Towards an Enterprise Interoperability Framework

Paula Kotzé[1] and Irina Neaga[2]

[1]Meraka Institute, Council for Scientific and Industrial Research
Pretoria, South Africa
[1]Institute for ICT Advancement, Nelson Mandela Metropolitan University
Port Elizabeth, South Africa

[2]Department of Electronic and Electrical Engineering, Systems Engineering Division
Loughborough University, Leicestershire, U.K.

Abstract. This paper presents relevant interoperability approaches and solutions applied to global/international networked (collaborative) enterprises or organisations and conceptualise an enhanced enterprise interoperability framework. The paper covers several key aspects including how holistic approaches of architecting principles, standards and semantics contribute to the development of an interoperability framework that can be flexibly used for interoperable complex systems, particularly ICT, that support global enterprises including organisations from multiple countries, e.g. European and African organisations. This proposed comprehensive approach of interoperability covers not only technical aspects, but also semantics alongside organisational and cultural aspects. The use of systems engineering thinking and architecting for achieving interoperability of complex systems is suggested.

1 Introduction

The term *enterprise* in the context of *enterprise architecture* can be used to denote both an entire and a specific domain within the enterprise. In both instances, the architecture traverses multiple systems, and multiple functional groups within the enterprise. Furthermore, an extended enterprise these days frequently includes partners, suppliers, and customers [27]. If the goal is to integrate an extended enterprise, then the enterprise architecture should comprise a reference to the partners, suppliers, and customers, as well as internal business units. In this case interoperability becomes a key issue to be considered in enterprise architecture.

Interoperability is a key concern for network enabled complex systems, which in turn have facilitated the collaborative enterprise and implicitly globalisation. Interoperability has, for example, been the focus of European and African IST programmes and initiatives such as INTEROP-VLAB (The International Virtual Laboratory for Enterprise Interoperability) (http://interop-vlab.eu/) and ATHENA [1], and the Interoperability in African Parliamentary Information Systems initiative [30]. Despite a huge amount of literature on interoperability research and applications [5, 16, 17], from a practical perspective interoperability research is still in an early stage. There

Kotzé P. and Neaga I. (2010).
Towards an Enterprise Interoperability Framework.
In *Proceedings of the International Joint Workshop on Technologies for Context-Aware Business Process Management, Advanced Enterprise Architecture and Repositories and Recent Trends in SOA Based Information Systems*, pages 26-29
DOI: 10.5220/0003027100260029

are still several issues that require novel solutions based on innovative approaches. Some of these issues are:

- Using standards do not always guarantee achieving interoperability.
- Applying architecting principles do not always guarantee achieving interoperability.
- Not comprehensively addressing enterprise-wide information protection, trust and security issues, which are crucial for assuring trusted electronic business relationships and virtual/online collaboration, as well as different networking enablement such as electronic supply chains or network centric operations /enabled capability in most enterprises [19, 26].
- Non-technical issues, such as cultural and human communication and interaction alongside computer and human domain specific knowledge, are proven to become barriers in achieving interoperability.
- There is a need for analysis and evaluation of interoperability itself.
- Improvements of existing system interoperability should be beneficial.
- Rapid development of technology may decrease the degree of systems interoperability if the interoperability requirements are not considered at design level.

There are several approaches, from different perspectives, to achieving interoperability. Examples include those based on semantic technologies and service orientation [5, 29], as well as support for different types of applications such as electronic business and electronic government [16, 17, 30].

However, the existing approaches are only part of potential solutions of interoperable complex systems (e.g. an enterprise or organisation) or ‘systems of systems’ (e.g. an enterprise operating in different cultural and political environments), and enabled through networking or collaboration. A holistic approach of enterprise interoperability on all levels of the enterprise is also required. A call therefore arises to define an integrated enterprise interoperability framework that could be applied to an extended enterprise, including its possible global divisions and supply chains. We use to term global to refer to the global (international) economy in which traditional barriers is no longer prohibitive.

The principles of systems engineering, including aspects such as holism, emergent behaviour, boundary, etc., can be applied to any system, complex or otherwise, provided systems thinking is employed at all levels of the system. Systems thinking is an approach to problem solving, by viewing ‘problems’ as parts of an overall system, rather than reacting to a specific part, outcomes or events and potentially contributing to further development of unintended consequences. Systems thinking involves a set of methods or practices within a framework that is based on the belief that the component parts of a system can best be understood in the context of relationships with each other and with other systems, rather than in isolation [4]. There is no doubt that interoperable systems are complex systems that should be holistically analysed and modelled.

The motivation behind this paper is to advance the research on enterprise interoperability using a systems engineering holistic approach in order to propose components to be considered in developing a global enterprise interoperability framework. The paper was motivated by the authors’ experience in collaborative enterprise projects spanning Europe and Africa, and the paper addresses enterprise interoperability in this context.

The specific aim of this paper is to present a first step towards proposing a harmonised set of concepts regarding interoperability that can support a wide range of applications and will also enable global organisations/enterprises, including European and African specific needs, requirements and cultural aspects.

In order to achieve this aim, the paper has two objectives:

– To provide an overview of existing interoperability approaches, standards and architectural practice in order to define a common approach or mapping possibility.
– To propose the way forward in conceptualising the requirements for a global enterprise interoperability framework based on sound enterprise architecture and systems engineering principles.

Section 2 of the paper provides some background to the concept of an enterprise. It also presents definitions and description of the levels of interoperability. Section 3 includes an overview of enterprise interoperability frameworks, models and solutions and positions them relatively to each other. Section 4 introduces first steps and suggestions for the requirements of a global enterprise interoperability framework. Section 5 concludes.

2 Background

2.1 What is an Enterprise?

The concept of the 'enterprise' is increasingly used by both practitioners and researchers from a wide variety of settings. Despite the wide usage, there are considerable differences in the scope of definition and the purpose in adopting the enterprise perspective. The term enterprise has been applied in the context of corporations, small businesses, non-profit institutions, government bodies, educational institutions, space stations, and other kinds of organisations such as living environments (e.g. households).

However, many authors have considered an expanded definition of enterprise clearly different from an organisation that is a single entity from an ownership perspective [12]. TOGAF defines an enterprise as a collection of organisations with a common set of goals, for example, a government agency, an entire corporation or a division of a corporation, a single department in a corporation, or a chain of geographically distant organisations linked together by common ownership [27]. The European Commission [11] defines an enterprise as 'an entity, regardless of its legal form including partnerships or associations regularly engaged in economic activities'. Some authors have retained the term enterprise for a single organisation and used 'extended enterprise' to represent a set of firms within a value chain or production network that collaborate to produce a finished product [9] in a global context/economy. Another definition for the extended enterprise that has several similarities with the global enterprise is that it is a loose partnership that is neither characterized as an arm's length relationship nor a vertical integration [10]. Despite the evident need for greater intra- and inter-organisational collaboration leading to more prolific use of 'enterprise', the term remains ambiguous [20].

An enterprise can thus be viewed as a complex system consisting of processes that can be engineered both individually and holistically. The majority of these processes require the involvement of or interaction with a human at some time. The nature of enterprises is therefore in essence socio-technical systems, where 'the operating principle consists of the ability of human beings to enter into and comply with commitments' [8: 12].

2.2 What is Interoperability?

There is yet no single definition for the term interoperability. Moreover, a unique definition of interoperability of complex systems is not provided here.

The term interoperability is often used in a technical systems engineering sense, or alternatively in a broad sense, taking into account social, political, and organisational factors that impact system to system performance.

On a technical level, the IEEE, for example, defines interoperability as 'the ability of two or more systems or components to exchange information and to use the information that has been exchanged' [15]. The Open Group [27: 32], likewise, defines interoperability, in the context of TOGAF Version 9, as the ability 'to share information and services', 'of two or more systems to exchange and use information', and 'of systems to provide and receive services from other systems' enabling them to operate together effectively. The European Interoperability Framework defines interoperability more holistically as 'the ability of information and communication technology (ICT) systems and of the business processes they support to exchange data and to enable the sharing of information and knowledge' [14: 5].

In contrast, NATO's definition of interoperability is, for example, more organisational focused: 'Interoperability is the ability of systems, units, or forces to provide the services to, and accept services from other systems, units or forces and to use the services so exchanged to enable them to operate effectively together' [18].

Interoperability is thus the ability of two or more different entities (be they pieces of software, processes, systems, business units, etc.) to 'inter-operate' [29].

2.3 What is Enterprise Interoperability?

To face current business challenges, modern enterprises have to be interoperable in terms of not only their IT systems, but also their business processes, their applications and even their human resources, whether from an intra or inter-organisational point of view. Enterprise interoperability is concerned with interoperability between organisational units or business processes either within a large (distributed) enterprise or within an enterprise network [29]. The challenge lies in facilitating communication, cooperation, and coordination among these units and processes. From an enterprise architecture and a systems engineering perspective operating into a networked environment place the requirements for interoperability alongside the maintainability, reliability, safety and supportability requirements of a system [2].

Enterprise interoperability is linked to enterprise integration. Enterprise integration can be vertical or horizontal, and full, loose or tight. Vertical integration refers to integration of a line of business from its tactical planning to operation levels. Horizontal integration refers to integration of the various domains (i.e. business areas) of the enterprise, or with its partners and environment. In full integration components systems are no longer distinguishable in the system. With tight integration components are still distinguishable but any modification on any of them may have direct impact on others. With loose integration component systems continue to exist on their own, but can operate as components of the integrated system [29].

Enterprise interoperability ties in with loose integration. It provides two or more business entities with the ability to exchange or share information and of using functionality of one another in a distributed and heterogeneous environment. Component systems are preserved as they are and the reuse process is facilitated.

2.4 Levels of Interoperability

The European Interoperability Framework (EIF) identifies three levels of interoperability [14]:

- Organisational interoperability is focused on the definition of business goals, modelling business processes and organisational collaboration issues.
- Semantic interoperability is concerned with ensuring that the exact same meaning of exchanged information is obtainable in the same way by any other computer system and/or human agent that were not initially trained for this purpose.
- Technical interoperability covers the technical matters of connecting systems and services through interfaces, protocols etc. applying appropriate software engineering techniques and methodologies.

Fig. 1 depicts these main levels of interoperability. The arrows show that in order to achieve the interoperability between system A and system B that are using different architectural frameworks, different levels of interoperability are considered.

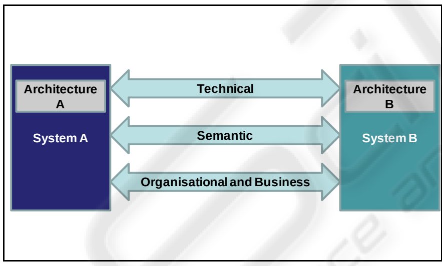

Fig. 1. European Interoperability Framework levels of interoperability.

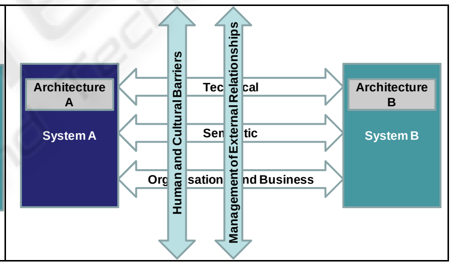

Fig. 2. Levels of interoperability and barriers.

However, in order to achieve enterprise interoperability the levels of interoperability must also take into consideration the socio-technical nature of an enterprise. Achieving enterprise interoperability therefore requires efforts from a technical as well as non-technical perspective. The technical issues are covered by EIF. The non-technical issues involve human and cultural barriers to interoperability. These aspects are shown in Fig. 2.

In defining business interoperability, Legner and Wende [17] considered some of the non-technical issues by identifying four levels of interoperability in the business interoperability framework (BIF): information systems (type of interaction, connectivity, and security and trust); collaborative business process interoperability (public process, process visibility and business semantics); employees and culture interoperability (trust and partner management), and management of external relationships (cooperation process and cooperation targets). Tsagkani [28] identifies a further level of enterprise interoperability, namely pragmatic interoperability, which captures the willingness of partners for the actions necessary for the collaboration and involves both capability of performing a requested action, and policies dictating whether the potential action is preferable for the enterprise to be involved.

Whitman and Panetto [31] refer to both knowledge and cultural differences. They have identified explicit and tacit knowledge communication gaps during the enterprise design activities involving multi-national teams, as well as in globally manufacturing processes of products. An experienced engineer would use some tacit rules involved in the design process that include assumptions that is not explicitly stated. What is tacit knowledge in one culture may be explicit in another, and vice versa. They have also indicated that language is not the only cultural issue in semantic interoperation, and that the concern of different cultures having different design philosophies is also important. Various cultures have different constraints and different objectives, and culture impacts business.

To be interoperable the exchange of knowledge across dissimilar cultures in different native languages is imperative. Successfully interchanging enterprise information therefore requires what is known as intercultural communication power [7].

2.5 Uncovering Systems Interoperability Issues by Applying Systems Thinking

From a systemic perspective interoperability problems and approaches should consider conceptual relations and interdependencies between interoperability and other system/sub-system/component characteristics such as agility and collaboration, which are supported through knowledge and ontology modelling, as illustrated in Fig. 3. The figure also outlines the key aspects which define the systems characteristics and conceptual or soft relations between them. Enterprise interoperability is therefore intrinsically an enterprise architecture issue in that it covers all the concerns that should be holistically addressed during an enterprise architecture exercise.

Systems thinking embedded in the Soft Systems Methodology (SSM) developed by Checkland [4] identifies problem situations, formulates from these a set of root definitions of relevant purposeful human activity systems, builds up conceptual models of the systems, compares the models with reality, and makes changes that should be systematically desirable and culturally feasible. Using SSM the systems or enterprise interoperability problems can be uncovered through the definition of a ‘big picture’ of the whole system or enterprise and its components, problem framing and stakeholder involvement in the different stages of systems definition, and modelling through interviews and workshops.

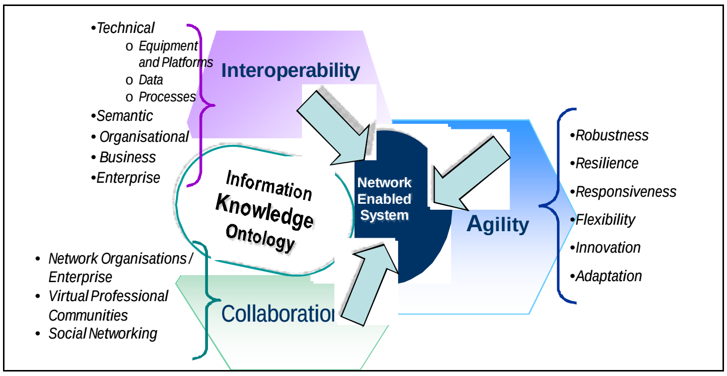

Fig. 3. Interoperability and other system characteristics (adapted from [22]).

3 Research into Enterprise Interoperability

A global interoperability framework and related models should consider the existing approaches and aim to their harmonisation at conceptual level, and mapping from a practical perspective. Therefore a brief comparative overview of existing approaches is presented, analysing their gaps and potential bridging solutions.

3.1 Current Solutions to Interoperability Frameworks

The European Interoperability Framework (EIF) [14] defines a set of recommendations and guidelines for services, especially for electronic government applications, in order for public administrations, enterprises and citizens to interact across borders in a pan-European context. For it to be extended and applied for applications in, for example, African countries the EIF framework should consider particular issues of African enterprises or organisations. A Euro-African (global) interoperability framework would therefore be required.

Progress has been made by the framework AKOMA NTOSO (Architecture for Knowledge-Oriented Management of African Normative Texts using Open Standards and Ontologies). It is enabling effective access to, and exchange of, machine-readable African parliamentary documents, such as legislation and debate record [30]. It aims to the standardisation of technology-neutral representations of African parliamentary documents in order to improve inter-parliamentary cooperation, and reduce the costs of parliamentary IT support systems.

C4IF (C4 Interoperability Framework), C4 from the first letters of the core concepts of the framework (connection, communication, consolidation, and collaboration), has been developed using some well-defined concepts from linguistics. Based on the language/action perspective this framework is focused on the techniques applied to information systems in order to communicate, and modelling this communication as a discourse [25].

DARPA and C4ISR have initiated the LISI (Levels of Information System Interoperability) capabilities model where a common frame/structure defined as a matrix was introduced with five interoperability maturity levels addressing four interoperability attributes organized as dimensions: procedures, applications, infrastructure, and data (PAID) [3]. The dimensions (attributes) are assessed in terms of five hierarchical levels of interoperability readiness, the stages through which systems should logically progress or 'mature' in order to improve their ability to interoperate: isolated systems (manual), connected systems (peer-to-peer), distributed systems (functional), domain systems (integrated), and enterprise systems (universal).

While the LISI model is technical in nature, and does not include the role of people and knowledge, it does expand the definition of interoperability beyond the ability to exchange data from one system to another: it considers the ability to exchange and share services between systems.

NCOIC (Network Centric Operations Industrial Consortium) has produced a framework and SCOPE Model (systems, capabilities, operations, programs, and enterprises) [21]. The model is designed to characterize interoperability-relevant aspects or capabilities of a system or set of systems over a network in terms of a set of dimensions and values along those dimensions. The SCOPE model can be applied to characterize networking capabilities and its impact on human and machine interaction.

3.2 Technical Solutions to Interoperability

Achieving interoperability usually means implementing specifications and standards that may support interoperability in the environment in which the systems have to operate. However, it is possible to implement a specification or standard and not achieve interoperability when the systems with which one seeks to interoperate (communicate, exchange information, etc.) do not make use the same specification or standard. This is why so much of implementing interoperability goes down to the planning and communicating stage. Therefore it is required to do extensive research, a thorough consultation, consider shared requirements and come up with a working consensus on what needs to be achieved. Projects which rush into implementation without proper enterprise architecture, consultation and development of requirements and specifications, may have difficulties further along the way. A systems engineering approach for enterprise interoperability solutions are therefore recommended.

3.3 Achieving Interoperability through Standardisation

Several standard-based application protocols (APs) and business objects (BOs) are available. They cover many of the major technological, economic and human activities, and have been produced by international organisations such as ISO (International Organisation for Standardization), UN (United Nations), CEN (European Committee for Standardization), OMG (Object Management Group), NIST (National Institute of Standards and Technology), etc. However, according to Grilo et al. [13], amongst practitioners most of these standards are not widely adopted, either by lack of awareness or due to especially private commercial interests within the software development process. Moreover, when they are selected, they are sometimes used inadequately, mainly due to an imprecise interpretation of the scope. This results in difficulties in achieving interoperability with other systems and introduces limitations in potential future reuse and model extensibility when creating new components.

3.4 Achieving Interoperability through Architecting

Architecting to support interoperable systems in terms of their definition, development, and through life cycle maintenance imply the realisation of the following main aspects [6]:

- Ensuring interoperability and connectivity of architectures, consistency, compliance with applicable directives, and architectural information sharing/dissemination.
- Facilitating implementation of policies and procedures, acquisition strategies, systems engineering, configuration management, and technical standards.
- Standardisation in terms of reference, modelling tools, architecture data elements, architecture data structures, hardware and software interfaces, architectural representations, and level of detail/abstraction.

Enterprise architecture refers to a comprehensive description of all the key elements and relationships that fully describe an enterprise. The elements to be described may be data, network equipments, software components, business locations, human resources, etc. Enterprise architecting aims at aligning the business processes and main objectives of an enterprise, with the applications and systems that build up its technical infrastructure. Enterprise architecture is therefore an important support for interoperability in network enabled environments, since they contribute to align the models of the enterprises/organisations that are required to interoperate.

There are many different approaches to describing the elements of enterprise architecture. For example, the Zachman Framework, an ontology for describing the enterprise [32], uses a two dimensional classification schema for descriptive representations of an enterprise. It intersects the primitive communication interrogatives (what (inventory sets), who (process transformations), where (network nodes), who (organisational groups), when (timing periods), and why (motivation reasons)) with reification transformations (identification, definition, representation, specification, configuration, and instantiation). Another example is the domain specific frameworks. MODAF (Ministry of Defence Architectural Framework) in the United Kingdom, for example, supports interoperability as a standard architectural framework, which enables the coherent sharing of architecting information that facilitates the identification of gaps and overlaps between operating processes and the systems that support them. MODAF has been developed based on the Department of Defence Architectural Framework (DoDAF), which provides operational, system and technical views. Within the domain of security, SABSA (Sherwood Applied Business Security Architecture) is an example of a framework and methodology for enterprise security architecture and service management used by numerous enterprises [26]. There have been identified mapping capabilities between the architectural frameworks, for example, DoDAF/MODAF mapped to Zachman [24]; and C4ISR mapped to GERAM (Generalised Enterprise Reference Architecture and Methodology) developed by the IFIP-IFAC Task Force, and adopted as an Appendix of ISO15704:2000 [23]. ~

3.5 Mapping Interoperability Frameworks and Exchange Languages

As a summary, Fig. 4 classifies approaches to interoperability into two classes, commonality-based and interaction-based, making a notional attempt to position specific concepts, initiatives, technologies, and products within that space.

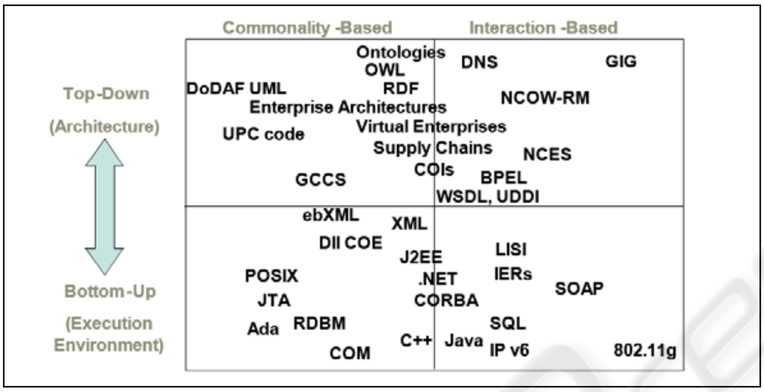

Fig. 4. Mapping Interoperability Frameworks and Exchange Languages [21].

One way to characterize and harmonise these approaches is top-down versus bottom-up. Top-down approaches typically address the problem from an enterprise architecture, or broad scope of a generic socio-technical system, and through different layers of abstractions using modelling tools. Bottom-up approaches seek to achieve interoperability by adoption of specific technologies or information representation standards. While contrasting top-down with bottom-up approaches is a useful distinction, commonality-based approaches focus on the execution environments of systems and are directed to achieve interoperability across an enterprise by defining how every system within that scope adopt a particular set of standard elements for their execution environment.

4 Towards a Global Enterprise Interoperability Framework

This paper has two objectives: the previous sections provided an analysis of existing interoperability approaches, standards and architectural practice, addressing the first objective. The second objective was to conceptualise the way forward in deriving the requirements for a global enterprise interoperability framework based on sound enterprise architecture and systems engineering principles, integrating a common approach or mapping of the various interoperability approaches. This section addresses the second objective.

4.1 Starting Research Questions

Fig. 5 attempts to illustrate the various components that should be considered in deriving a global enterprise interoperability framework. These requirements are based on the following research questions:

– How to effectively combine the various components depicted in Fig. 5 to create an effective and efficient enterprise architecture methodology, leading to an effective and efficient systems engineering approach to interoperable secure systems?
– How to make (newly) designed enterprises and systems interoperable when deployed in any place, at any time?
– How to enhance systems security aspects, since many interoperability approaches do not consider security requirements and security engineering does not include systems interoperability?
– How to include the human aspects, e.g. social and cultural issues, in order to develop interoperable socio-technical systems/complex systems?
– How to consider and address external and unexpected events affecting an enterprise operation?

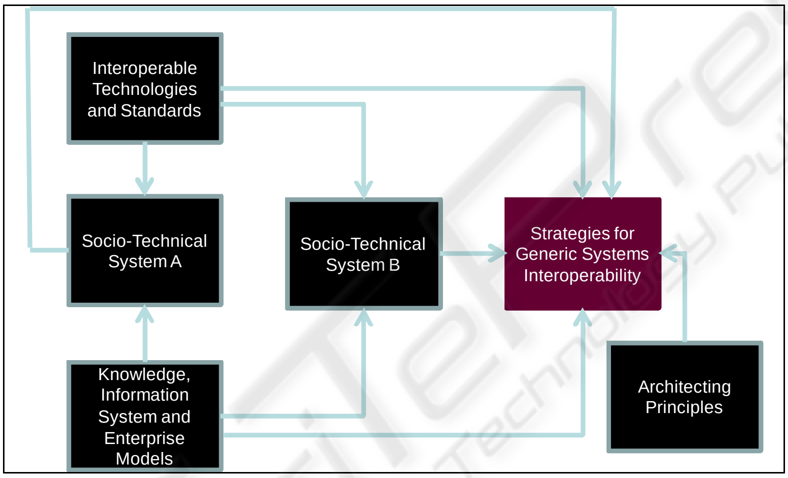

Fig. 5. Towards a global enterprise interoperability framework.

4.2 Proposed Research Methods

We propose the use of roadmapping as a research technique in order to define the vision of enterprise interoperability, the current state of the art, as well as the existing gaps and methods including an implementation plan to achieve the vision. Roadmapping has the advantages of a consistent and unified presentation of the concepts and can harmonise the views of researchers and practitioners through a consensus building approach.

To determine the state of the art, we propose the use of an analytical research method, involving an in-depth study and evaluation of existing approaches and solutions to enterprise interoperability in an attempt to unify or harmonise them. This should be combined with sound systems engineering and enterprise architecture principles in guiding the way forward.

The work of Chen and Doumeingts [5] provides some guidelines that can serve as a starting point for investigating the interoperability of enterprises. Their work presents basic concepts, framework and roadmaps to develop interoperability of enterprise applications and software, tackling the interoperability problem from multiple but integrated views. Some of the issues addressed include: why enterprises need to interoperate, how enterprises interoperate, as well as what constitutes interoperability as a capability.

The proposed systems engineering research methods include holistic problem space definition, multiple perspective/view approaches, as well as multi-disciplinary studies and systems thinking. Applying SSM [4] as a research methodology in addition to systems engineering approaches, for example, could provide an integrated enhanced method to analyse complex systems and situations involving human activities. SSM is a research methodology initially designed for management studies, SSM distinguishes itself from 'hard' systems approaches in the way it deals with the notion of 'system'. Hard systems approaches see systems as ontological entities, i.e., as entities existing in the real world, as bounded entities with a physical existence that can be formally described or designed to fulfill a given purpose. SSM treats the notion of system as an epistemological rather than ontological entity, as a mental construct used for human understanding. A combined hard and soft systems approach applied to interoperable complex systems could therefore be useful due to the following reasons:

1. Exploring of systems thinking about real-world situations in which interoperable systems in collaborative and competitive networked environments are operating.
2. Exploring the diverse perspectives relevant to the identified situations through 'root definitions'.
3. Analyzing, presenting and discussing interoperable systems operating in different situations/contexts stressing diverse perspectives.
4. Building diverse conceptual models corresponding to different perspectives.
5. Debating the situations and debating models.
6. Defining feasible and desirable changes through new implementation solutions.
7. Repeating the process for a new perception of the situation, seeking to accommodate the conflicting systems characteristics and their relationships.

5 Conclusions

This paper discussed various interoperability issues related to enterprises and the approaches aimed at addressing interoperability at various conceptual levels. We conceptualised the basic requirements for a global enterprise interoperability framework to address the interoperability of complex systems enabled by a networked environment. One of the main issues identified in the paper is explicitly addressing the non-technical factors (human and cultural issues, and the management of external relationships) that could be barriers or obstacles in achieving enterprise interoperability, identifying the gaps and potential solutions based on using existing approaches and frameworks.

Addressing interoperability in a clear unambiguous manner at several levels (organisational (business and human interaction), semantic (service and information sharing) and technical, is a useful architecture planning tool. The notions of interoperability will become ever more important in the service oriented architecture (SOA) environment where services will be shared internally and externally in ever more inter-dependent extended enterprises [27].

Future research directions include the provision of a complete definition of the framework and applying it to different situations and case studies using systems engineering and enterprise architecture methods, combined with a dynamic roadmap. There is also an important need to develop an agreed architectural framework and representation language, as well as an evaluation method/metrics to support complex interoperable systems including the analysis of their degree of interoperability.

References

1. Berre, A.-J., Elvesæter, B., Figay, N., Guglielmina, C.J., S. G., Karlsen, S.G.: The ATHENA Interoperability Framework Proceedings of the 3rd International Conference on Interoperability for Enterprise Software and Applications (I-ESA'07). Springer (2007) 569-580
2. Blanchard, B.S.: System Engineering Management. John Wiley & Sons Inc (2008)
3. C4ISR Architecture Working Group: Levels of Information Systems Interoperability (LISI). (1998) 4 - 97; D91 - D13
4. Checkland, P.: Systems thinking, systems practice. Wiley, Chichester, West Sussex (1981)
5. Chen, D., Doumeingts, G.: European initiatives to develop interoperability of enterprise applications—basic concepts, framework and roadmap. Annual Reviews in Control 27 (2003) 153-162
6. Curts, R.J., Campbel, D.E.: Architecture: The Road to Interoperability. Command & Control Research & Technology Symposium, U.S. Naval War College, Rhode Island (1999)
7. de Silva, D., de Silva, D.: How to gain a competitive edge in international business through inter-cultural communication power. Proceedings of Pan-Pacific Conference XII: A Business, Economic, and Technological Exchange, Dunedin (1995)
8. Dietz, J.L.G.: Enterprise Ontology - Theory and Methodology. Springer-Verlag, Berlin (2006)
9. Dyer, J.H.: Collaborative Advantage. Oxford University Press, London (2000)
10. Dyer, J.H., Singh, H.: The relational view: cooperative strategy and sources of inter-organizational competitive advantage. The American Academy Review 23 (1998) 66-79
11. European Commission: Commission recommendation of 6 May 2003 concerning the definition of micro, small and medium-sized enterprises. Official Journal European Union C (2003) L124/136-141
12. Gollner, J: Managing Knowledge in the Fractal Enterprise. (1999)
13. Grilo, A., Jardim-Goncalves, R., and Cruz-Machado, V.: A Framework for Measuring Value in Business Interoperability. IEEE Transactions (2007) 520-524
14. IDABC: European Interoperability Framework for Pan-European eGovernment Services, Luxembourg (2004)
15. Institute of Electrical and Electronics Engineers: IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries. IEEE, New York (1990)
16. Legner, C., Lebreton, B.: Business interoperability research: Present achievements and upcoming challenges. Electronic Markets 17 (2007) 176−186
17. Legner, C., Wende, K.: Towards an Excellence Framework for Business Interoperability. 19th Bled eConference eValues (2006)
18. Moon, T., Fewell, S. and Reynolds, H.: The What, Why, When and How of Interoperability. Defence & Security Analysis 24 (2008) 5-17

19. Mouratidis, H., Giorgini, P.: Integrating Security and Software Engineering – Advances and Future Visions. Idea Group Publishing (2007)
20. Murman, E., Allen, T., Bozdogan, K., Cutcher-Gershenfeld, J., Mcmanus, H., Nightingale, D., Rebentisch, E., Shields, T., Stahl, F., Walton, M., Warmkessel, J., Weiss, S., Widnall, S.: Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative. Palgrave Macmillan, Basingstoke (2002)
21. NCOIC: Network-Centric Operations Industry Consortium - SCOPE (Systems, Capabilities, Operations, Programs, and Enterprises) Model for Interoperability Assessment V1.0. (2008)
22. Neaga, E.I., Henshaw, M.: NEC Themes: A Conceptual Analysis and Applied Principles. Proceedings of the Conference RNEC'08, Leeds (2008) CD
23. Noran, O.: A systematic evaluation of the C4ISR AF using ISO15704 Annex A (GERAM). Computers in Industry 56 (2005) 407-427
24. Orne, D.: Architectural Framework Meta Models and NEC. NECTISE MODAF/DoDAF Seminar SEIC, Loughborough University (2006)
25. Peristeras, V., Tarabanis, K.: The Connection, Communication, Consolidation, Collaboration Interoperability Framework (C4IF)for Information Systems Interoperability. IBIS - Interoperability in Business Information Systems 1 (2006) 61-72
26. Sherwood, J., Clark, A., Lynas, D.: Enterprise Security Architecture: A Business Driven Approach. CMP Books (2005)
27. The Open Group: TOGAF Version 9. Van Haren Publishing, Amersfoort (2009)
28. Tsagkani, C.: Inter-Organizational Collaboration on the Process Layer. Proceedings of the IFIP/ACM SIGAPP INTEROP-ESA Conference. Springer Science, Geneva (2005) 129-138
29. Vernadat, F.B.: Interoperable enterprise systems: Principles, concepts, and methods Annual Reviews in Control 31 (2007) 137 - 145
30. Vitali, F., Zeni, F.: Working Towards Open Access to Parliamentary Information and Interoperability in African Parliamentary Information Systems" in (Eds) , 2006. In: Cunningham, P., Cunningham, M. (eds.): IST-Africa 2006 Conference Proceedings. IIMC International Information Management Corporation (2006)
31. Whitman, L.E., Panetto, H.: The missing link: Culture and language barriers to interoperability. Annual Reviews in Control 30 (2006) 233-241
32. Zachman International: The Zachman Framework. (2008)