Dynamic Software Adapters as Enablers for Sustainable Interoperability Networks

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Abstract — **Enterprises are motivated to join collaborative networks, looking forward to reducing time to market, innovating products and lowering prices. However, each enterprise has its own legacy on Enterprise Information Systems, a fact that has been creating a significant interoperability problem when intending to cooperate with others using dissimilar information systems. This paper proposes to reuse existing modelling and architecture technology in a framework to support the sustainability of interoperability among networked enterprises. It suggests the implementation of dynamic software adapters to assure the continuous transformation of heterogeneous information, achieving an adaptive mechanism for interoperation among the different enterprise applications, and guaranteeing a seamless communication among the networked enterprises.**

I. INTRODUCTION

Enterprises cooperate with others to improve their capability to reach new markets, produce with better quality and have cheaper production costs. Hence, globalization brings important opportunities to work with other organizations scattered all over the world. Nevertheless, to achieve seamless collaborative working environments in industrial domains, it is needed an adaptive management of the business processes, supported by software to handle the dynamicity of the business network, formed by the many collaborating partners.

Enterprise Information Systems (EIS) are key towards the management of the enterprise information and it is through them that automatic communication among partnering enterprises can be achieved. EIS are capable of dealing with the use of products and resources (personnel, material, equipment, etc), monitoring operation, or identifying issues such as the delay in production and missing material, which can occur in the enterprise daily activity. Nevertheless, the use of different types of EIS in the same collaborative network may cause problems between the several enterprises within the network [1]. If each uses their own legacy system, the exchange of information becomes more complex since each is following a different information model and a different representation of products and processes. This results in a serious source of interoperability problems', with companies not being able to understand their partner's information. In more difficult situations, the information can even be misunderstood due to semantic divergence, causing production faults that can result in the loss of a considerable amount in the company's profit. Hence, the need for seamless information sharing in a collaborative network is becoming more important [2].

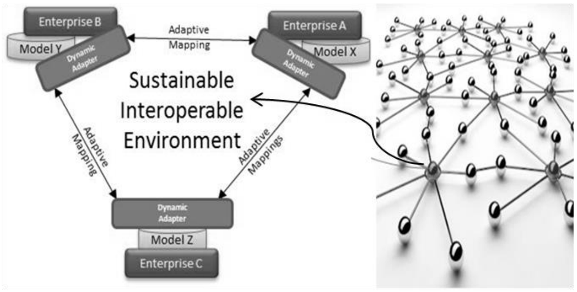

Figure 1. Concept of Sustainable Interoperable Environment

A. Sustainable Interoperability in Networked Enterprises

To evolve further in the advent of the enterprise collaboration, there is the need for Sustainable Interoperability (SI) of the networked environment. SI is defined as "Interoperability that convenes the needs of the present without compromising the ability of future changes, meeting new system requirements, and performing adequate adaptation and suitable management of the transitory elements" [3]. This can be achieved building on the concept of complex systems dynamicity, together with automated methods for adaptive processes and solutions. Indeed, previous research advocates that gradual peer-to-peer mappings, implemented by software adapters, can be established on a need-to-serve basis among different information structures, independently of language, local context, and the number of business relationships within the collaboration networks each enterprise is part of [4]. This paper further develops this idea, investigating how the reuse of existing modelling and architecture technology helps in the semi-automatic generation of software adapters to enable SI.

Figure 1 depicts the concept of a sustainable interoperable environment, detailing a Collaborative Network (CN) instance composed by 3 enterprises cooperating between each other, in an adaptive process. Indeed, a CN is not a static network, and several situations can occur to disestablish the seamless integration of the network (formalized by model mappings). Examples can include the update or change of EIS, new partner with a dissimilar information model, etc. Any of these situations may cause harmonization breaking in the network, which can propagate through the many existing relations (right side of Figure 1. Hence to avoid such situation it is necessary to be prepared to react and adapt in real time to the new circumstances and ensure the interoperability along the whole life cycle of the collaborative environment.

Therefore, the instantiation of the concept of SI Environment benefits from the 3R's principles [5]:

- **Reuse** - Reuse proven methodologies and solutions for EIS specification and modelling, as well as implementation of adaptation and interoperability services. This could avoid big expenses resulting from the need to implement "yet" another solution from scratch;
- **Reduce** - Reduce the time lost on solving interoperability problems. The system will re-adapt using past knowledge and recover the interoperability environment. This will benefit in less loss of money, since time is money;
- **Recycle** - Recycle legacy systems and models, by adapting in-house EIS to new needs. This will avoid drastic changes on the information models and reduce the impact on the network.

Readjust should be added as another principle to the software adapters to ensure the continuous interoperability of heterogeneous and evolving systems. With it, it will be assured an adaptive mechanism for continuous interoperation among the different enterprise applications, and guaranteeing a seamless communication among the networked enterprises. This framework will allow reusing methodologies, reducing costs, recycling legacy systems, and readjusting adaptors, acting in 3 different ways:

1. Create the software adapters to have a first level of interoperability within the network. This level can then be increased along the life-cycle of the collaboration;
2. Maintain the interoperability in the network, monitoring and providing support to dynamicity;
3. Predicting potential problems based on past behaviour at the enterprise level or fluctuations at the network level (companies joining or withdrawing from the network). This will foresee potential issues before they can be a real problem, thus solving them in advance.

During this paper, the presented work is focused in the reuse phase and the creation of the adaptors.

II. Enterprise Information Systems Interoperability

Enterprise Information Systems (EIS) are integrated application-software packages that use the computational, data storage, and data transmission power of modern Information Technology (IT) to support processes, information flows, reporting, and data analytics within organizations. The integrated content may be used to run a configuration management solution throughout the life cycle in relation to products, assets, processes and requirements of the entity (laboratory, facility, etc.) [6].

EIS are mostly based on commercial software packages (could also be custom developed) without implementing a global strategy for the seamless integration of all the information flowing throughout the company or the network of cooperating enterprises. If an organization has two systems and they cannot seamlessly communicate between each other, this will bring some problems in the productivity and customer responsiveness suffers. In such case, one is facing the problem of fragmented information, and consequently fragmented business [7].

Moreover, EIS use data repositories to collect and store massive amounts of data. Yet, since systems normally evolve with the needs of the companies, and usually different repositories are created, each company has to manage many heterogeneous repositories. This leads the information to be spread across several different computer systems, each hosted in separate business unit, region, factory, or office, without a global seamless capabilities which harnesses efficiency.

From an enterprise architecture and a systems engineering perspective, operating in a networked environment places the requirements for interoperability alongside maintainability, reliability, safety of a system [8]. Hence technologies and frameworks for enterprise modelling are analysed next (non-exhaustively) in order to be reused and support the creation of dynamic software adapters, and the methods necessary for the sustainability of interoperability among networked enterprise.

A. Enterprise Modelling Techniques

Vernadat (2001) defines Enterprise Modelling (EM) as the efficient design, analysis and optimization of enterprise operations requiring notations, formalisms, methods, and tools to depict the various facets of a business organization. A relevant advantage of using EM is that it helps describing the various elements of an enterprise, including its functions, behaviour, information, resources, organization or economic aspects of a given business resource. In order to support enterprises during their modelling process, several methodologies exist. For the purposes of our study a few were selected: Integrated Enterprise Modeling (IEM) [9], GRAI Integrated Methodology (GRAI-GIM) [10] and CIMOSA [11].

CIMOSA has a strong focus on process-oriented approaches aiming at integrating functions by modeling and monitoring the action flow, while GRAI sees integration as the coherence between global and local decision objectives. IEM seeks to support the development of a unified enterprise model and to represent the different aspects of a manufacturing enterprise as views of that model.

Although our study takes greater focus in these referred methodologies, other frameworks exist that are not necessarily less important than the ones here discussed A relevant state of the art of these EA is proposed in [12] and [13].

B. Engineering Modelling Techniques

Each year the need to plan, develop, and manage the enhancements of enterprises infrastructure, products, and services, including marketing strategies for product and service offerings based on new, unexplored, or unforeseen customer needs with clearly differentiated value propositions, is increasing [14]. These events raise the relevance of having engineering modelling within the enterprises themselves. As previously mentioned, in order to better support this modelling process, several methodologies exist that can effectively aid to achieve it. For our purposes, and as already referred previously, this study focused mainly on the following: Model-Based Systems Engineering (MBSE) [15], [16], to formalize modelling in support to the systems engineering processes; Model-Driven Architecture (MDA) [17], [17], to support software engineering involving the multiple actors from the business level down to the programmer; Model Driven

Service Engineering Architecture (MDSEA) [18], [19], merging more classical EM technologies with the engineering perspective of MDA, extending it to the engineering context of product related services in the virtual enterprise environment; and Service-Oriented Modelling Framework (SOMF) [20] for software and web services orientated development.

C. *Holistic Modelling Frameworks (Architecture)*

Enterprises have the need to internally organize their structures, aiming to be more efficient and achieve their objectives more quickly. For this reason, they seek solutions that are able to guide them in the best course of direction. An example is the creation of an enterprise architecture as an answer for their needs. This is important because an architecture is a framework of principles, guidelines, standards, models, and strategies that direct the design, construction, and deployment of business processes, resources, and information technology throughout the enterprise [21]. To support the enterprises in the modelling several methodologies exist and for our study a few ones were selected: Zachman Framework [22] and TOGAF [23]. They structure various EM and engineering concepts according to the perspectives of various stakeholders involved in the enterprise engineering. Other frameworks exist, however, are not necessarily less important that the ones discussed here [24], [25].

D. *Metamodelling*

GERAM is a complimentary paradigm that provides a set of recommendations, which are baseline requirements to support enterprise architecture and engineering. This baseline is conceptually located at the meta-modelling level, supporting enterprises in the assessment of the different architectures/methodologies known, and to choose the one that is best suited to their enterprise business needs. Hence, it was developed to encompass and generalize the commonalities of various existing frameworks and reference architectures, by including all knowledge needed for enterprise engineering/integration [26], [27]. It therefore differs from the other architectures/ methodologies, since it just gives support to choose one instead of developing new.

E. *Analysis of Different Techniques and Frameworks for EIS specification and Modelling*

The several methodologies/frameworks presented are different in nature. Some are more directed to information modelling of the enterprise, others to the information system, while others are more holistic and address the enterprise as a whole, treating requirements, product, process, and software in an integrated manner. All have pros and cons and, in the end, their adoption depends on the cost-benefit, as well as the learning curve for the tools implementing each paradigm.

Figure 2 depicts the coverage of each of the described architectures and methodologies in the operative levels of an EIS, i.e., Business, Process and Service [28]. It illustrates the models and concept used by each paradigm to manage each level of information. From this analysis, it is observed that all addressed architectures and methodologies tackles Process and Service level, whilst MDA, MDSEA, TOGAF, and SOMF additionally embrace the Business level with high level of detail. This means that these methodologies enable interoperability at all levels inside of an organization. In terms nature of data managed, Zachman and TOGAF are both focused on the whole

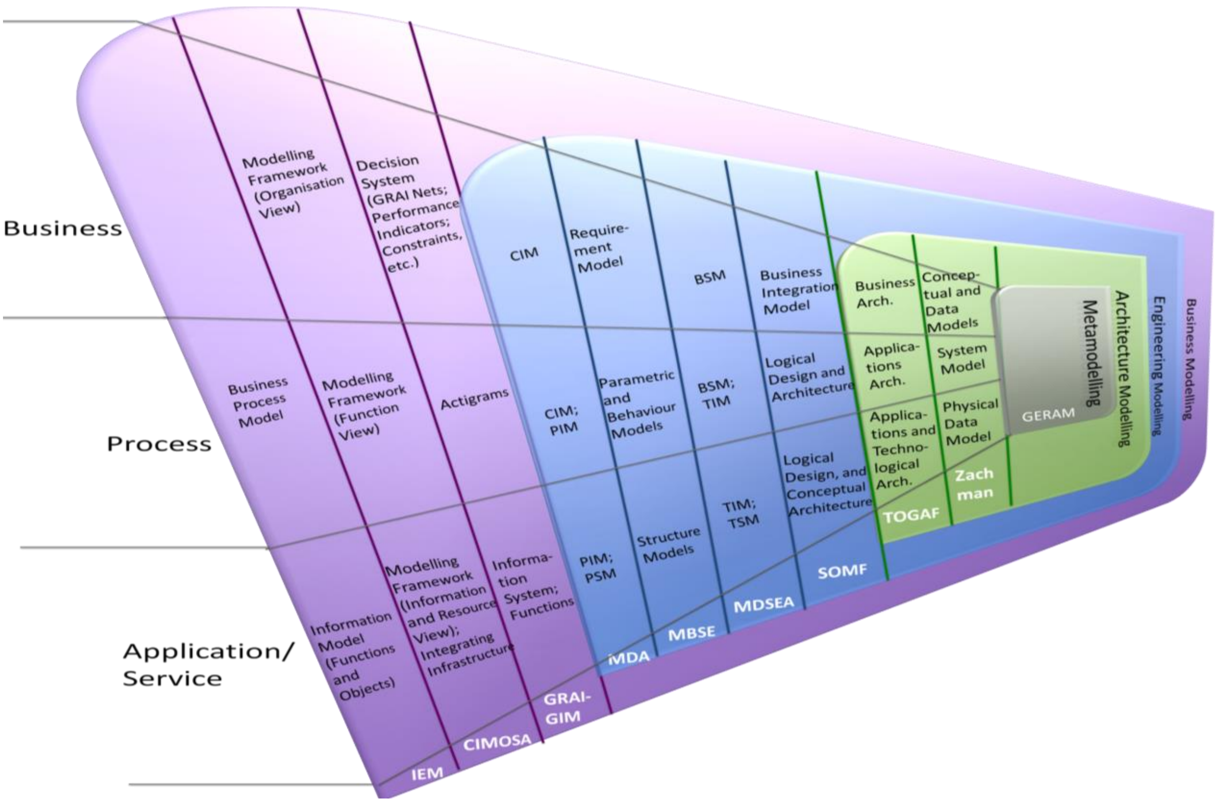

Figure 2. Coverage of modelling architectures and methodologies

enterprise data. CIMOSA and GRAI-GIM are meant to handle computer integrated manufacturing (CIM) data, while IEM is emphasising more on the enterprise process data. MBSE is providing a strong emphasis on the product data and its lifecycle, whilst MDSEA is targeting the manufacturing services. Finally MDA and SOMF are both managing software-related data. In conclusion, all were developed with different purposes, yet, in the end all of them share the same goal, i.e. to provide guidelines for the

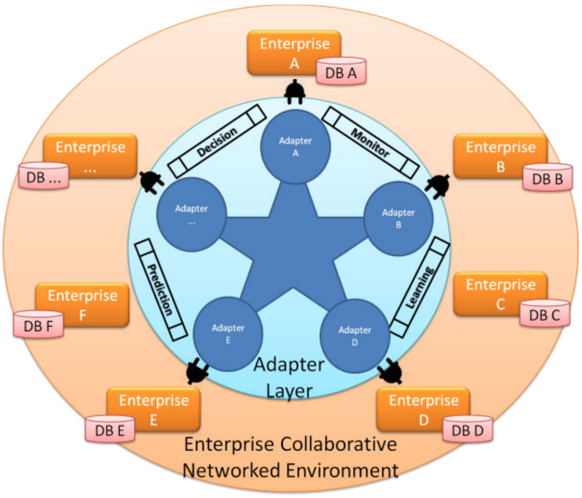

Figure 3. Sustainable Interoperable EIS Network.

enterprises to properly manage their own EIS [8], enabling an interoperable environment inside the enterprise. Yet, none is focused on the network.

III. TOWARDS SUSTAINABLE INTEROPERABILITY

A. Sustainable Interoperability Requirements

As explained before, the sustainable interoperability is an ideal to allow enterprises to adapt their EIS and still maintain the interoperability along its operating life cycle. However, to reach this status is needed to identify requirements that will give the possibility to fulfil the desired goal. To have a sustainable interoperable environment, it is important to understand the modelling paradigm in use, the relationship among the business partners so that intelligent reconfiguration of components becomes possible. To create this maintenance system and manage such dynamics, it is necessary to **monitor** and adapt to the changes while **learning** over time. Nevertheless, in another perspective it is needed to **predict** the transient that results from the dynamics of the individual systems, since a network (and network of networks) will face changes that impact third parties in the global operative environment. Hence, an evolution of a particular system should only be **decided** in case it brings more benefits than damages. According to the reflectivity principle [29], changes can follow a cyclic loop that impacts the same system that motivated the initial evolution.

Another important aspect is to have a conformance test and interoperability checking for systems interoperability assessment. This assessment is needed to discover and notify every time that a new system node is integrated in the collaborative network, or it is updated. The conformance checking is required to check for conformance of data, models, knowledge and behaviours of the systems and assure accuracy in the seamless communication. The interoperability checking will verify and assess the network to assure the maintenance of the network interoperability system [30], [31].

B. Dynamic Software Adapters at Work

To exemplify the concept, let's consider a collaborative network composed by several enterprises (nodes A, B, C, etc.), as represented in Figure 3. To create an interoperable environment on this collaborative network, it is necessary to identify the models of each enterprise, to establish and assure the integration between each other. From this circumstance it can happen different situations in the network: Company A uses the same EIS as Company B (in this case the integration should be easier); Company C has an EIS that is different from the one owned by Company A and B, but still, it has interoperability potential. The software adapter is the component responsible for the identification of the models and mapping between each other, that as the name implies, has the function of adapting each model to another. Creating a way to propose a solution to do the relations between them is an important step to achieve the global interoperability status in the network. Due to this, the study made in section 2 is important to identify how the EIS work, and how they represent their models. Since allowing the different enterprises to use their preferred systems is important, the adapter is reusing the legacy systems of each enterprise, creating a sustainable environment in the network.

In Figure 3, one can see how each enterprise uses its specific adapter to communicate with others, and are associated with the monitoring, learning, prediction and decision activities, directly related with the systems evolution and adaptation.

C. Methodology for the Semi-Automatic Generation of Software Adapters reusing on Enterprise Models

A crucial characteristic to be considered in the support for the sustainable interoperability concept, is to allow the network to detect the changes that occur over time, and adapt to them using semi-automatic technology such as

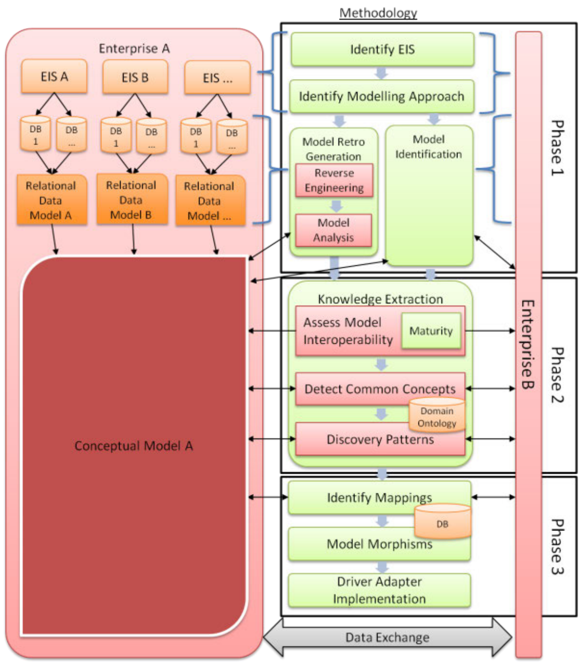

Figure 4. Methodology proposed.

software adapters to translate data from one system to the other, giving the possibility to learn, as well as to provide the capabilities for monitoring, supervision, and context awareness. The authors propose a methodology for the semi-automatic generation of software adapters, applying and reusing existing enterprise data, models and knowledge from modelling paradigms such as the ones analyses in section 2.

As illustrated in Figure 4, the methodology details the process followed to put two or more enterprise information systems exchanging the information needed by the partner enterprises (A and B) to collaborate. It is divided in three phases as described next:

Phase 1 - A first step (manual) is related with the identification of all the EIS in use. As each enterprise can have different systems, e.g. ERP, MES, CRM, etc., it is important to start by identifying which are them, and which are relevant for the collaboration. Directly related with this, is the identification of the modelling approach (if any). As discussed along section 2, enterprise modelling can follow different paradigms, maintaining different types of models and information views. At this point one can immediately access the conceptual models needed, or apply an automated retro-generation procedure to inspect the local databases and derive one or more relational models (see the work of Lezoche et al. [32]), which can then be abstracted to conceptual level. The purpose of these initial steps is to identify the conceptual data models that need to be interoperable.

Phase 2 - The second phase of the methodology is related with knowledge extraction to initially assess the models interoperability status and/or requirement, detect the common or similar concepts in use (with the help of domain ontologies), and discover patterns of existing relationships. These semi-automatic steps enable to identify the mappings needed to relate both enterprises. If there is already an adapter implemented to relate both enterprises, this phase will also validate the existing mappings if they are stored explicitly (as in the work of Agostinho et al. [33]).

Phase 3 – Having the mappings duly identified, one can apply the software engineering modelling paradigms of section 2, e.g. MDA, to formalize the morphisms using models and enable semi-automated implementation of the transformation services/functions based. This phase is not so thoroughly detailed here because there is parallel research exclusively focused on the topic (e.g. Agostinho et at. [4]).

After the implementation of the software adapter, the information can be exchanged as needed, and there will be enough meta-information on the adaptor to enable to regenerate it based on new modelled morphisms, whenever necessary for a sustainable interoperability. The methodology is in an experimental phase. Yet, some parts were already tested and validated. In the Phase 1 the authors are making tests in the Model Retro Generation module, where they are researching for methods to improve the Model Analysis used in the IMAGINE project. The Phase 3 is the phase that have more results, the Identify Mappings and Model Morphims modules were already validated and it is being developed a way of auto generate automatically the transformation of the models, allowing the system to readapting the changes in the models without breaking the harmonization in the network.

D. Adapter Implementation

The adapter implemented following the methodology proposes is able to identify the EIS, models and standards in use by the enterprise, and to use that new knowledge to create a bridge that will allow the integration between other enterprises. In terms of architecture, the adapter will be composed of different modules that contribute with different targets such as monitoring, decision, etc., and reach the final goal, establishing an SI environment and avoiding harmonization breaking in the network.

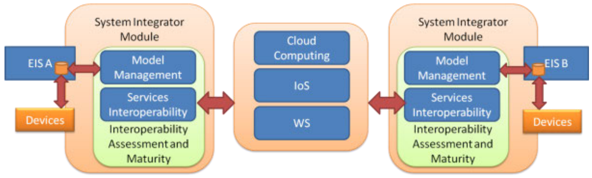

Figure 5. System Integration Module (SIM).

In this paper only a part of the adapter is addressed, namely the System Integration Module (SIM), as illustrated in Figure 5, and whose model and services for interoperability results from the presented methodology. Model Management component is used to display and relate the different models, enabling an interaction with the user that can complement the results of the automatic mattings obtained. The Service Interoperability component creates the physical bridges in the communication, relation with other SIM modules from other adapters through cloud technology. With these components, the adapter is ready to evaluate and relate the different enterprise models, and giving support to the three R's more exactly to the Reuse, since it is reusing proven methodologies and the EIS conceptual models used by each enterprise even they are not explicitly defined at the beginning.

To validate the methodology and the module presented, it was developed a first approach in the IMAGINE project [34]. A software adapter, following the same principles discussed here was implemented for a specific cluster of companies to connect to a services platform (refer to for specific details on the implementation conducted there [35]). However, due to project requirements, the approach was made in a different perspective, since this methodology proposes a decentralized approach (each company has its specific adapter) as opposed to the centralized implementation from IMAGINE, where there is a single complex adapter for a full set of enterprises. Since, in that case an enterprise only needed to create mappings to transform their data to the model of the platform (unidirectional), that approach was possible. The adapter developed for the IMAGINE project is represented in Fig. 3, where each enterprise connects to the adapter to provide the needed information data to be used by the IMAGINE platform. Each adapter is specific for each enterprise, since their models are different. So, it was needed to create specific mappings to allow the flow of information between enterprises and platform.

In conclusion, during the IMAGINE implementation, phase one of the methodology (retro-generation path) was applied to several EIS, phase two was skipped since the modelling of phase three was done manually due to the degree of dissimilarity of the destination model. Some parts were manual/semi-automatic (as the identification of the model and identification of the mappings) and others parts were automatic (as the transformation of the models), making the first approach of the adapter with good results. In the adapter of the project, it was missing an automatically system to identify changes in the models, allowing the adapter to identify and to do the changes in real-time without creating a harmonization breaking in the network. This is a point needed to allow the methodology to be dynamic, being a point for future work and in study as a result for this work.

IV. Conclusions and Future Work

Adaptive systems theory is taken as a basis for this work, considering that EIS collaborative networks are a complex macroscopic collection' of relatively similar and partially connected micro-structures, formed in order to adapt to the changing environment and increase its survivability as a macro-structure. It is particularly difficult to maintain the interoperability in such enterprise collaborative network. This is mainly because of how EIS systems are designed, since each system usually has different information models and interfaces.

To assure the sustainability of interoperability in a network of EIS, it is necessary to create seamless relations between the heterogeneous systems, its standards and models. In this paper, it was made a study on several EIS modelling paradigms, to identify how they work and how they represent the enterprises and their own resources, enabling the reuse of proven methodologies and systems' models in a semi-automatic generation of software adapters to enable SI. If every time enterprises need to cooperate, the philosophy of the three R's is applied, it reduces costs, improves the efficiency, and maximizes the collaboration potential of networks.

This paper proposed a paradigm to support the sustainability of interoperability among networked enterprise, suggesting the implementation of dynamic adapters to assure the continuous transformation of heterogeneous information models. Following a 3 phase's methodology, it assures an adaptive mechanism for continuous interoperation among the different enterprise applications, and guaranteeing a seamless communication among the networked enterprises. To achieve this sustainability, it is necessary to identify the EIS/models in use, extract knowledge out of them to enable automation in the creation the mappings between the different models. An architecture for the software adaptors has been proposed and implemented in a trial case for the IMAGINE European project.

In the future, the knowledge extraction part of the methodology is to be further developed, creating a solid basis for automatic reasoning. Also, the management of such complexity and number of relations requires an evolved model management human-interface, supporting decision making and enabling simulation of transients in the different networks each enterprise belongs to. Complex Event Processing (CEP) and MAS (Multi-Agent System) are examples of candidate technology that may improve the monitoring of networks.

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