A methodology for modeling interoperability in a context of cooperative industrial networks

Izunildo Cabral (i.cabral@campus.fct.unl.pt)[1] and Antonio Grilo[1]
[1]Unidade de Investigação em Engenharia Mecânica e Industrial, Faculdade de Ciências e Tecnologia/Universidade Nova de Lisboa, Campus da Caparica, 2829-516, Caparica Portugal

Abstract
This paper presents a methodology for modeling business interoperability in a context of cooperative industrial networks. The purpose is to develop a methodology that supports the analysis of the impact of business interoperability on the performance of cooperative networked organizations and the networks in which they are part. The analysis of the impact is grounded on the agent-based simulation. Different simulation environments are created to explore different scenarios of business interoperability problems and how they affect the performance measures such as cost and time. To test the applicability of the proposed methodology, an illustrative example to implement reverse logistics in a context of automotive industry is presented. The proposed methodology should serve as a conceptual tool for guiding managers in the analysis of the impact of different levels of business interoperability in the implementation of collaborative management practices such as reverse logistics.

Keywords: Business Interoperability, Cooperative industrial networks, Agent-based simulation

Introduction
Interoperability has been a topic of concern for at least the last 30 years. It is a property that refers to the ability of different systems and organizations to work together (Rezaei et al., 2014), be in a context of collaboration, cooperation or not. According to Guédria et al. (2013), a major issue in global collaboration and cooperation is the development of interoperability. In fact, academics and practitioners argue that interoperability affects the performance of firms working in cooperative environments. For instance, Jardim-Goncalves et al. (2012), argue that the lack of interoperability would disturb creation of cooperative work and networked systems.

Considering the importance of business interoperability in today's networked business environments, organizations are increasingly establishing new cooperation mechanisms towards the improvement of the way how they interact with their business partners. Within this context, it is necessary to analyze the current situation and perform a diagnosis of it in order to be able to identify any problems that might exist, as well as opportunities for improving (Campos et al. 2013). However, a very limited number of studies on this have been developed up to now. Based on our literature review, three main studies on the analysis of the impact of business interoperability were found. The first, prepared by Brunnermeier and Martin (1999, 2002) for the National Institute of Standards and Technology estimating that imperfect interoperability imposes at least $1 billion a year on the members of the U.S. automotive Supply Chain (SC). A second, conducted by Gallaher et al. (2004) identified and estimated the efficiency losses in the U.S. capital facilities industry resulting from inadequate interoperability. This study quantified $15.8 billion in annual interoperability costs for the capital facilities industry in 2002. Third, an empirical study conducted by Loukis and Charalabidis (2013) investigated the effect of adopting three types of information systems interoperability standards (industry-specific, proprietary and eXtensible Markup Language (XML) horizontal on the four perspective of business performance proposed by the balanced scorecard. Their study concluded that all three examined types of interoperability standards increase considerably the positive impact of firm's information and communication technologies (ICT) infrastructure on the four perspectives of the balanced scorecard. Despite the importance of these studies in the development of theory on the analysis of the impact of business interoperability, the literature reveals little effort to build a unified framework or methodology that can be used as a reference, mainly in a context of cooperative industrial networks. One of the criticisms that can be addressed to those studies is that they only focus on the study of one dimension of business interoperability, e.g. information systems (Loukis and Charalabidis 2013), or on the combination of only a couple of dimensions, e.g. technical, syntactic, semantic, and organizational (Rezaei et al. 2014)) rather than on the integration of all of them. As stated by Grilo and Jardim-Gonçalves (2010), the actual perspective of business interoperability advocates that this problem is not just an ICT technical issue, which is to say that it is not just about connecting information systems between agents within an industrial network, but rather there are other relevant dimensions that have been only partially addressed by the research community. For instance, the dimension related to the network complexity has not been explored in the existing studies. Another important gap is that those studies have not explored the network effect, i.e. how business interoperability problems can spread over the network. Questions remain on how business interoperability problems in one or more dyadic relationships can affect the interoperability of other neighbor relationships and consequently the performance of the organizations belonging to these relationships. Thus, the purpose of this paper is to fill those research gaps by developing a holistic methodology that enables the conjunction of all the dimensions of business interoperability in the analysis of the impact of business interoperability on the performance of networked organizations in a context of collaborative management practices implementation. Collaborative management practices are defined as those that require the interaction of two or more organizations in their implementation (Cabral et al. 2013b), or those that require high level of collaboration among organizations at different levels (Espadinha-Cruz et al. 2012) (e.g. reverse logistics, collaborative product development, collaborative transportation management, etc.). This paper is organized as follows: Next section provides a theoretical background on industrial networks, cooperation and collaboration. Following we introduce the concept of business interoperability and its dimensions. Next, a theoretical agent-based model that supports the analysis of the impact of business interoperability is proposed. Then, the applicability of the proposed methodology is tested through an application scenario to implement reverse logistics in a context of automotive industry. We end with a discussion on the potential contributions for theory and practice.

Theoretical background

Industrial networks

The term 'network' is widely employed and is an object of research across multiple scientific disciplines and professional fields (Carneiro et al. 2013). In its most abstract form, a network is a structure where a number of nodes are related to each other by specific threads (Håkansson and

Ford 2002). With regard to business relationships, a network represents a set of connected actors performing different types of business activities in interaction with each other (Holmlund and Törnroos 1997). An industrial network is defined as a set of three or more entities (suppliers, customers, distributors, retailers, etc.) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer (Mentzer et al. 2001). Generally, the relationships between network participants, from upstream suppliers to downstream customers, are not single line connected. Because of their complexity, supply chain networks (SCNs) are difficult to understand, describe, predict and control. To reduce the level of uncertainty in such networks, it is necessary to understand the diverse roles of the SC's members, their interactions, and the transaction models they use to interact with one another (Cheng et al. 2013). Understanding the inherent complexity of the SCN and taking necessary actions to reduce-manage-prevent it, would lead to better performances and higher customer satisfaction (Serdarasan 2013).

Cooperation and collaboration in industrial networks

Central to any kind of cooperation or collaboration is the concept of business relationship. The concepts of cooperation and collaboration are closely related but they can have different interpretations according to the context. Cooperation is defined by Carneiro et al. (2013) as 'the articulation of strategies and activities of two or more organizations in order to achieve commonly set objectives'. On the other hand, collaboration is defined as 'the process by which two or more organizations perform tasks together in order to obtain collective results'. In terms of cooperation, the key ideas are need for mutual trust, division of labor and adoption of common practices. For collaboration, the key ideas are shared tasks and the impossibility of achieving collective results individually, cited in (Carneiro et al. 2013). According to Whipple and Russell (2007), collaboration occurs when "two or more independent companies work jointly to plan and execute SC operations with greater success than when acting in isolation, allowing the development of synergy among partners and encouraging joint planning and real-time information exchange. In terms of the definitions for cooperative network, Chituc et al. (2007) define it 'as a collection of heterogeneous organizations with different competences, but symbiotic interests that join and efficiently combine the most suitable set of skills and resources (e.g., knowledge, capital, assets) for a period of time in order to achieve a common objective, and make use of ICT to coordinate, develop and support their activities'. On the other hand, collaborative network is often referred as any kind of network where some form of interaction exists, from virtual professional communities to SCs (Carneiro et al. 2013). Apart from the difference between those two concepts, the objective of cooperative or collaborative network is to achieve synergistic results that are more than the sum of the individual contributions.

Business interoperability

One approach that allows improving the collaboration among all the organizations within a SC is interoperability. Interoperability allows the organizations in the SC to collaborate in an efficient manner while preserving their own identities and their own ways of doing business through mechanism that act as facilitators (Corella et al. 2013). Interoperability is defined as 'the ability of two or more systems or components to exchange information and to use the information that has been exchanged (IEEE 1990). This definition highlights the technical aspects of exchanging information, ignoring the other aspects of business (e.g. collaborative business process). Therefore, a more comprehensive definition is needed for business interoperability. For the purpose of this paper, we define business interoperability as 'a field of activities with the aim to improve the manner in which organizations, by means ICTs, interoperate with other organizations, or with other business units of the same organization, in order to conduct their business' (Figay et al. 2008).

One of the important issues within the process of analyzing the impact of business interoperability is the consideration of its dimensions as it is important to understanding the way that the individual dimensions operate, as well as how they relate to each other. A dimension of business interoperability can be defined as 'the different levels of interactions at which collaborating organizations can engage in (Zutshi et al. 2012)'. While some authors investigated interoperability in a technical perspective or as a one-dimensional construct, e.g. Loukis and Charalabidis (2013), we argue that in the context of business networks, the dimensions of interoperability can ultimately be divided into nine dimensions, that are those proposed by the business interoperability quotient measurement model (BIQMM) (Zutshi et al. 2012) and after extended by Cabral et al. (2013a): business strategy, management of external relationships, collaborative business processes, products and services, employees and work culture, business semantics, knowledge management, information systems, and network complexity.

Each dimension consists of a set of factors that are responsible for the interaction between two or more collaborative business units. For instance, collaborative business process consists of clarity, visibility, alignment, coordination, synchronization, integration, flexibility, and monitoring of collaborative business process. On the other hand, information systems consists of information system model, interaction type, connectivity, security and privacy, information systems breakdown, IT platforms, speed, database structure, user interface, compatibility of software and hardware, type of applications and devices, programming languages, and information quality. The role of those dimensions business interoperability in this paper is to enable their decomposition into detailed sub-factors that can be used to evaluate the actual and required level of interoperability in order to estimate their impact on the performance measures under analysis.

Development of the theoretical agent-based simulation model

According to Rand and Rust (2011), agent-based simulation (ABS) is most useful when the rules of behavior are easily written at the individual level and then the behavior of the system emerges (often referred to as an emergent property of the system). The basic concept of ABS is that by describing simple rules of behavior for individual agents and then aggregating these rules, researchers can model complex systems, such as the procurement of services in a marketplace (Rand and Rust 2011), or the interaction of agents within a collaborative SCN. An agent is defined as any autonomous entity with its own properties and behaviors (Rand and Rust 2011). In this study, the need for simulation models and more precisely, the need for ABS can be justified by the following reasons:

- The impact of low interoperability on the performance of organizations is not linear, i.e. low level of interoperability may have different impact in different organizations.
- Agents in collaborative SCNs are socially influenced, i.e. low level of interoperability in one or more relationships may have an impact on other relationships/organizations.

The ABS model presented in this paper consists of a set of networked organizations and a set of links (relationships among the networked organizations). Our ABS consists of two types of agents. First, the 'links agents' are used to evaluate of the actual and current level of interoperability. For this purpose, we use as links' variables a set of interoperability design parameters (last level DPs) achieved in previous work (Cabral et al. 2013b) and a business interoperability maturity model, also developed in previous work (Cabral and Grilo 2014). Our approach to this task suggests that the interoperability design parameters should be evaluated separately according to levels of maturity. In our model, five levels of maturity were defined: level 0 (isolated), level 1 (initial), level 2 (functional), level 3 (connectable), and level 4 (interoperable). The analysis of the level of business interoperability is made at the (dyadic) relationships level but the impact is estimated at the organizational level. Therefore, a second type of 'organizations agents' was introduced in the model. These agents are the organizations involved in each relationship established in the network. Our approach to carry out the analysis of the impact is described as follows: first, one should evaluate the current and required levels of interoperability in each dyadic link; based on the results of this evaluation, a distance between these two states is calculated. Having calculated this distance, a probabilistic event of problem occurrence at the organizational level can be estimated, with an associated probability. Then, one should start to conduct the analysis of the impact using information related to the performance measures (e.g. cost of transportation of one unit from organization i to organization j, cost and time spent in reprocessing information, cost and time spent in re-planning the production, etc.) and the amount of problems occurred at a given period of time. The distance for each interoperability design parameter is calculated according to the Equation 1:

$$\text{interoperability distance} = \text{current level of interoperability} - \text{required level of interoperability} \tag{1}$$

Demonstration of the theoretical agent-based simulation model

In order to demonstrate the applicability of the proposed methodology, an illustrative example is presented in this Section. This illustrative example is based on an application scenario to implement reverse logistics in a context of an automotive industry. In order to ensure an effective implementation of reverse logistics, an interoperable reverse network platform was designed in previous work (Cabral et al. 2013b) through the application of the axiomatic design (AD) theory (Suh 1990, Suh 2005). In this Section we will evaluate the effectiveness of that reverse network platform through the application of the ABS. The structure of the reverse logistics network considered is shown in Figure 1. The main reverse logistics operations considered are: return of nonconforming and damaged components to be re-manufactured; return of pallets and packages to be reutilized; transport of waste and scrap to recycling or disposal center. It was assumed that the sorting and separation of returnable items (pallets/packages, damaged items, waste or scrap) are carried out internally by each organization. The costs of the reverse logistics implementation are supported by all partners according to the volume of returnable items produced. However, it is assumed that there is an incentive system supported by the automaker, depending on the achievement of established objectives, in terms of RL performance. The first tier suppliers (FTSs) are responsible for the remanufacturing of nonconforming and damaged components.

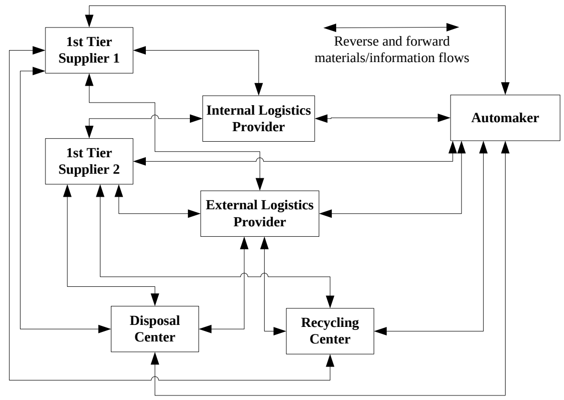

Figure 1 - The structure of the RL network considered

The analysis of the impact is supported by a simulation environment created through the software *NetLogo* (Wilensky 1999). We used three interoperability design parameters derived from the theoretical AD model cited previously: '$DP_{3.1}$: mechanisms to ensure clarity on the definition of entities in charge of each RL collaborative process' and '$DP_{3.3}$: mechanisms to communicate the processing status of the RL collaborative processes along the network'. The $DP_{3.3}$ is further decomposed into $DP_{3.3.1}$: mechanisms to communicate the processing status of the components being remanufactured and $DP_{3.3.2}$: mechanisms to provide visibility of the inventory level of the returnable products/materials. Within this process of analyzing the impact we made a set of assumptions as the empirical data are not available at this moment: the FTS_1 delivers to the Automaker 600 components A per day, and five times a day; the lead time for remanufactured component A is one hour; the FTS_2 delivers to the Automaker 1200 components B per day, and five times a day; the lead time for remanufactured component A is fourth five minutes; the transportation of these components from the FTSs to the Automaker is carried out by the internal logistics provider; in each deliver of the component A, four pallets are used and each component A is packaged using one packaging; for the component B, six pallets are used and each component is also packaged using one packaging; both pallets and packages used to ship components from the FTSs to the Automaker are reusable; the organizations operate eight hours a day and five days a week; the levels of business interoperability (LBI) for the interoperability design parameters are normally distributed, i.e. LBI ~ N (μ, σ^2); Table 1 shows how the average levels of business interoperability of the links change over time.

Table 1 - Evolution of the average levels of business interoperability

Interoperability design parameters	**t = [0, 90[**		**t = [90, 179[**		**t = [179, 266]**	
	Current	**Required**	**Current**	**Required**	**Current**	**Required**
$DP_{3.1}$	*LBI ~ N (1.5; 0.5)*	*LBI ~ N (3; 0)*	*LBI ~ N (2.5; 0.5)*	*LBI ~ N (4; 0)*	*LBI ~ N (3; 0.15)*	*LBI ~ N (4; 0)*
$DP_{3.3.1}$	*LBI ~ N (1; 0.3)*	*LBI ~ N (3; 0)*	*LBI ~ N (2; 0.4)*	*LBI ~ N (4; 0)*	*LBI ~ N (3; 0.3)*	*LBI ~ N (4; 0)*
$DP_{3.3.2}$	*LBI ~ N (1; 0.5)*	*LBI ~ N (3; 0)*	*LBI ~ N (2; 0.6)*	*LBI ~ N (4; 0)*	*LBI ~ N (3; 0.2)*	*LBI ~ N (4; 0)*

We also assumed that: the levels of interoperability of the 'mechanisms to ensure clarity on the definition of entities in charge of each RL collaborative process' have impact on the return rate of pallets and packages; the return rate of pallet/packages is between 95 and 100% if the distance is zero, between 85 and 94% if the distance is -1, between 65 and 84% if the distance is -2, between 38 and 64% if the distance is -3, and between 0 and 37% if the distance is -4; it was assumed that for each non-returned pallet and package, the impact is on the inventory cost of that non-returned pallet and/or package at the Automaker and on the cost of acquiring new pallets and/or packages at the FTSs; it was assumed that the unit inventory cost at the Automaker is 4€ for non-returned pallets and 2 for non-returned package; at the FTSs, it was assumed that the cost of acquiring a new pallet is 10€ for both FTSs; the cost of acquiring a new package is 5€ for the FTS1 and 4€ for the FTS2; regarding at the 'mechanisms to provide visibility of products being remanufactured/repaired' we assume that its impact is on the cost and time spent in production planning at the Automaker; it was assumed that the impact (both on time and cost) is zero if the distance is zero, between 0.05 and 0.12 if the distance is -1, between 0.13 and 0.30 if the distance is -2, between 0.31 and 0.60 if the distance is -3, between 0.61 and 1 if the distance is -4; for the 'mechanisms to provide visibility of the inventory level of the returnable products/materials', it is assumed that its impact is on the cost and time spent in production planning at the organization that will receive the returned products/materials; in this application scenario, we considered that the links from the Automaker to the FTSs and the links from the Automaker and from the FTSs to the Recycling Center; it was assumed that the impact (both on time and cost) at the FTSs is zero if the distance is zero, between 0.12 and 0.18 if the distance is -1, between 0.19 and 0.32 if the distance is -2, between 0.33 and 0.58 if the distance is -3, and between 0.59 and 1 if the distance is -4; in terms of the impact on the Recycling Center, is was assumed that the impact is zero if the distance is zero, between 0.05 and 0.15 if the distance is -1, between 0.16 and 0.30 if the distance is -2, between 0.31 and 0.6 if the distance is -3, and between 0.61 and 1 if the distance is -4; the time spent in production planning in each organization is also assumed to be normally distributed as follows: the average time spent at the Recycling Center is 2.5 hours a day with a standard deviation of 15 minutes (0.25 hour); the cost of each hour spent in production planning is assumed to be fixed in 600€; at the FTSs, the time spent in planning remanufacturing process is normally distributed with a mean of 2 hour and a standard deviation of 15 minutes (0.25 hour) and the cost of each hour spent in planning is fixed in 800€; At the Automaker the time spent in production planning is normally distributed with a mean of 4 hours and a standard deviation of 30 minutes (0.5 hour) and that the cost of each hour spent in planning is 1000€.

Computational experiments and simulation outputs

In this paper the statistical analysis of the simulation outputs is not conducted as we have grounded on a set of assumptions to 'get' data for the ABS model. Another reason for not analyzing statistically the simulation outputs is because the purpose of this paper is to explore and demonstrate the applicability of the proposed methodology through an application scenario, rather than to achieve generalization about the outputs obtained. Therefore, the issues such as the number of replications, warm-up period as well as the confidence interval for the mean of the performance measures are not considered. The run-length of the simulation is defined to be equal to the established duration of the collaboration, i.e. one year. We assume that there are six holidays during the year. In each quarter it will be discounted two holidays. Therefore, the simulation runs 265 (271 – 6) time periods (days) of 8h. In this paper the simulation run is executed only one time due to the reason pointed out above. The average values for each performance measure considered in our application scenario are summarized in Table 2.

Table 2 - average value for the performance measures

Performance measures	Automaker		FTS_1		FTS_2		Recycling Center	
	Total	Mean	Total	Mean	Total	Mean	Total	Mean
Number of returned pallets from the Automaker to the FTSs	-	-	3907	14.74	5854	22.09	-	-
Number of non-returned pallets from the Automaker to the FTSs	-	-	1388	5,24	2048	7,73	-	-
Number of returned packages from the Automaker to the FTSs	-	-	120246	452.49	23963	90.09	-	-
Number of non-returned packages from the Automaker to the FTSs			39146	147.72	7826	29.53	-	-
Number of non-returned pallets at the Automaker	3439	13.10	-	-	-	-	-	-
Number of non-returned packages at the Automaker	45659	174.72	-	-	-	-	-	-
Total cost of acquiring new pallets at the FTSs (€)	-	-	13880	52.37	20480	77.28	-	-
Total cost of acquiring new packages at the FTSs (€)	-	-	195730	738.60	31304	118.12	-	-
Total inventory cost of non-returned pallets at the Automaker (€)	13756	51.91	-	-	-	-	-	-
Total inventory cost of non-returned packages at the Automaker (€)	91318	344.60	-	-	-	-	-	-
Total impact on the cost of production planning (€)	227622.55	858.95	152815.20	576.66	45376.29	171.23	117117.37	441.95
Total impact on the time spent in production planning (hour)	223.99	0.85	190.74	0.72	117.69	0.44	194.40	0.73

Conclusions

The purpose of this paper was to add to the knowledge on operations management research by developing a methodology for modelling business interoperability in a context of cooperative industrial networks. As this study presents a holistic methodology that integrates the various dimensions of business interoperability (and their corresponding sub-factors), it represents a novelty on how to analyze their impact on the performance of networked organizations. Overall, this study contributes to the knowledge of the importance of the dimensions of business interoperability on the establishment of cooperative industrial networks. Regarding at the application scenario presented in this paper, we believe that we have contributed to a number of further research on the analysis of the performance of reverse logistics networks.

The preliminary findings of this research suggest important implications for the managers in the collaborative SCNs to understand how to analyze the impact of low interoperable platforms in the performance of networked organizations. More importantly, the proposed methodology provides decision makers with the ability to evaluate the current level of business interoperability and the points where improvement can be achieved. The preliminary findings also suggest that the ABS proved to be a suited tool for modeling business interoperability in a context of industrial networks. Summarizing, the main contribution of this work is to assist managers with a tool that guide them in the implementation of collaborative management practices and that enable them to understand how different levels of business interoperability can affect the implementation of these management practices in terms of business performance.

Acknowledgments

The authors thank the Fundação para a Ciência e Tecnologia, project PTDC/EME-GIN/115617/2009 for funding this research.

References

BRUNNERMEIER, S. B. & MARTIN, S. A. 1999. Interoperability Cost Analysis of the U.S. Automotive Supply Chain. National Institute of Standards and Technology.

BRUNNERMEIER, S. B. & MARTIN, S. A. 2002. Interoperability costs in the US automotive supply chain. *Supply Chain Management: An International Journal*, 7, 71 - 82.

CABRAL, I., ESPADINHA-CRUZ, P. & GRILO, A. 2013a. Extended Business Interoperability Quotient Measurement Model (work in progress). UNIDEMI, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa.

CABRAL, I., ESPADINHA-CRUZ, P., GRILO, A., GONÇALVES-COELHO, A. & MOURAO, A. A Methodology for Designing an Interoperable Industrial Ecosystem, using the Axiomatic Design Theory. IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), 2013b December 10 - 13, Bangkok, Thailand.

CABRAL, I. & GRILO, A. 2014. A maturity model for assessing the interoperability of collaborative supply chain networks (work in progress). UNIDEMI, Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa, unpublished.

CAMPOS, C., CHALMETA, R., GRANGEL, R. & POLER, R. 2013. Maturity Model for Interoperability Potential Measurement. *Information Systems Management*, 30, 218-234.

CARNEIRO, L. M., SOARES, A. L., PATRICIO, R., AZEVEDO, A. L. & DE SOUSA, J. P. 2013. Case studies on collaboration, technology and performance factors in business networks. *International Journal of Computer Integrated Manufacturing*, 26, 101-116.

CHENG, C.-Y., CHEN, T.-L. & CHEN, Y.-Y. 2013. An analysis of the structural complexity of supply chain networks. *Applied Mathematical Modelling*, in press.

CHITUC, C. M., TOSCANO, C. & AZCVEDO, A. 2007. Interoperability in collaborative networks: An innovative approach for the shoe up-stream business segment. *Enterprise Interoperability II: New Challenges and Approaches*, 557-568.

CORELLA, V. P., ROSALEN, R. C. & SIMARRO, D. M. 2013. SCIF-IRIS framework: a framework to facilitate interoperability in supply chains. *International Journal of Computer Integrated Manufacturing*, 26, 67-86.

ESPADINHA-CRUZ, P., CABRAL, I., GRILO, A. & CRUZ-MACHADO, V. 2012. Information Model for LARGeSCM Interoperable Practices. *34th International Conference on Information Technology Interfaces.* June 25-28 , Cavtat/Dubrovnik, Croatia.

FIGAY, N., MAN-SZE, L., CRAVE, S. & GRILO, A. 2008. Unleashing the Potential of the European Knowledge Economy: Value Proposition Enterprise Interoperability. European Commission.

GALLAHER, M. P., O'CONNOR, A. C., DETTBARN, J. L., JR. & GILDAY, L. T. 2004. Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry. National Institute of Standards and Technology.

GRILO, A. & JARDIM-GONCALVES, R. 2010. Value proposition on interoperability of BIM and collaborative working environments. *Automation in Construction,* 19, 522-530.

GUÉDRIA, W., NAUDET, Y. & CHEN, D. 2013. Maturity model for enterprise interoperability. *Enterprise Information Systems*, 1-28.

HOLMLUND, M. & TÖRNROOS, J.-Å. 1997. What are relationships in business networks? *Management Decision,* 35, 304 - 309.

HÅKANSSON, H. & FORD, D. 2002. How should companies interact in business networks? *Journal of Business Research,* 55, 133-139.

IEEE 1990. Standard Computer Dictionary - A Compilation of IEEE Standard Computer Glossaries. *IEEE Std 610.12-1990.* The Institute of Electrical and Electronics Engineers.

JARDIM-GONCALVES, R., POPPLEWELL, K. & GRILO, A. 2012. Sustainable interoperability: The future of Internet based industrial enterprises. *Computers in Industry,* 63, 731-738.

LOUKIS, E. N. & CHARALABIDIS, Y. K. 2013. An empirical investigation of information systems interoperability business value in European firms. *Computers in Industry,* 64, 412-420.

MENTZER, J. T., DE WITT, W., KEEBLER, J. S., MIN, S., NIX, N. W., SMITH, C. D. & ZACHARIA, Z. G. 2001. Defining Supply Chain Management. *Journal of Business Logistics,* 22, 18.

RAND, W. & RUST, R. T. 2011. Agent-based modeling in marketing: Guidelines for rigor. *International Journal of Research in Marketing,* 28, 181-193.

REZAEI, R., CHIEW, T. K. & LEE, S. P. 2014. An interoperability model for ultra large scale systems. *Advances in Engineering Software,* 67, 22-46.

SERDARASAN, S. 2013. A review of supply chain complexity drivers. *Computers & Industrial Engineering,* 66, 533-540.

SUH, N. P. 1990. *The Principles of Design,* New York: Oxford Press.

SUH, N. P. 2005. *Complexity: Theory and Applications,* New York, Oxford University Press, Inc.

WHIPPLE, J. M. & RUSSELL, D. 2007. Building supply chain collaboration: a typology of collaborative approaches. *International Journal of Logistics Management,* 18, 174 - 196.

WILENSKY, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.

ZUTSHI, A., GRILO, A. & JARDIM-GONCALVES, R. 2012. The Business Interoperability Quotient Measurement Model. *Computers in Industry,* 63, 389-404.