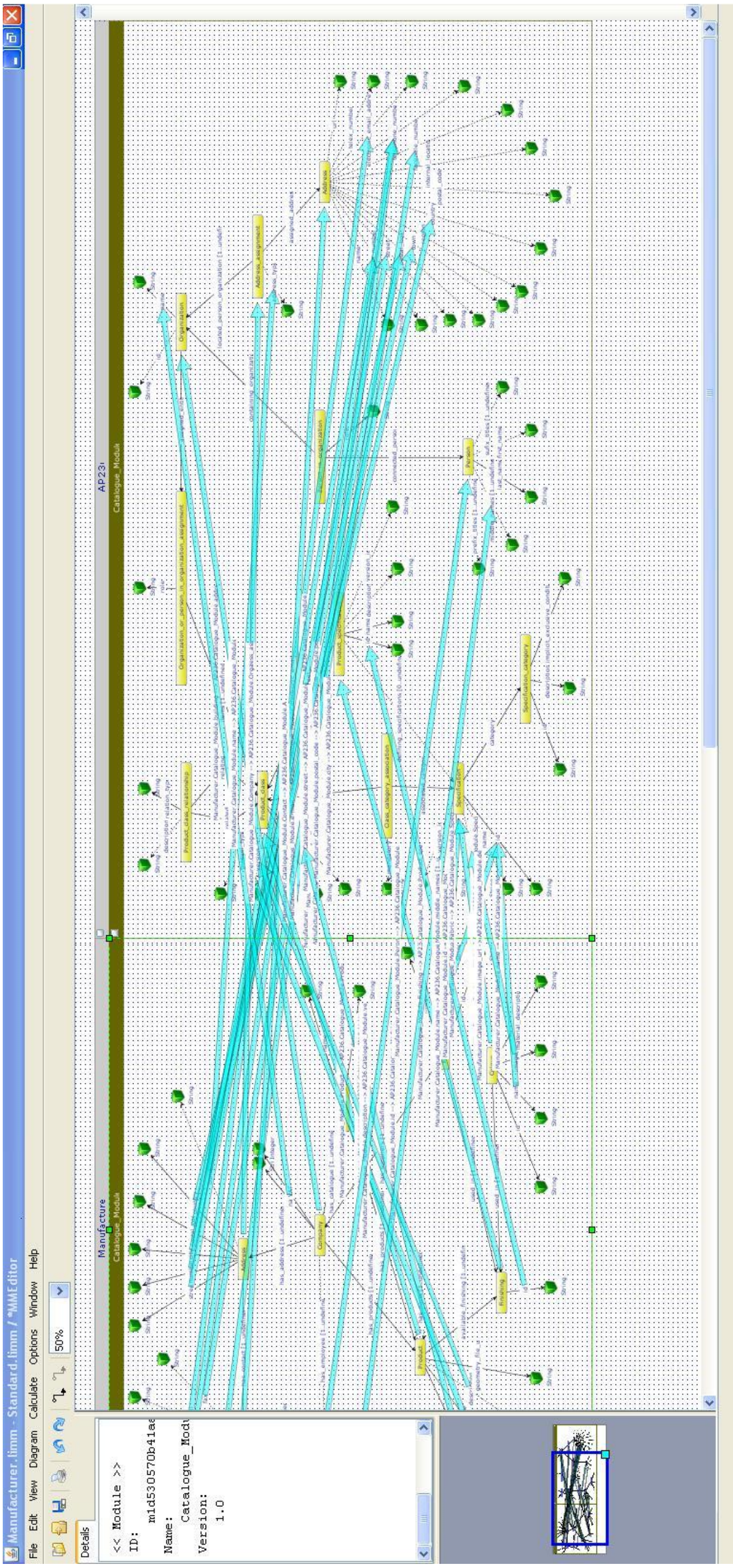

Figure 5-7 - Mapping idenfitication from the manufacturer model to the AP236

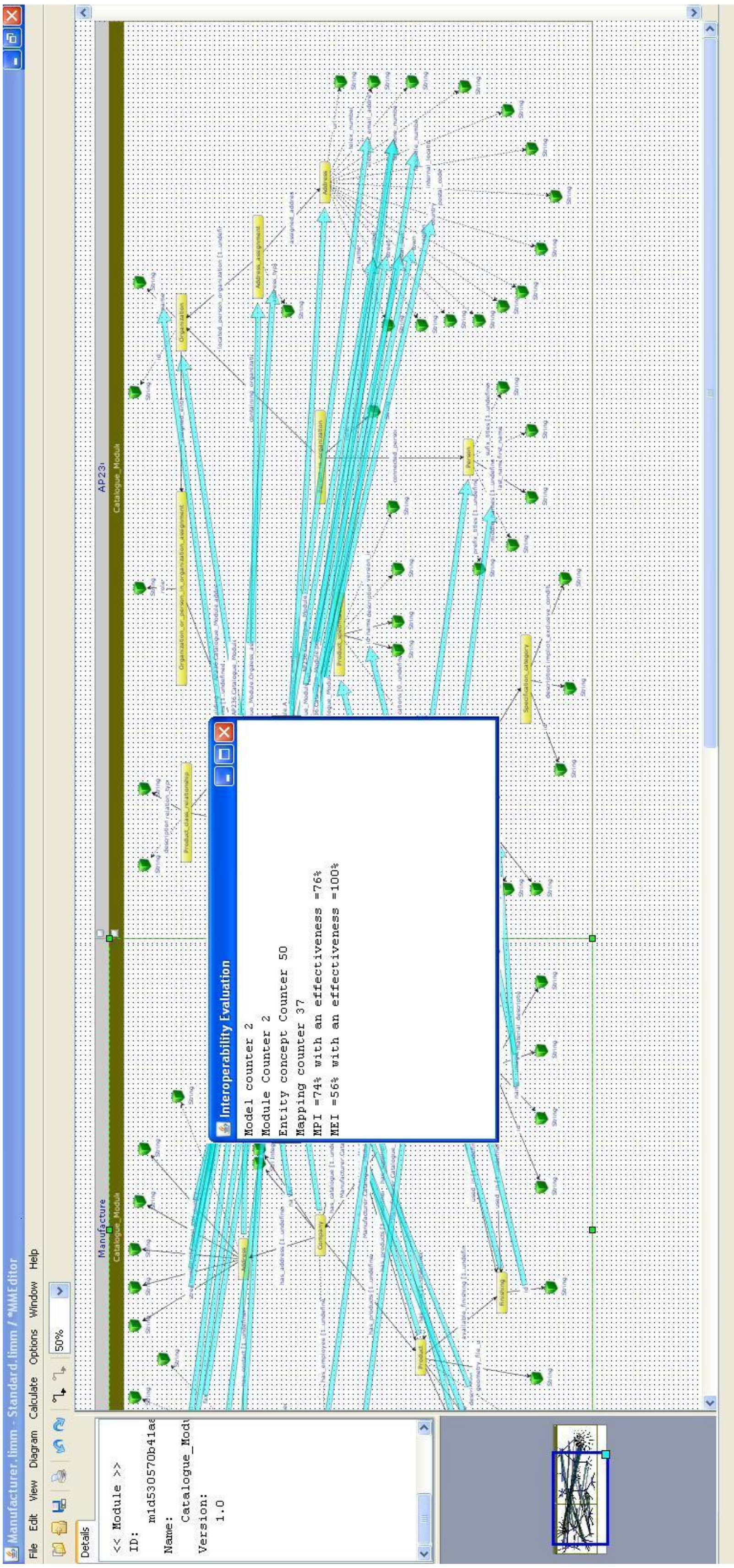

Figure 5-8 - Results from MMeditor interoperability assessment

5.2.3 Technological testing

This step of the framework will be demonstrated for both scenarios, but with some differences.

For the first scenario, was only applied the funStep conformance checking tool, Figure 5-9. The enterprise is still willing to develop the software, and analysing if the effort is worthy, there is no implementation ready for testing with front-end actions. For this test case, data from the manufacturer model was generated in AP236, and was tested the conformance with standard in order to validate the manufacturers' implementation of the standard.

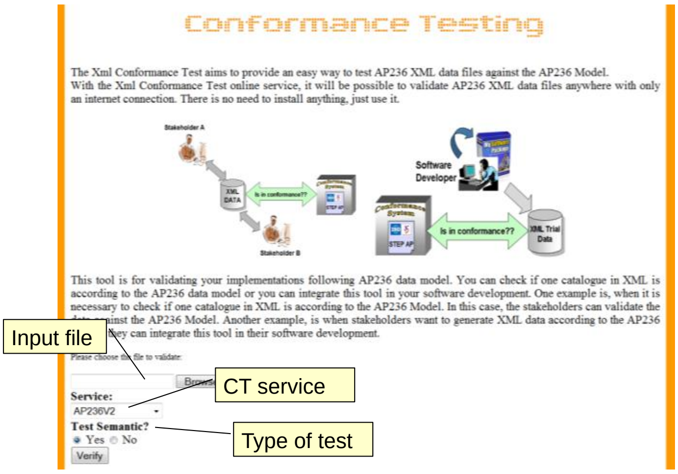

Figure 5-9 - funStep conformance testing tool

The results of that conformance testing exposed a set of errors, shown Figure 5-10. The funStep conformance testing tool identified that the data generated have some mismatches with the standard, concluding that it is not ready to be implemented yet.

Figure 5-10 - Conformance testing report

The manufacturers' implementation of the standard need to be revised in order to pass the conformance testing, and so allow the development of an implementation with no conformance issues. At that point, the report generated by the funStep tool shall not detect any kind of errors.

For the second scenario, was used a set of commercial UML tools available on the market. Thus, the access to its conceptual model is unachievable, and so, the conceptual testing for this scenario is unfeasible.

On the other hand, there are implementations prepared to be tested in terms of interoperability checking recurring to front-end actions. The first stage of the geometric shape development was executed in a prototype implementation named UniSTEP that developed by GRIS, Figure 5-11. At this phase of the process was developed an information model of a triangle, recurring to Express data modelling language, and it was exported using XMI 1.2.

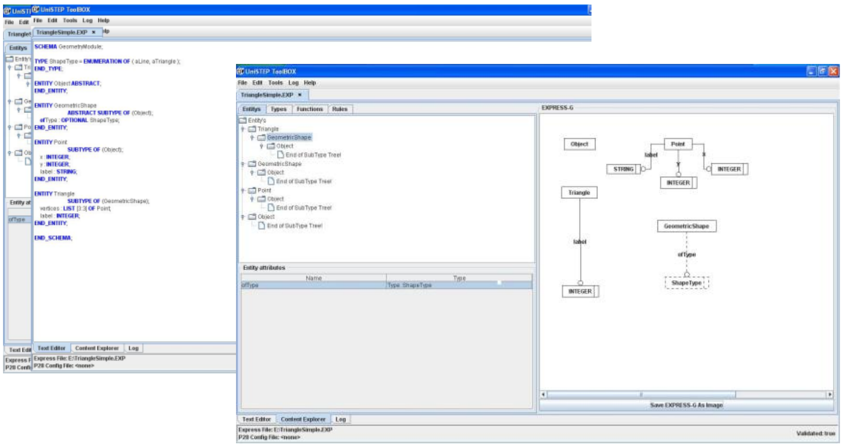

Figure 5-11 - Triangle developed in UniSTEP tool to be exported in XMI

The next step of the testing flow was importing the XMI file to a different UML tool used by another enterprise in the network, in this case was used ArgoUML. Since ArgoUML is considered the correct implementation of the XMI standard, the expected result was a perfect interoperation between those tools. In fact, the result was the expected and from this stage resulted no interoperability issues, Figure 5-12.

The subsequent test started by exporting a XMI 1.2 file from ArgoUML, and try to import with another UML tool used in this collaborative network. That file was imported to MagicDraw UML, and was expected a perfect interoperation like in the previous stage because as said above, ArgoUML is considered the correct implementation of the standard. Once again, the result obtained was the expected, and it was achieved a perfect interoperation Figure 5-13.

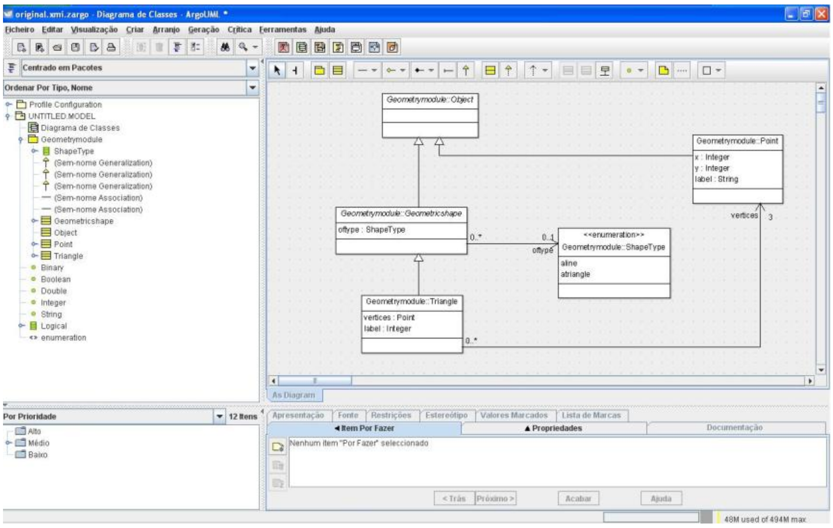

Figure 5-12 - Importation of an XMI 1.2 file to ArgoUML

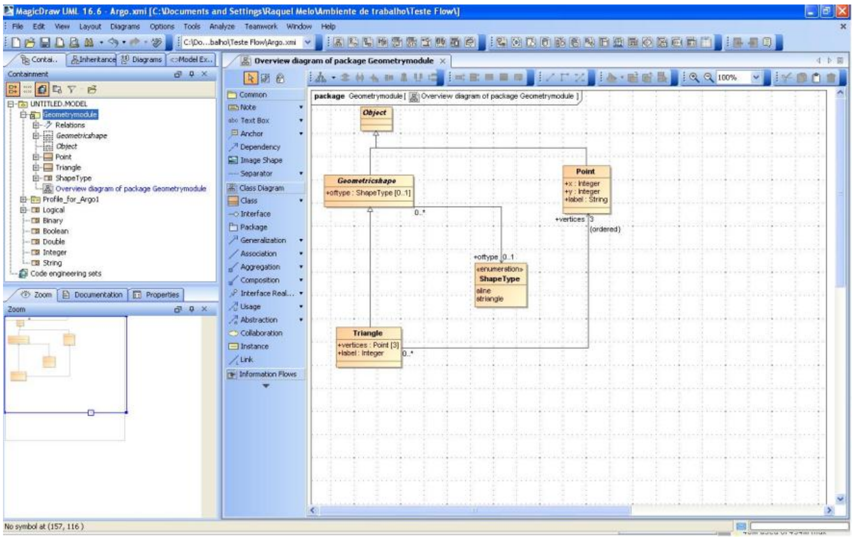

Figure 5-13 - Importation of an XMI 1.2 file to MagicDraw UML

The fourth stage consisted in executing another exportation, but at this step was used XMI 2.1 instead of XMI 1.2. At this step the process was not linear as it was in the previous steps. At the importation to Altova UModel emerged several warnings and automatic error corrections, Figure 5-14, those errors derived from data exported by MagicDraw UML that is not comprised in the XMI standard. However, the issues that emerged along this process did not caused a loss of information, so the interoperability was achieved perfectly.

In order to validate that no data was lost with the automatic error correction in the previous step, was exported by Altova UModel another XMI 2.1 file to be imported again by MagicDraw UML tool. As expected there was no data loss, or even warnings in this process, resulting in a perfect interoperability.

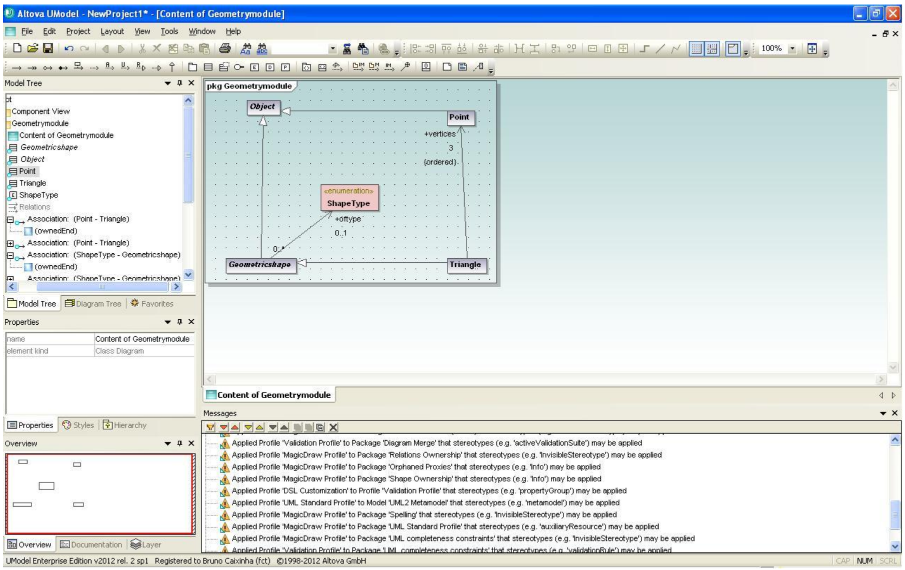

Figure 5-14 - Importation of an XMI 2.1 file to Altova UModel

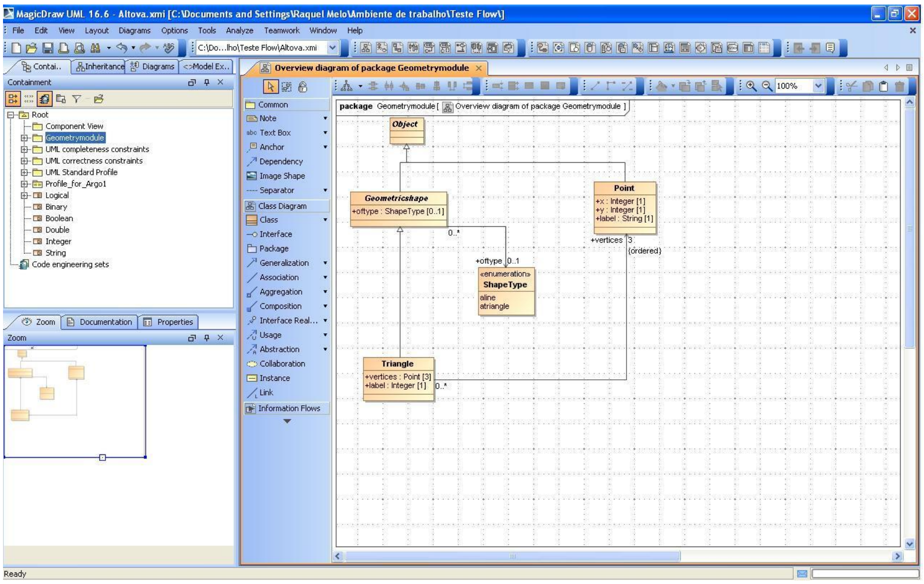

Figure 5-15 - Importation of a XMI 2.1 file to MagicDraw UML

After the conclusion of all test cases can be concluded that all the importation and exportation processes was executed with success with an interoperability of 100% because no core data was loss along the process. However, some tools export more than core data, that is ignored by other tools, causing no issues to the process. In fact, that extra data is only used to facilitate the importation process to users of the same tool. The technological test was concluded with the best case scenario.

This test case is also an example for the Figure 4-3, because each step of tests certifies the involved tools as qualified equipment, which allows them to certify the latter steps

5.2.4 Technology used

To implement and execute test cases was needed the technologies and tools listed in Table 5-8

Table 5-8 - Technology used

Technology	Purpose
Java	Development of conceptual testing application
MMeditor	MMeditor is a prototype developed by GRIS. Was used to do model management and support to conceptual testing application development
UML tools: UniStep, ArgoUML, Magic Draw UML, Altova UModel	UML designing tool for UML class diagrams definition and export to other formats as a interoperability checking test case
XMI	Format for models and data interchangeable representation within the package
funStep Validation Services http://gris-public.uninova.pt:8080/funStepServices/Conformance_Testing.jsp	Conformance checking tool in order to execute interoperability checking test case
Google Forms	Used to apply the questionnaires to execute organisational testing

Chapter 6 - Proof-of-Concept and Hypothesis Validation

6.1 Testing Methodology

Finding errors in a system implementation using experimentation is also known as the process of testing. This process can be carried out in a special environment where normal and exceptional use of the system can be simulated. Although testing show to the creator of the system the presence of errors and not their absence, it doesn't ensure the complete correctness of an implementation (Tretmans, 2001).

According with each specific field of application, different methods exist to test the suitability of the solutions to meet their requirements (Onofre, 2007), making use of the international standard for conformance testing of Open Systems, i.e. the ISO-9646 (ISO & JTC, 1994): "OSI Conformance Testing Methodology and Framework" .

A striped-out approach of this standard is used and showed in Figure 6-1. To test the hypothesis specification, a set of tests must be defined. But for them to be executed the hypothesis must be implemented as a proof-of-concept. This implementation doesn't need to be completely functional, but have to fulfill the requirements defined in the architecture proposed. The results of the test execution are observed, leading to a verdict on the compliance of the system under test with the initial requirements defined (Tretmans, 2001).

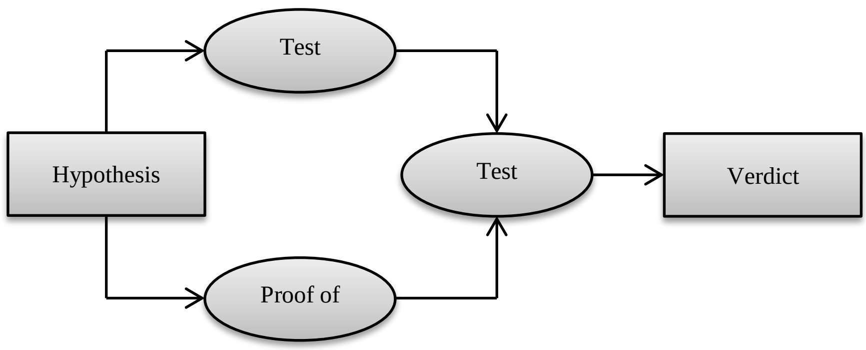

Figure 6-1 - Global view of the conformance testing process

The abstract tests must be specified with a well-defined notation, independent of any implementation. The notation used is TTCN-2 where the internal behavior of the system is not relevant, being the sequence of events, determined through observation and revealed during the tests is the core of the concept referred (Tretmans, 1992).

The TTCN-2 is presented in a tabular form, which shows the various parts that defines the test, like, a chain of successive events, a verdict and a header. Each table possesses a header, where the test name, the purpose, the inputs and outputs are stated. The chain of successive events is indicated by increasing the indentation of the same, and is identified by a line number.

The events that compose the chain are divided in two types: actions and questions. The actions are represented with an exclamation mark ("!") at the beginning of the event,++ define the interaction with the system. The questions, which are represented with a question mark ("?"), define the expect answers from the system. The sequence ends with the specification of the verdict that is assigned when the execution of the sequence ends.

The verdict can output three results: *"Success"*, *"Fail"* and *"Inconclusive"*. Success indicates that the test was executed successfully with the expect result, Fail indicates that the implementation does not conform to the specification, and Inconclusive indicates that there were no non-conformance was found, but the test was not achieved.

An example of a TTCN-2 based table test is shown in Table 6-1. It exemplifies an invocation of a model transformation. The presented test starts with the invocation of a model transformation to the execution engine. The next step is verifying if there is any data returned from the model transformation execution. If there is an output of the model transformation and the expected result is equal to the output, the verdict of the test is *"SUCCESS"*, otherwise if the output of the transformation is not equal to the expected output then the verdict of the test is *"FAIL"*. In case the invocation is made and there is no output of the test the result of the test is *"INCONCLUSIVE"*, since there are several reasons for this behavior.

Table 6-1 - Example of a TTCN-2 based table test

Multiplication by 2 Service Invocation

Test name:	Test the Multiplication by 2 Service	
Purpose:	Check if the service is available, and provide the result of the operation	
Inputs:	I1: Number to be multiplied, I2: Expected Result	
Outputs:	O1: Result of the multiplication of the input by two	
1	! Invoke Service with parameters (I1)	
2	? Returned data as Service Result (O1) so Service is Available	
3	? Result (O1) is equal to Expected (I2)	SUCCESS
4	? Result (O1) is different from the Expected (I2)	FAIL
5	? No Data Result	INCONCLUSIVE

In order to present a test case example of the TTCN-2 based table test defined in Table 6-1, Table 6-2was created. The parameters of the table are the inputs for testing, the expected results and the results obtained during the test. Each row of Table 6-2 represents a specific test case. With this approach more than one test case can be represented for each abstract test.

Table 6-2 - Example of a test case

Test	Input		Output	Result (Line number)	
	I1: Number	I2:Expected Result	O1: Result	Expected	Actual
1	60	120	120	(3)	(3)
2	8	16	120	(3)	(4)
3	0	0	No Data	(3)	(5)

6.2 Functional Testing

Along this section will be presented the TTCN tables that formalise the tests executed to validate the implementation of the proposed methodology, by identifying all possible results for each test case presented in 5.1 – "Application Scenarios and Test Cases".

TC1.1: Organizational assessment - applying questionnaires to the manufacturer and retailers side and evaluate the number of equivalent answers, Table 6-3.

Table 6-3 - TC1.1 - Organizational assessment table

Test name:	Organizational assessment	
Purpose:	Apply questionnaires to all involved parts, and determine the number of equivalent answers	
Group:	Scenario 1	
1	! Apply questionnaires to all involved parts (2)	
2	? Returned data with all answers	
3	?All answers are valid	SUCCESS
4	Otherwise	FAIL
5	Otherwise	INCONCLUSIVE

This test case was executed with success and all answers was validated. The purpose of the test was achieved with a result of 64% of equivalent answers, which enough to continue with the evaluation process.

TC1.2: Conceptual assessment – identify the mappings from the manufacturer catalogue to the standard AP236 and determine the amount of data loss, Table 6-4

Table 6-4 - TC1.2 - Conceptual assessment table

Test name:	Conceptual assessment	
Purpose:	Identify the mappings from the manufacturer catalogue to the standard AP236 and determine the amount of data loss	
Group:	Scenario 1	
1	! Load both models (manufacturer catalogue and AP236)	
2	? Valid and not empty	
3	!identify the mappings	
4	?mappings identified?	
5	!Apply equations to detect the data loss	
6	?Valid result	SUCCESS
7	Otherwise	FAIL
8	Otherwise	FAIL
9	Otherwise	INCONCLUSIVE

This test case revealed a satisfactory result, by identifying 37 mappings out of 50 expected. Since this scenario consists in an inquiry about the viability to interoperate, cannot be expected much better results than it was obtained. It was quantified a maximum potential interoperability of 74% with an effectiveness of 76%, and a minimum effective interoperability of 56%.

<u>TC1.3: Conceptual assessment</u> – mapping the standard AP236 to the retailers catalogue and determine the amount of data loss, Table 6-5

Table 6-5 - TC1.3 - Conceptual assessment table

Test name:	Conceptual assessment	
Purpose:	Identify the mappings from the standard AP236 to the retailers catalogue and determine the amount of data loss	
Group:	Scenario 1	
1	! Load both models (manufacturer catalogue and AP236)	
2	? Valid and not empty	
3	!identify the mappings	
4	?mappings identified?	
5	!Apply equations to detect the data loss	
6	?Valid result	SUCCESS
7	Otherwise	FAIL
8	Otherwise	FAIL
9	Otherwise	INCONCLUSIVE

This test case was not executed because it was similar to the previous one, and would not add something new to the process.

TC1.4: Technical assessment – Executing conformance checking on the manufacturer implementation, Table 6-6.

Table 6-6 - TC1.4 – Technical assessment table

Test name:	Technical assessment	
Purpose:	Executing conformance checking on the manufacturer implementation	
Group:	Scenario 1	
1	! Load manufacturer XML model to the funStep conformance checking application	
2	? Model loaded	
3	!Conformance checking	
4	? no mismatches identified	SUCCESS
5	Otherwise	FAIL
6	Otherwise	INCONCLUSIVE

This test was concluded with the fail verdict because was encountered several mismatches while testing the adherence of the model to the specified standard. However this is also a positive test case because it means that there is a need of adjustments in the manufacturer's implementation of the AP236 standard.

TC1.5: Technical assessment - Executing front-end actions from the manufacturer to the retailers side Table 6-7

Table 6-7 - TC1.5 - Technical assessment table

Test name:	Technical assessment	
Purpose:	Executing front end actions from the manufacturer to the retailers side	
Group:	Scenario 1	
1	! Exchange data from manufacturer to the retailer	
2	? data exchanged without losses	SUCCESS
3	Otherwise	FAIL
4	Otherwise	INCONCLUSIVE

This test case was not possible to be executed because the implementation is still in progress by the involved entities.

For the second scenario, will only be presented one generic table, Table 6-8. In fact, all of those defined test cases are equivalent and have the same test phases and possible results. The only difference is the network members involved in the test case.

TC2.1: Technical assessment – Model data exchanging from first to the second member of the network

TC2.2: Technical assessment - Model data exchanging from second to the third member of the network

TC2.3: Technical assessment - Model data exchanging from third to the forth member of the network

TC2.4: Technical assessment - Model data exchanging from forth to the third member of the network

Table 6-8 - TC1.5 - Technical assessment table

Test name:	Technical assessment	
Purpose:	Model data exchanging between two members of the network	
Group:	Scenario 2	
1	! Exchange data from manufacturer to the retailer	
2	? data exchanged without losses	SUCCESS
3	Otherwise	FAIL
4	Otherwise	INCONCLUSIVE

The set of tests represented by the generic table above, shown that the implementations in use are perfectly interoperable with each other. Some warnings and automatic corrections was identified while importing XMI files generated by other tools. This test case revealed a solid interoperation between the involved tools.

6.3 Scientific Validation

6.3.1 ENSEMBLE

The ENSEMBLE (Envisioning, Supporting and Promoting Future Internet Enterprise Systems Research through Scientific Collaboration) collaboration project, funded by the EC since May 2010, aims to coordinate and promote research activities in the domain of FInES and to systematically establish EI as a science. ENSEMBLE combines systemic approaches, scientific multi-disciplinarity and innovative Web 2.0 collaboration tools with a community-driven mentality, in order to significantly increase the impact of the Future Internet Systems.

The project is not industry-driven, nevertheless it is validating many of the work and concepts proposed, by incorporating them in the EI science base (EISB) problem and solution spaces formulation. This dissertation is contributing by supporting the EISB toolbox, in particular the EI evaluator with the assessment framework.

6.3.2 DoCEIS’13

Centered on a timely and relevant theme of 'Technological Innovation for the Internet of Things', the 4th Doctoral Conference on Computing, Electrical and Industrial Systems (DoCEIS’13), brings the importance of Internet of Things (IoT) under the spotlight.

Interoperability assessment is a concern when managing small devices and applications in the IoT environment. However, when operating at the level of the Future of the Internet, both IoT and IoS (Internet of Services) bring a renovated relevance to interoperability and its evaluation. This dissertation enabled the elaboration of research a paper that is currently under evaluation at DoCEIS’13.

6.4 Industrial Acceptance

In the furniture sector, this dissertation work is contributing to the developments proposed in the funStep initiative where research is validated in a SME enterprise-ruled sector where the usage of product data standards is not yet a reality and electronic partnerships still work on a P2P basis. Industries characterized by a strong presence of small and medium sized enterprises (SMEs), mostly family owned and diversified, are generally flexible and quick in adapting to market changes. However, despite of being fairly ICT equipped, these types of industries face relevant constraints and barriers that are preventing them to evolve and apply that ICT to support e-commerce and e-business, and ultimately to be interoperable with its business partners.

In this sector, companies are frequently guided by their distribution chains and business partners which are using a wide range of systems from different software houses. As an example, furniture products within the Home, Kitchen, Bedroom and/or Bathroom market are becoming more and more complex as the value chain is driven to offer consumers better quality and services. The phenomena has mushroomed the number of choices, and despite accounting with very good software applications, namely CAD/CAM systems, most are incompatible, not being able to communicate with each other. This diffuse range of systems inhibits interoperability and the development of network-based trading partnerships using effective e- business, thus restricting innovation and development of the sector.

The EI evaluation framework and methodology proposed in this dissertation have been validated in the form of a proof-of-concept application in the furniture industry in the scope of the funstep initiative, as explained in section 5.1.1 “Supply Chains in the Furniture Industry”. The companies involved have participated in the questionnaire for organizational interoperability assessment, the conceptual evaluation, and are currently pending the technical interoperability evaluation as in-house implementations are currently on-going.

6.5 Hypothesis Validation

In section 1.4 - ”Hypothesis” the hypothesis drawn for this dissertation was defined following the research questions and the background analysis. To better recall and revise it, it is here included again:

- *“If the maturity and compatibility of the different knowledge levels within two enterprises can be evaluated and categorized, then one can determine if those enterprises are fit for interoperation, as well as identify existing problems and eventual solution paths”.*

Based on the observations gathered during implementations and feedback received at testing stage, it is possible to conclude that the hypothesis has been validated. Indeed, if the maturity and compatibility of at least two enterprises can be evaluated, and that evaluation be classified through a hierarchical maturity level architecture, then the interoperability assessment process, can evaluate the viability of enterprise collaboration. It has been proved that the maturity level classification system is satisfactorily dynamic to classify status of the three knowledge barriers, along the defined scientific areas.

When enterprises are not fit for interoperability at the organizational level, then they may not be the best business partners. With the questionnaire proposed, problems are identified in specific scientific areas. The assessment of interoperability at the conceptual level enables to identify the maximum potential and minimal effective interoperability thresholds, which constitute the interval where collaboration is empowered. With these values companies can check whether they are taking the most out of their collaboration. Finally the technical interoperability assessment allows to evaluate real communications, identifying implementation errors and systems’ incompatibilities at the physical level.

The functional testing of the proof-of-concept implementation provided the expected results towards a hypothesis validation with success. The definition and/or identification of solution paths is enabled though existing knowledge bases of solutions (e.g. the EISB knowledge base – solution space), but that has not been explored in this dissertation. After having identified the technological gap, companies can search the Internet and knowledge repositories for solutions that help them move towards more efficient interoperability.

Chapter 7 - Conclusions and Future Work

Most of the enterprise systems are heterogeneous and distributed, and so, the main concern about those systems is the capability for them to interoperate correctly. It was proposed in this dissertation, a methodology that allows evaluating, quantifying and qualifying the interoperability process from the initial phase to the working implementation. To achieve this purpose were defined specific tests to all three barriers that inhibit the process, such as organizational, conceptual and technological. Despite these barriers are defined separately, the test phases are dependent on the validation of the results from the previous phases. Since a group of enterprises isn't able to cooperate due to their own structures, it isn't necessary to spend money and time to test the models and implementations. Otherwise if the system passes all the tests, the conceptual and technological gaps are identified, if they exist, making easier the process to find the solution path. A generic advancement scale of maturity levels from 0 to 4 classifies each test. Thus, the significance of those maturity levels depends on each interoperability barrier, because organizational issues can't be evaluated the same way as conceptual or technical.

However the proposed methodology have some weaknesses along the process. The results produced by the questionnaires applied to assess the organizational barrier are highly dependent of the amount of samples, thus, for small and medium enterprises the results obtained through this kind of evaluation are unreliable. Also the questions are somewhat subjective, and must be adapted for each situation, in order to maximize the results reliability.

In terms of conceptual testing there are also some fragilities. This stage of the methodology can only be executed if one has access to the conceptual models of the enterprises systems that compose the test environment, which sometimes is not available especially in the industry. This weakness is also present at the last stage of the methodology because those conceptual models are also needed to execute the conformance testing, if the systems are standard based.

The execution of this methodology is highly dependent of an interoperability expert to identify the mappings between conceptual models or even define and execute the interoperability tests on both implementations. This lack of automatic mechanisms, at certain point, turns the process too exhaustive particularly in big systems. However, the introduction of those automatisms is still a huge challenge, even with the technology available nowadays, because there are a lot of variable involved and adaptations to the done on the fly.

Despite of the presented weaknesses, the proof-of-concept implementation provided satisfactory results as expected along the development of the proposed methodology. In fact, it can be concluded that the work developed in the elapse of this thesis resulted in a very satisfactory result. The initial problem with all its characteristics was solved successfully, and it was proved that the proposed hypothesis is correct.

Future works should be able to reduce the dependency of the interoperability experts, by giving the process some methods to automatically or semi-automatically identify mappings and a set of generic tests for a well defined group of systems, depending on its morphology.

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